PART 1 : SECTION 5

CHAPTER 2

WING AND FUSELAGE CONSTRUCTION

Introduction

1. Some understanding of the problems confronting the aircraft designer and the weight/strength ratio of the materials available to him will help to explain the forms of construction chosen for various types of aircraft. Adequate strength and stiffness of the wings must be the primary consideration, since they support the aircraft in the air. The strength of a beam is proportional to its depth squared, and its stiffness to its depth cubed ; consequently, the thicker a wing can be made, the stiffer and stronger it will be for a given weight. External bracing struts and wires can be used to increase the effective depth, and consequently the stiffness and strength of a thin wing, but they cause more drag. Thickness/chord (t/c) ratios of 15 to 20 per cent. are satisfactory for speeds of 200 to 300 knots ; but as speeds increase, lower ratios must be used, until for supersonic speeds t/c ratios as low as 3 per cent. are used.

2. The speed required of an aircraft will thus dictate the limits of wing thickness, and probably the form of construction chosen, since the thinner the wing the more essential it becomes to use the skin as the flanges of the main spar. The various forms of construction will now be considered.

Biplanes

3. The wing spars, inter-plane struts, and bracing wires form in effect a large lattice girder of great rigidity compared with the strength and weight of its components. As very few biplanes can exceed 180 knots in level flight, air loads are low and doped fabric, which is light in weight, is satisfactory for covering the wings. Former ribs hold the fabric to the aerofoil section and transfer the loads from it to the wing spars. The leading edge, where the aerodynamic loads are highest, is stiffened by additional nose ribs or by longitudinal metal or plywood covering. The two spars (very occasionally there may be more) are the main structure of the wing, and transfer the load to the fuselage. In doing so, they are subject to bending loads, shear loads, and compression loads, exerted by internal and external bracing wires. The spars run throughout the length of the wing, and are kept parallel to one another by internal compression struts, drag and anti-drag wires. With the use of external bracing to take most of the lift forces, the bending loads on the spars are greatly reduced. Thin wing sections can therefore be used to advantage. Leading-edge slats are often used on biplanes to improve the stalling characteristics, but flaps are rarely used.

Braced Monoplanes

4. The braced monoplane design is used almost exclusively for small high-wing aircraft, of which the Auster series is a typical example. The bracing struts, running from the fuselage to a point about halfway along the wing, relieve the spars of much of their vertical load and anchor them in torsion. A form of wing construction similar to the biplane is therefore possible, but the spars must be deeper to resist the greater bending loads, and consequently a thicker wing section is used. To minimize the wing area and the weight without an excessively high landing speed, flaps are generally fitted.

Unbraced or Cantilever Monoplanes

5. With the elimination of all external bracing, the wing structure must be much stiffer in bending and torsion. This requires the deepest possible spars, but, as explained in the chapters on aerodynamics, thick wing sections are unsuitable for high speeds. A compromise is made by tapering the wings in elevation from a thin tip to a thicker root, where the stresses are greatest. To keep the wing section approximately uniform the wing is also tapered in plan. Compared with a rectangular plan form, this has the additional advantage of bringing the centre of lift nearer the fuselage, so reducing bending loads. However, excessive taper causes undesirable tip-stalling characteristics.

Structure

6. Aerodynamic loads increase as the square of the I.A.S. and at about 500 knots are six times as great as at the 200 knots achieved by the fastest biplanes. A fabric wing covering is therefore no longer suitable and a heavier and more rigid plywood or metal surface must be used. The higher the maximum speed of the aircraft the thicker and stiffer the skin must be ; at the same time the t/c ratio must be reduced. A thin wing

in turn calls for thicker, heavier, and consequently less efficient wing-spar flanges. The combination of these two factors makes it desirable to carry more and more stress in the skin by attaching it rigidly to the spars. The conventional ways of doing this are described in the following paragraphs.

7. **Stressed Skin.** All stressed skin designs suffer a severe weight penalty from the local thickening of the skin which is necessary to combat the stress concentrations caused by cut-outs for undercarriage legs, wheel wells, inspection panels, etc. Also, if full advantage is to be taken of the design, break-down joints between components must be made with many small bolts, which will again add to the weight. To overcome these difficulties many designs have two wing spars, built up of sheet metal webs and thick extruded flanges, which take the bending and shear loads ; and the skin is stressed only to supply the necessary torsional stiffness.

