CHAPTER VI.

METAL CONSTRUCTION.

General description.

163. The development of all-metal construction has been greatly facilitated by the introduction of the many and diversified kinds of materials now available. Much attention has been devoted during recent years to the production of steels and non-ferrous alloys on a commercial basis in a suitable form for aircraft construction, and these materials can now be obtained in a variety of forms and conditions which allow a wider choice of material possessing the required properties, and consequently give a greater freedom in design. Aircraft which are of fundamentally good design, and which, apart from the fabric, are composed entirely of metal, should require less work on erection, rigging, and general maintenance and repair than similar wooden structures, but, on the other hand, much closer attention to detail is required for metal aircraft under normal service conditions.

164. All-metal construction provides a rigid structure that is relatively durable, and which can be made to comparatively fine limits. All the attachments and connections are metal to metal, and are therefore definite; also, accurate interchangeability of parts is easily obtained because the materials lend themselves readily to precise measurement and consistent reproduction. Two of the greatest enemies of metal construction are vibration and corrosion, and the utmost care is always taken during manufacture to eliminate as far as possible any likelihood of failures due to these causes, but it is necessary to be very attentive during inspection to detect any actual or incipient fractures, elongation of holes, or oxidation. For all structural purposes the metals used on aircraft are practically unaffected by changes of climatic condition, but they are subject to surface oxidation and other forms of corrosion unless reasonable care is taken for their preservation. The various measures taken to prevent corrosion are discussed in detail in a later chapter, but broadly the methods consist almost entirely of the preparation of the surface of the metal in such a manner as to prevent contact with the atmosphere.

165. The types of construction used for metal aircraft may be classified as strip steel, tubular steel, and light alloy. For the details of construction of any particular aircraft, reference should be made to the aircraft handbooks which are specially provided to supply this information.

Strip steel.

166. A strip steel structure of good design is strong, rigid, and light, but on account of the fact that very thin and high-tensile materials are used, it is susceptible to damage if roughly handled. Corrosion and fatigue failures must also be guarded against as, owing to the thinness of the materials employed, failures due to these causes are more probable than when heavier gauges of material are used. Strip steel construction is not normally used throughout the aircraft, but is confined to the planes and other parts where, by its use, an advantage is obtained over tubular or other forms of construction. Also, although an aircraft may be built mainly of steel, other materials such as aluminium or duralumin are used for fairings and similar sub-structures, if there is a distinct benefit derived by so doing.

167. The strip steel material is obtained from the steel manufacturers in long lengths, or strips, which are of the requisite gauge and only slightly wider than is required for the finished article. The strip is pulled through dies, or specially shaped rollers, which force the steel into the required shape. Then the formed strips are riveted or otherwise connected together and trimmed up, and so form the various sections used on different parts of the aircraft. An infinite variety of sections may be produced by this means. The gauges of the steels used depend to some extent upon the purpose for which the finished part is to be employed ; gauges between 24 S.W.G. and 30 S.W.G. are common, but, for practical reasons, gauges below 33 S.W.G. are seldom, if ever, used. The tensile strength of the material varies between 60 and 80 tons per sq. in., depending upon the specification used. Built-up strip steel sections can be used for any of the members, though their use is normally confined to spars and certain forms of strut.

Non-corrosive steels.

168. Stainless steels are employed mainly on those aircraft subject to conditions conducive to excessive corrosion, such as contact with sea air or sea water. Although it is obviously the ideal material, aircraft are not usually built entirely of these steels owing to the cost and the difficulty of obtaining the materials in the exact form required.

169. Several forms of non-corrosive steel are produced which are all more or less successful in their non-corrosive properties. In other respects, taken as a whole, they are not quite so successful as ordinary steels, as in some instances there is a little difficulty in working or machining, and in others the heat treatment required to give the tensile strength has a

somewhat critical value, and demands considerable care. Nevertheless, in spite of the consequent higher technical skill required in working, considerable use is being made of this material.

170. Non-corrosive steels are used mainly for fittings, wiring lugs, and similar highly stressed parts which are exposed or otherwise subjected to corrosive conditions, the failure of which would involve the possible collapse of the structure. These materials are also used for contact faces, such as bearings, where the inter-action between the materials is liable to induce excessive corrosion. This point is dealt with more fully in paras. 416 to 419.

Solid drawn tubes.

171. Solid drawn tubes are perhaps the most frequently used form of material for metal aircraft construction. This is because for many parts, especially struts, round tubes are the most economical shape, and also because other than providing an end attachment, there is little or no work to be done on them, and they can be easily adapted to the type of structure required. Solid drawn round tubes are obtainable in practically any material, diameter, and gauge, and also special sections of many varieties, such as square and streamline, are made to suit particular purposes.

172. Square tubes are often used on fuselages in conjunction with flat side plate fittings, and combine well with wood when necessary. Streamline and oval tubes are used as struts in certain external positions, usually where a built-up form of strut would not be an economical proposition, or where it is subjected to rough treatment.

Light alloys.

173. Light alloys are composed mainly of aluminium or magnesium, and have a low specific gravity. On account of their unstable nature and low tensile strength, pure aluminium or magnesium is seldon used, except for sub-structures and fairings, but alloys of these materials, such as duralumin, are used extensively.

174. Duralumin is a metal consisting mainly of aluminium with the addition of a little copper and other substances, which gives the material, in its hardest state, a strength comparable with mild steel. Duralumin derives its hard, tough condition owing mainly to the rolling and other working processes during manufacture. It can be easily machined, but needs heat treatment before it can be safely bent, or worked in a like manner. The heat treatment of duralumin is dealt with in Air Ministry Technical Order 361 of 1930. Duralumin

can be obtained in all the usual forms and sections, such as forgings, sheets or tubes, and the general design of the structure employing this material does not vary greatly from the design used for steel structures, excepting that duralumin is not welded or soldered owing to the fact that it suffers a great loss of strength if excessive heat is applied to it.

175. The greatest drawback to the use of duralumin, or any light alloy, is corrosion. The corrosion is not confined to surface oxidation only, but is inter-crystalline, a form of corrosion which may, or may not, present surface indications. This subject is more fully treated in a later chapter.

176. Duralumin fittings and other parts are usually thicker and larger than corresponding steel fittings. This is on account of the fact that a high working stress is not allowed for this material, 16 tons per sq. in. being the generally accepted figure. There would not be a great deal of difference in the weight of precisely similar members when constructed in either steel or duralumin, but as the duralumin parts would be thicker and more bulky to give the equivalent strength, they would probably be more stable under load, and more resistant to accidental damage.

Welded structures.

177. Oxy-acetylene welding is extensively used in modern aircraft, especially for the smaller plate fittings, as by its use an extremely cheap and homogeneous part is provided. The main disadvantages against welding are that the process usually alters the character and reduces the tensile strength of the metal in the neighbourhood of the weld, and also, without actual test, it is not always possible to ascertain if the material has been slightly burnt or if it has been completely welded right through.

178. Aircraft on which welded structures are utilised find considerable favour in some quarters, more particularly abroad than in this country, mainly on the score of low cost of production and ease of maintenance. Welded structures are permitted on service aircraft provided that materials of the correct specification are used, and other necessary restrictions are observed. The general conditions governing welding by aircraft manufacturers is dealt with in a later chapter, but broadly, the restrictions are that the failure of any one welded joint must not involve the collapse of the structure, and also that the maximum tensile stress encountered must not exceed 66 per cent. of the strength of the material before welding.

179. There are many instances to be found of the welding of small parts, and those shown in fig. 51 are given merely

to show the kind of work done by this process. The upper illustration of fig. 59 can also be referred to as an instance of a welded fuselage.

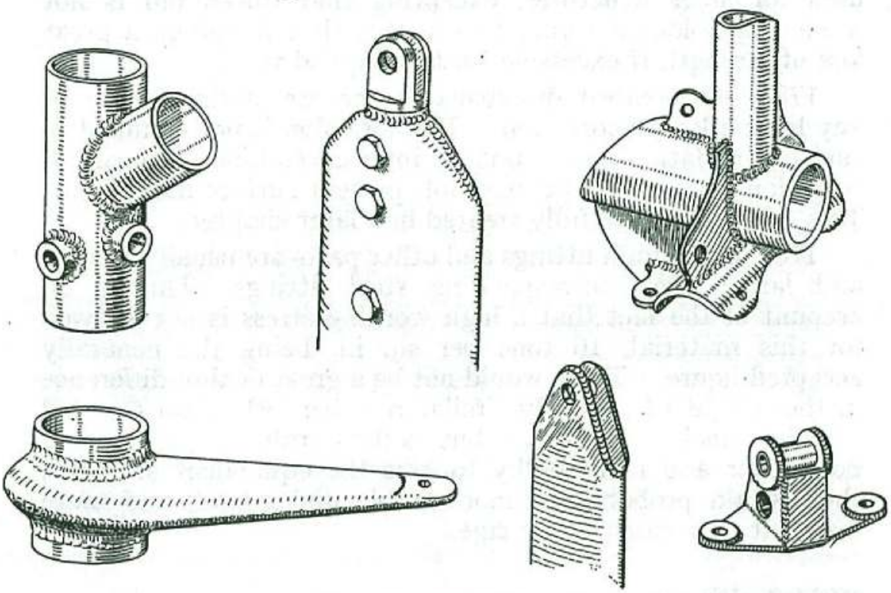


FIG. 51.—Welded parts.

Metal planes.

180. The production of a sound design of structure for a metal wing, which was to be no heavier than a corresponding wooden wing and equally as strong, was the cause of considerable experimenting before success could be claimed, and is still the subject of much investigation. The necessity of providing the lightest possible structure forced the designers into using high-tensile steel or light alloy, and metal wings are constructed of either of these materials or a combination of both. The most successful designs which have been adopted for service use conform in a great measure to the normal arrangement of the wooden two-spar construction, and therefore there are approximately the same number of members, placed very much in the same relation to one another. The greatest difference, apart from materials, is in the detail design of the parts. There are other forms of construction, notably the multi-spar and the mono-spar types shown diagrammatically in fig. 29, but, owing to the fact that they are typical cantilever wing designs, it is doubtful if these types will ever supersede the two-spar design for biplanes.