8. **D-Spar Construction.** The front spar, which takes most of the bending load, is placed as near as possible to the point of maximum thickness of the wing, and the skin of the leading edge is rigidly attached to it to form a D-shaped tube (Fig. 1) which takes nearly all the torsional stresses of the wing. The rear spar forms little more than a mounting for the aileron and flaps, and is connected by the skin and a light rib structure to the D-spar. In the D-spar and box spar (see para. 9) forms of construction, instability of the skin in compression is overcome by corrugation, or by breaking it up into narrow strips by means of supporting stringers. The latter run parallel to the spars and are supported by ribs at right angles to them.

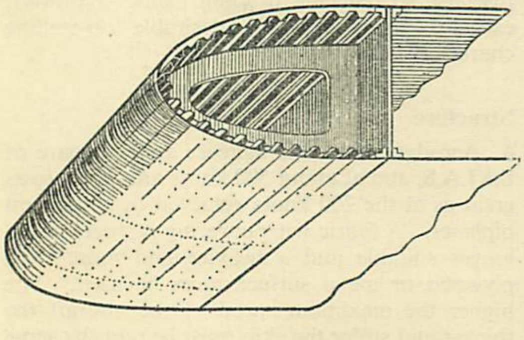


Fig. 1. D-Spar Construction

9. **Box-Spar Construction.** In the box-spar form of construction (Fig. 2) the skin of the upper and lower surfaces of the wing joins the front and rear spars rigidly together in the form of a box. To the front of this is attached the leading edge and to the rear the ailerons and flaps. To increase the load-carrying capacity of the skin between the spars, it is common to corrugate it and then cover the corrugations with a thin sheet. This form of construction is much used and a variation of it, which has a number of spars one behind the other forming a series of boxes, appears particularly suited to aircraft with low aspect ratios.

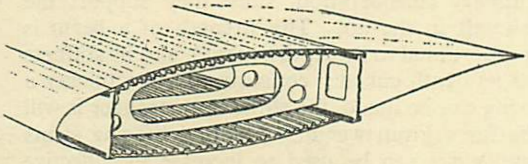


Fig. 2. Box Spar Construction

10. **Pure Monocoque.** If a sufficient thickness of skin is used, a single sheet can be folded over to form the contour of the wing forward of the flaps and ailerons. The rear edge is closed by a false spar, which carries the flap and aileron hinges, and a few former ribs ensure the retention of the correct aerofoil section. In the pure monocoque form of construction all loads are carried by the skin, which must have sufficient thickness and rigidity not to suffer from crinkling in compression. It is therefore evident that a stiff lightweight material is needed. These qualities can be obtained by constructing a sheet in sandwich form, the outer layers being thin and of a dense, strong material, and the centre portion of very light material just strong enough to ensure that the outer layers remain parallel and do not crinkle under stress.

11. **Control Surfaces.** For speeds up to 300 to 350 knots, fabric-covered ailerons built up on a spar and ribs are usually satisfactory. Higher speeds demand a rigidity that can only be obtained by a stressed-skin covering built up in much the same way as a D-spar wing. An interesting variation of the D-spar form is employed on the Pembroke (Fig. 3B), in which longitudinal fluting of the skin (*i.e.* spaced corrugations) is used to obtain stiffness ; also, in this design, most of the ribs can be eliminated. At moderate speeds the extra drag of the flutings, which stand up into the air stream, is very small. For very high speeds the flutings would have to be reversed and be faired over, a complication which would probably be unacceptable.