181. As in the wooden type of construction, the most important members in a metal wing are the spars. With wooden spars, the actual volume of material required for

strength, the space available within the wing, and the usual woodworking methods of construction employed, restrict the design within definite limits. With metal spars, on the other hand, the design varies to a considerable extent, owing to the fact that the space available is the same, but the bulk of the material is far less, which allows the designer greater liberty of choice in the disposal of it. The materials used for the construction of metal wings may be in the form of tubes, or they may be flat sheets or strips which are pressed, or otherwise worked, into the desired shapes and sections. The normal method of attaching the various parts together is by riveting or bolting, mainly the former. Welding or brazing is very seldom employed, as the materials normally used are not suitable for these processes. Soldering also is seldom used, except for the attachment of tube end sockets. Fig. 52 represents a section from a wing which is mainly constructed from strip sheet.

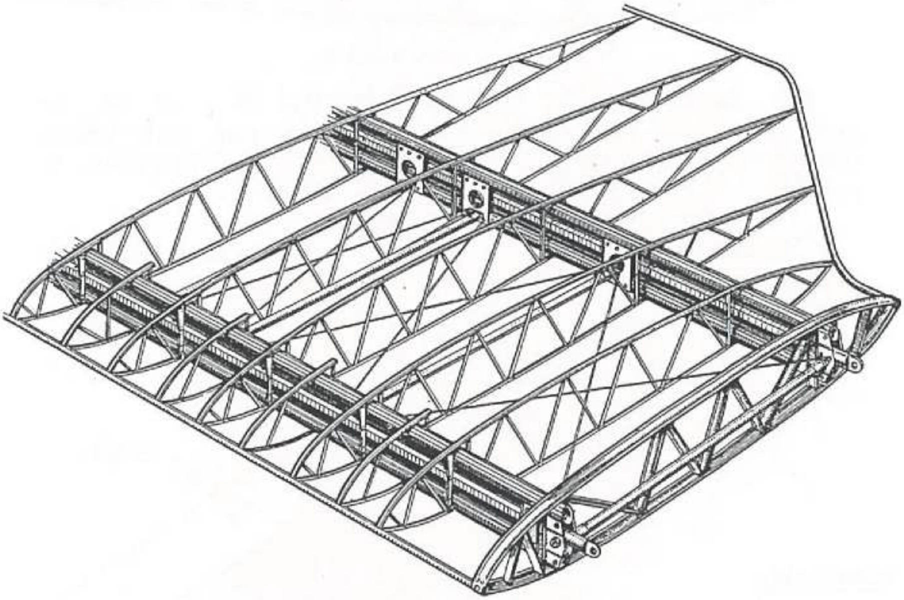


FIG. 52.—Section of metal plane.

Lateral control surfaces.

182. There are several forms of lateral control surfaces for aircraft, but the more usual form is that of the aileron, or hinged wing flap, which forms part of the actual wing surfaces aft of the rear spars. Control is obtained by simultaneously raising the aileron on one side and lowering the other, and accordingly diminishing or increasing the lift. As the movement of an aileron is obtained by pulling or pushing one or more levers attached to the aileron structure,

it is necessary that it should be strong enough to withstand the torsional effects so produced. Ailerons are therefore provided with a spar member of tubular or other form, which normally also forms the attachment points for the hinge. In other respects the construction follows the general lines employed on the wing to which it is attached. Fig. 53 shows a normal type of " Frise " aileron in which the hinges are placed some way back from its leading edge. In this type, in addition to the aerodynamic advantages already described in para. 28, the torsional loads are reduced by placing the hinge approximately at the centre of pressure of the aileron.

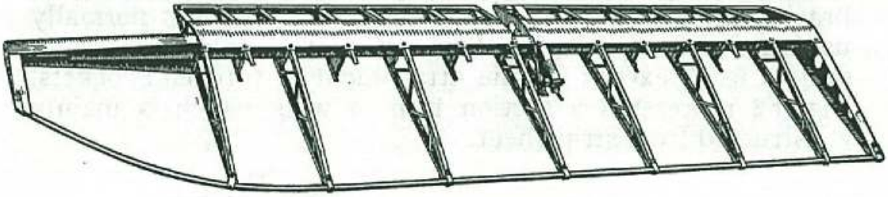


FIG. 53.—Frise aileron.

183. Another form of lateral control is that of the automatic slot. Fig. 54 shows a normal arrangement of slot, the action of which has already been described in paras. 31 and 32.