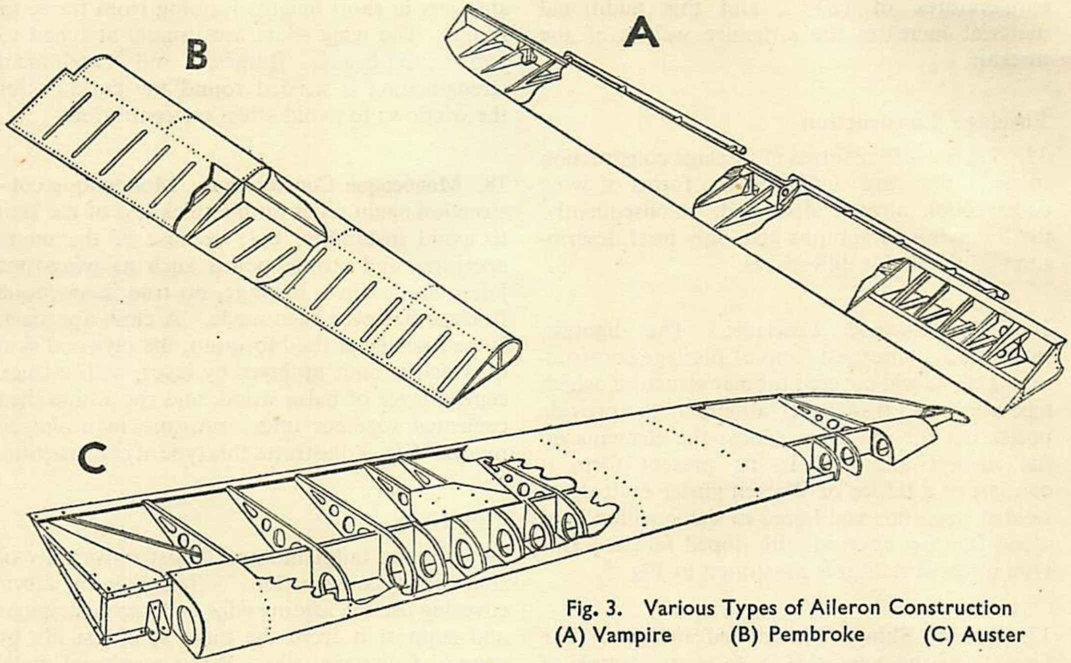


Fig. 3. Various Types of Aileron Construction
(A) Vampire (B) Pembroke (C) Auster

Wing Construction for Supersonic Speeds

12. The design of wings for supersonic speeds introduces extra problems. The most important of these are :—

(*a*) Small thickness/chord ratios of 6 per cent. or less.

(*b*) The heating effects of supersonic flight.

13. The thin wing cannot be manufactured easily by conventional methods, and to obtain adequate torsional stiffness the wing skin needs to be much thicker than that used on subsonic wings. It may be necessary, therefore, to use an alternative method of construction such as that known as integral construction. The wing skin and stringers are machined from solid slabs of metal, or extruded as a panel, formed and finally machined to obtain the desired profile. A possible adaptation of this process is shown in Fig. 4. Here the upper and lower skins, complete with their stringers, have been formed either by machining from solid slabs or by the use of extruded panels, and are held together by bolts passing from top to bottom. This produces a very strong multi-cell wing structure.

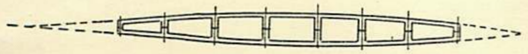


Fig. 4. Section through a Typical Supersonic Wing
The leading and trailing edges are attached separately. The vertical lines are the axes of the bolts which secure the upper and lower surfaces.

14. **The Effect of Temperature Rise on the Structure.** At high T.A.S. large increases in temperature are caused by the compression of air. The forward-facing parts of an aircraft are being subjected continuously to this heat and take on the temperature of the air with which they are in contact. For example, at 40,000 feet at the standard temperature of −56·5°C. and at a sustained speed of mach 2 the temperature rise results in an airframe temperature of about 120°C. This temperature is above the safe limits of the materials used in erstwhile conventional aircraft construction. While the effects of the temperature rise on the external portions of the airframe can be overcome by use of special metals such as titanium, the cockpit and various electronic and hydraulic components have to be artificially refrigerated. In the absence of special metals, stainless steel or a thicker aluminium alloy must be used to allow for the loss of strength at the high temperatures accompanying high speeds. At about 94°C. aluminium alloy loses 10 per cent. of its strength but at about 120°C. it loses 40 per cent. This means that 40 per cent. more aluminium alloy must be used on those parts of the airframe exposed for any length of time to stabilized

temperatures of 120°C., and this additional material increases the structure weight of the aircraft.

Fuselage Construction

15. There are four forms of fuselage construction in use. They are similar to the forms of wing construction already discussed. Consequently, the following paragraphs give only brief descriptions of the major differences.

16. **Fabric-Covered Fuselage.** The lightest, simplest, and cheapest form of fuselage construction is the fabric-covered tubular structure, which has survived from the attempts to provide protection for the crew against the elements on the earliest aircraft. In its present form it consists of a lattice or Warren girder built up of welded steel tube and faired to shape with a light wood framing covered with doped fabric. This type of construction is illustrated in Fig. 5.