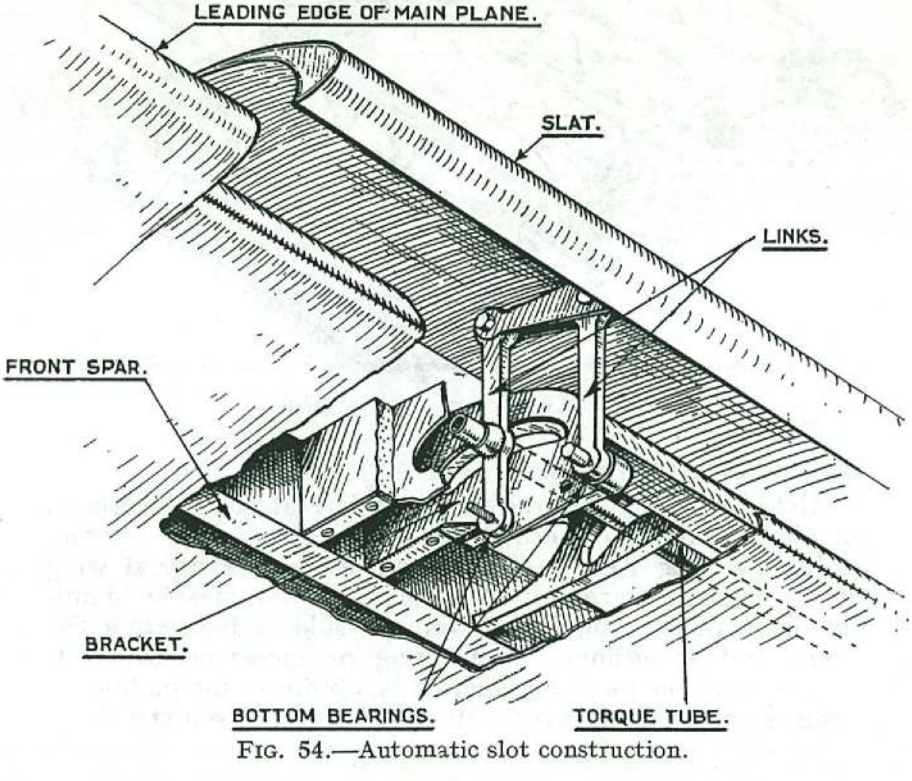
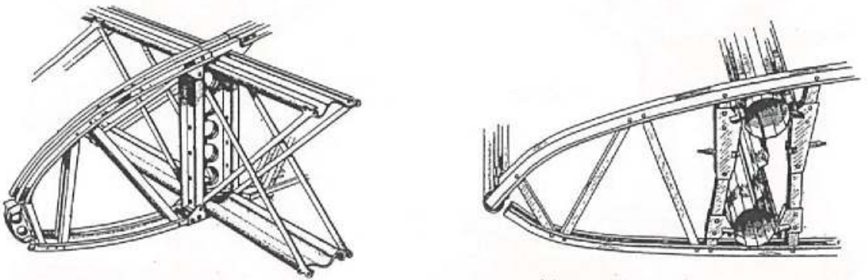


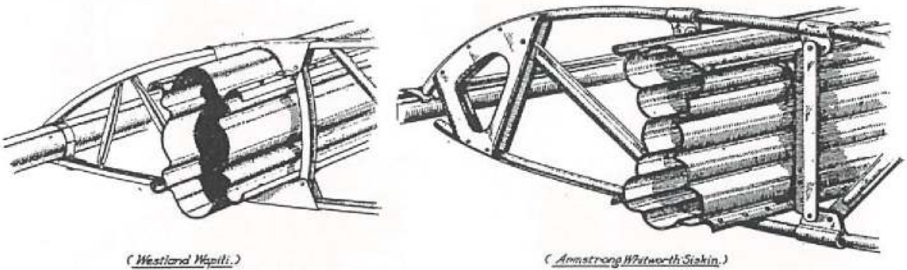
FIG. 54.—Automatic slot construction.

Metal spars.

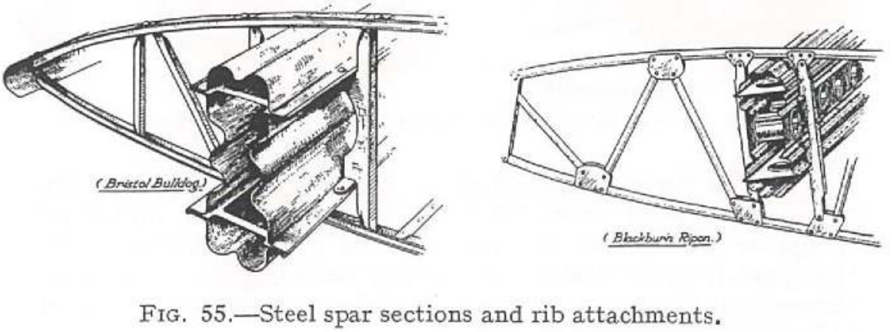
184. The simplest form of metal spar used is that of the solid drawn round tube, but owing to the uneconomical distribution of the material, this form of spar is comparatively heavy. A much lighter form of spar can be made if the tube is reshaped by rolling, or if it is built up, and the material disposed to greater advantage. Built-up metal spars are made from strip steel or duralumin, the form being governed to some extent by the size and load they have to carry, but to an even greater extent by the type of construction adopted by the designer. Fig. 55 shows some of the types of steel spars used. All the spars shown are suitable for large or small aircraft, excepting the top left-hand illustration, which shows a type of design particularly suitable for the large types.



(Gloster Air Survey.) (Armstrong Whitworth Atlas.)



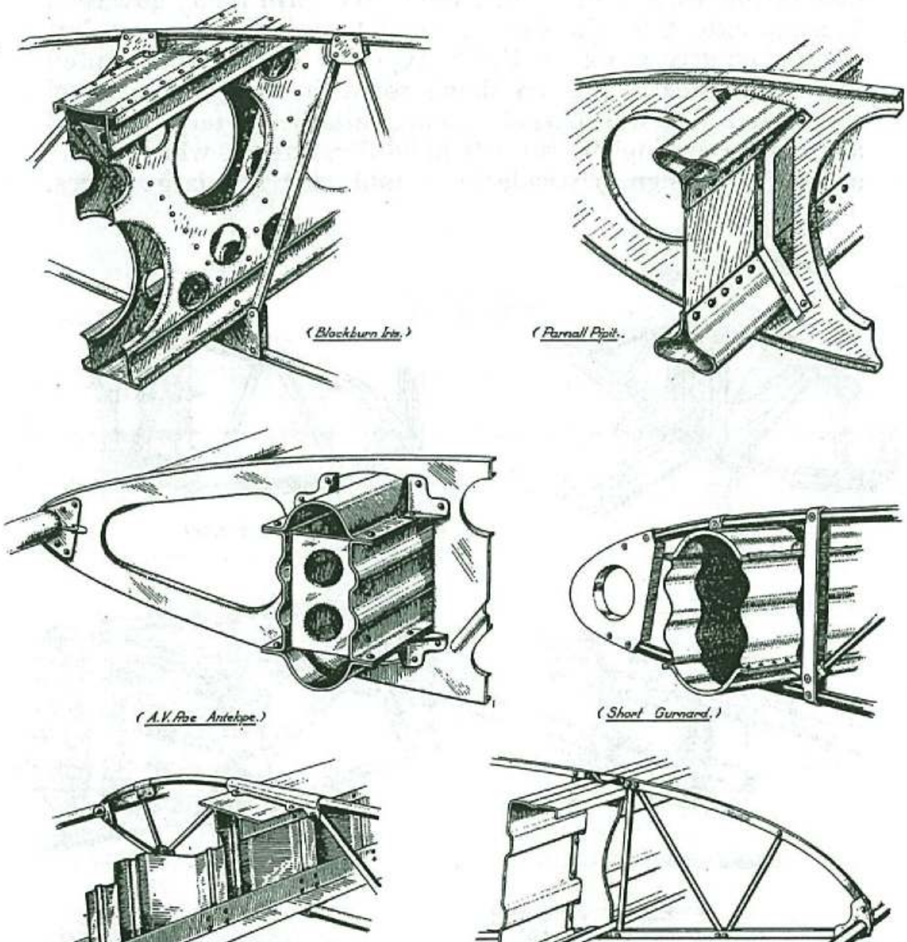
(Westland Wapiti.) (Armstrong Whitworth Siskin.)



(Bristol Bulldog.) (Blackburn Ripon.)

FIG. 55.—Steel spar sections and rib attachments.

Fig. 56 shows some of the types of duralumin spars used, and, as will be noted, the designs are somewhat more open in section, due to the fact that, strength for strength, duralumin is thicker and more bulky than steel, and therefore more stable under load. The designs shown are applicable to all types of aircraft, with the exception again of the top left-hand illustration, which is more suitable for the larger aircraft.



(Blackburn Iris.)

(Parnall Pipit.)

(A.V. Roe Antelope.)

(Short Gurnard.)

(Vickers Wildebeeste.)

(Vickers Southampton.)

FIG. 56.—Light alloy spar sections and rib attachments.

185. In the majority of cases, the flanges of the spars are made in heavier material than the webs, and additional flange or web plates are used at the attachment points of the spars, in order that the stress may be as uniform as possible throughout the length of the spar under any normal condition of loading.

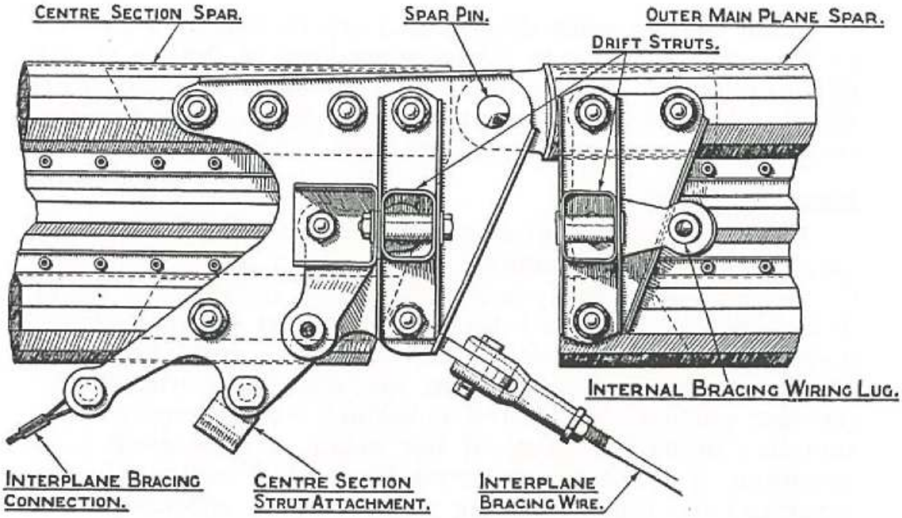


FIG. 57.—Metal spar end fitting.

186. The form that the spar attachments take varies with each design of spar, but they can roughly be separated into two types, those employing side plates, and those where the attachment is made directly to the spar surfaces. In the latter case, there is usually some form of internal fitting or bulkhead plate. Figs. 57 and 58 illustrate both these methods.