17. **Stressed Skin on Frames and Stringers.** The fuselage of the Varsity (Fig. 6) is an example of the type of construction that uses stressed skin on frames and stringers. The stringers, some of which are cut away in the illustration, run from nose to stern and are attached to the transverse frames (which correspond to the ribs of the wings). In certain places the skin is riveted to both stringers and frames. Another method of construction, common in flying-boats where the frames are used as watertight bulkheads, is to rivet the skin to the frames and to make the stringers in short lengths running from frame to frame. The wing spars are usually attached to two extra-heavy frames, and additional strengthening is needed round the cut-outs for the windows to avoid stress concentrations.

18. **Monocoque Construction.** Monocoque construction again relies on the thickness of the skin to avoid instability, but, because of the many apertures and strong points such as wing-root joints needed in a fuselage, no true monocoque fuselage has ever been made. A close approach is the fuselage of the Mosquito, the plywood skin of which is built up layer by layer, with a thick central layer of balsa wood, and the whole then cemented together under pressure in a shaped mould. Fig. 7 illustrates this type of construction.

Tail Units

19. Fin and tailplanes are almost universally of single-spar construction. Those with fabric covering use the leading edge as a secondary spar and support it from the main spar, usually by means of diagonal ribs. When a stressed metal skin is used, the leading edge is rarely given additional support, being kept in shape by suitable former ribs (Fig. 8). In both fabric and stressed skin designs the torsional loads are transferred to the fuselage by an additional attachment near the leading edge which is supported by a specially rigid former rib. A typical fabric-covered tail unit is shown in Fig. 9. The tail units of supersonic aircraft are constructed similarly to the wings, as described in para. 13.

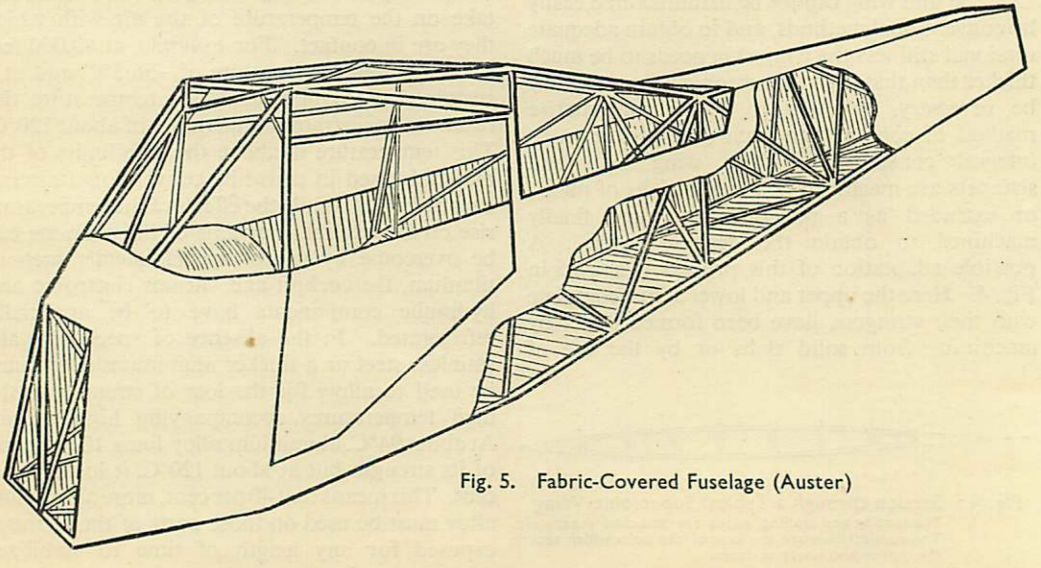


Fig. 5. Fabric-Covered Fuselage (Auster)