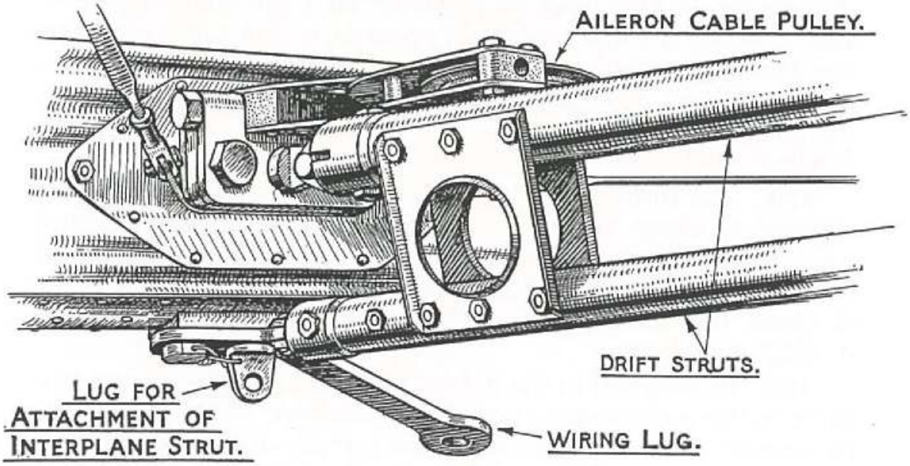


FIG. 58.—Metal spar fitting.

Metal ribs.

187. It is not unusual for light alloy ribs to be used with steel spars, but it is a more common practice for steel ribs to be used. The construction of metal ribs and the method of attachment to the spars are shown in figs. 55 and 56. It will

be noted that in some designs ribs are riveted or bolted on to the spars, whereas in others some form of flexible spring clip is employed. The flexible type of attachment is used with the intention of damping out any excessive vibration in the wings, which may be transmitted from the engine.

Metal fuselages.

188. The members of all-metal fuselages may be composed entirely of steel or duralumin, or may be a mixture of both. On account of its easy adaptability for the purpose, solid drawn round or square tubes are to a great extent used for metal fuselage construction, especially the front end, but different forms of construction are sometimes utilised for the rear portion. Strip steel is seldom used throughout the complete fuselage because, if the weight is kept down to a minimum, it is not always a suitable type of construction to withstand the rough handling which may be encountered in cockpits and engine mountings, and also the many attachments required are not so easily made to this type of structure as to the tubular form.

189. Fuselage structures may have pinned joints, or may be constructed with fixed-ended struts, and the joints may be riveted, bolted or welded together, but in all cases it is customary to employ jigs during manufacture, in order to ensure that the structure will be true when completed. Fig. 59B shows a pin-jointed fuselage construction, employing ball-ended struts which are maintained in position in the cap sockets by the bracing wires. Fig. 60A shows also a tubular type of structure with fixed-ended struts riveted by side plates to the longerons. Fig. 60B shows a typical strip steel type of fuselage, and fig. 59A represents the welded type.

190. The fuselage fairings are arranged in a very similar manner to those for wooden aircraft, but the formers and solid fairings are normally made of light alloy instead of three-ply. The formers are composed of sheet material or of small diameter tubes, and are bolted or clipped to the fuselage members.

191. In addition to the braced forms of fuselages illustrated, there is the monocoque type of construction shown in fig. 61. In the type illustrated, the structure is made of sheet duralumin rings or sections, reinforced between the formers by stiffeners.

Metal struts.

192. Whenever they can be economically used, solid drawn round tubes are employed as struts, with the addition of some form of fairing to reduce the head resistance if they are used externally. When struts are very long, some reduction in weight can usually be made if they are built up from sheet

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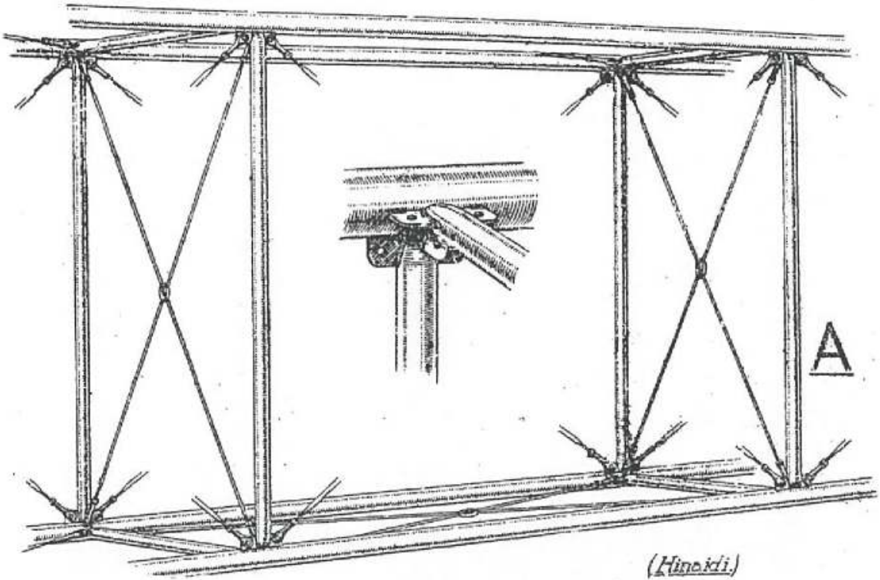
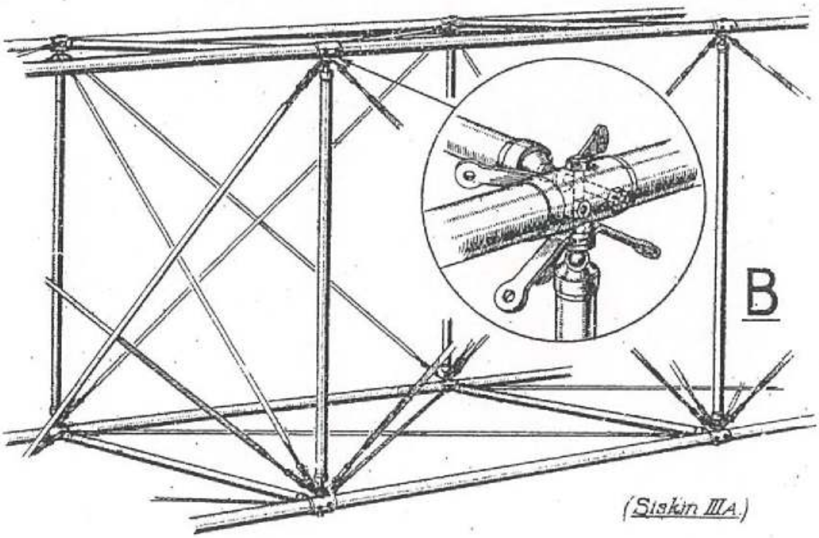


(Hinaidi.)



(Siskin IIIA.)

FIG.59. TYPICAL METAL FUSELAGES.—I.

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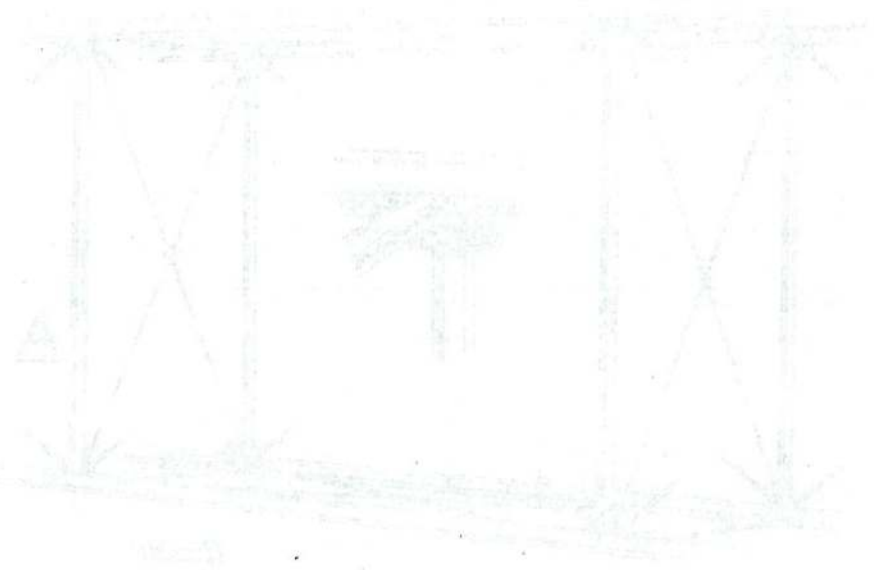

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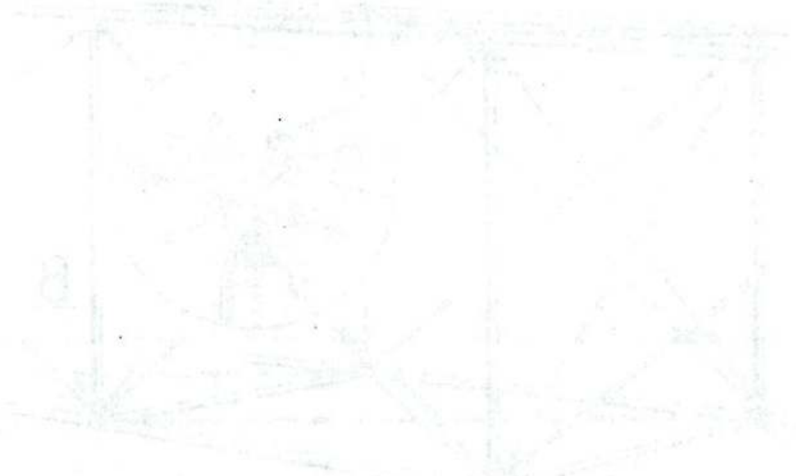