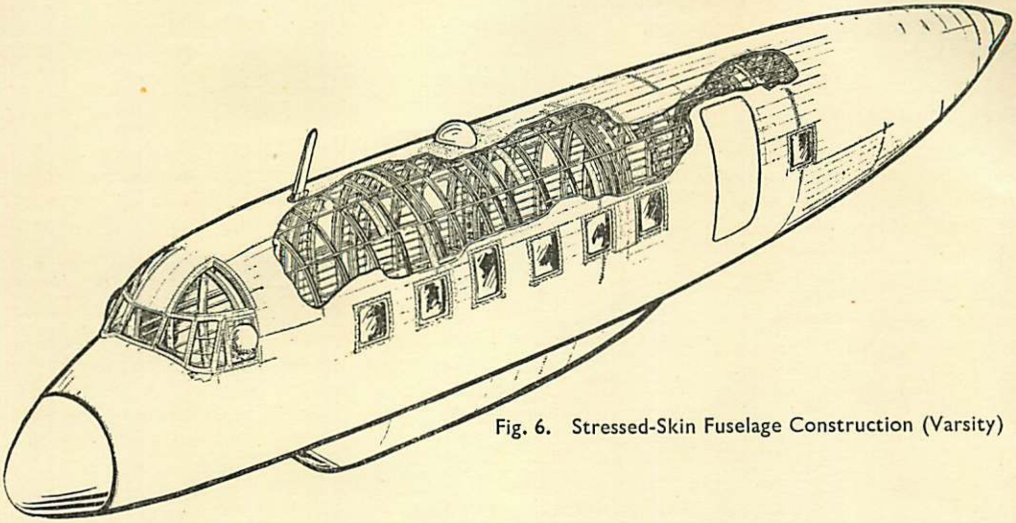


Fig. 6. Stressed-Skin Fuselage Construction (Varsity)

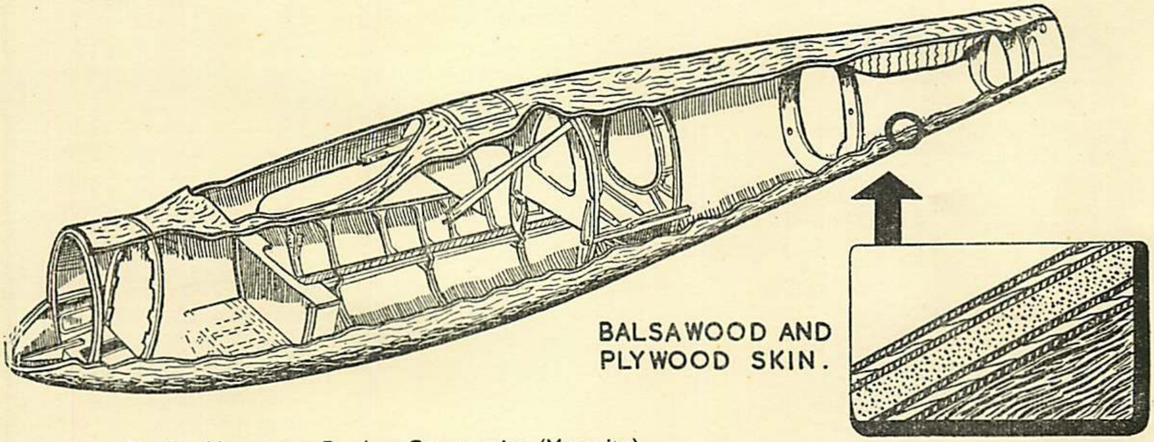


Fig. 7. Monocoque Fuselage Construction (Mosquito)

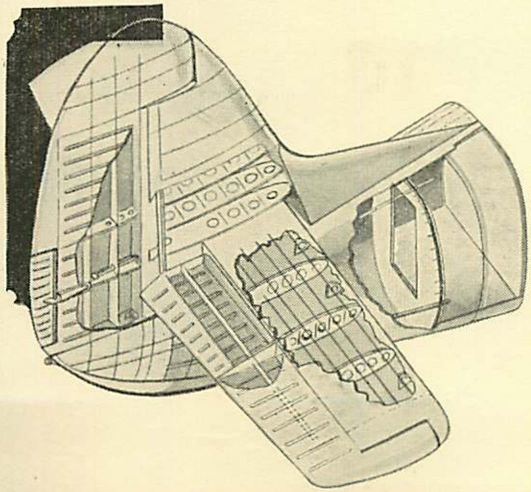


Fig. 8. Stressed-Skin Tail Unit (Pembroke)

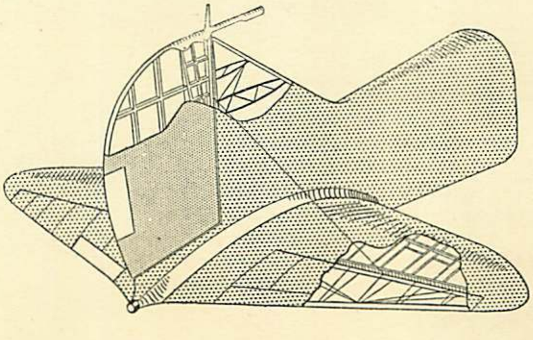
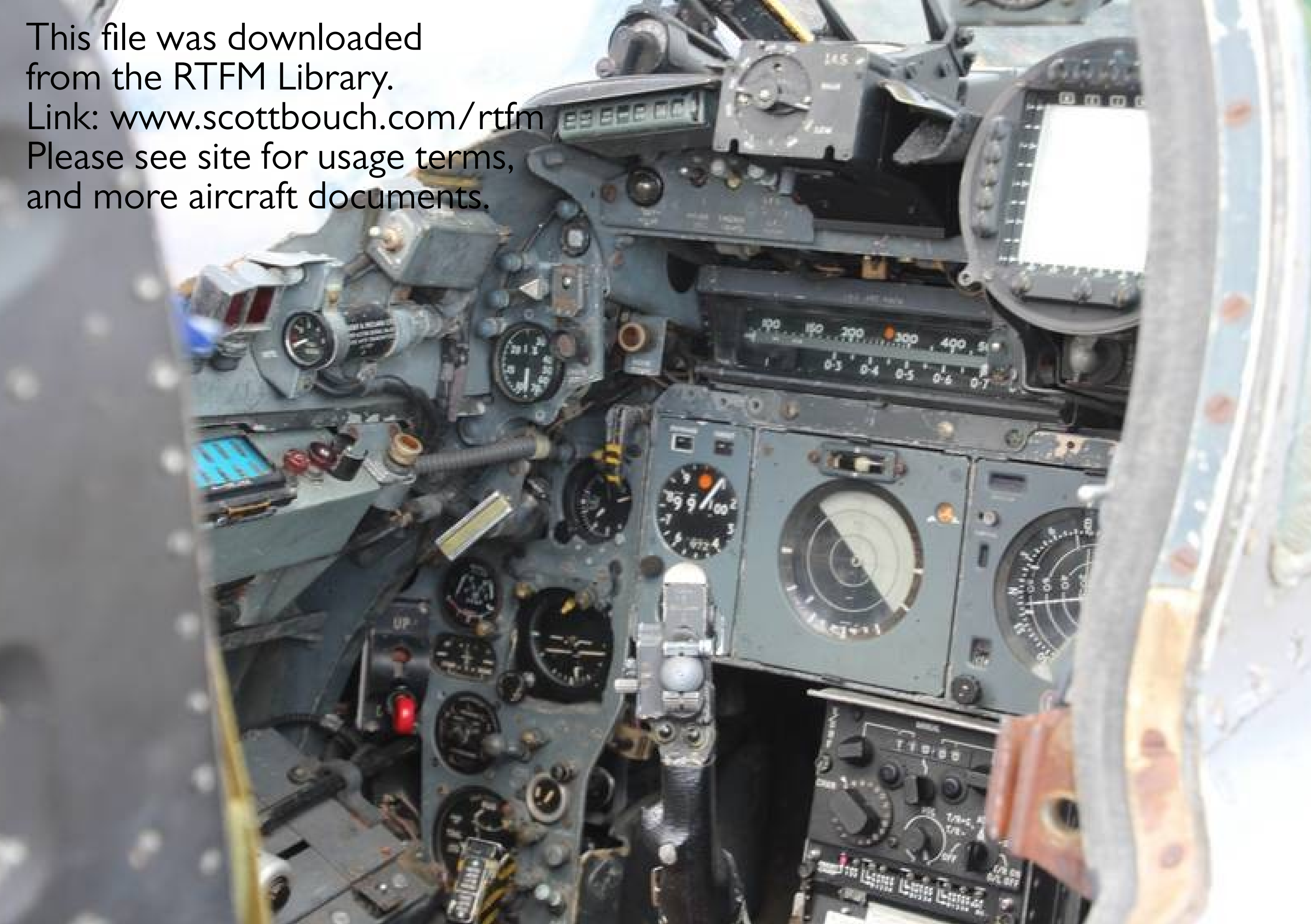


Fig. 9. Fabric-Covered Tail Unit (Anson)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