B

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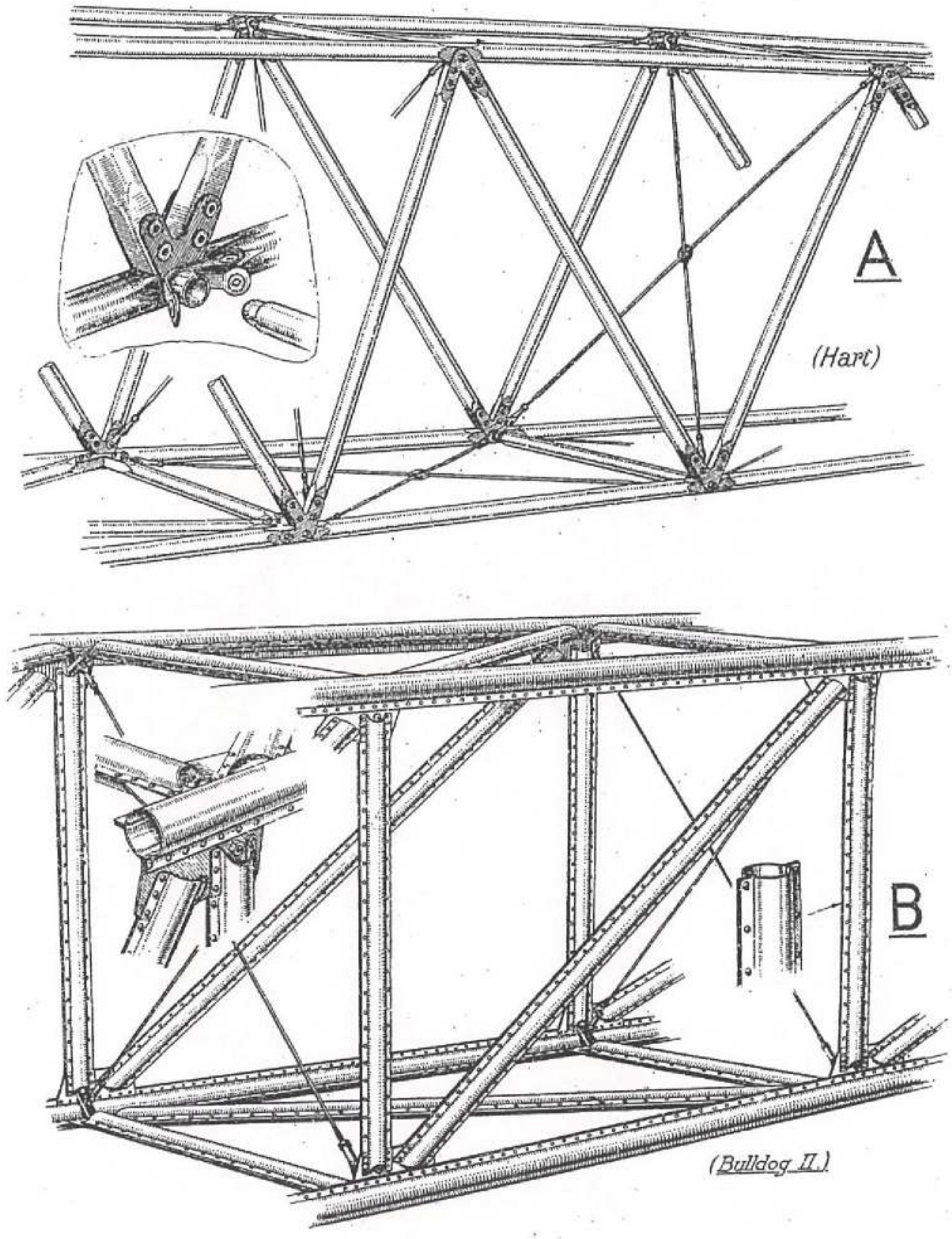

FIG. 60. TYPICAL METAL FUSELAGES.—2.

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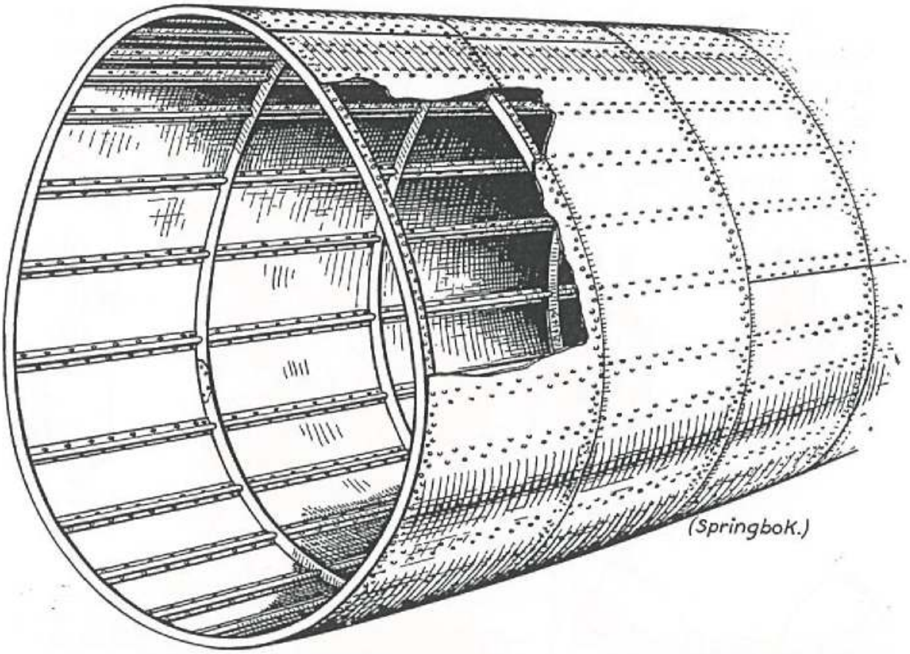

FIG. 61.—Metal monocoque construction.

or strip materials, as indicated in fig. 62. Occasionally, it is convenient to use one of the streamline section tubes which are obtainable in many shapes and sizes, but as these special section tubes are fairly heavy compared to their strength as struts, they are generally used only for the shorter and more heavily loaded struts, such as are met with at the centre sections or undercarriages, or where, owing to their small size, it would be uneconomical to use a built-up form.

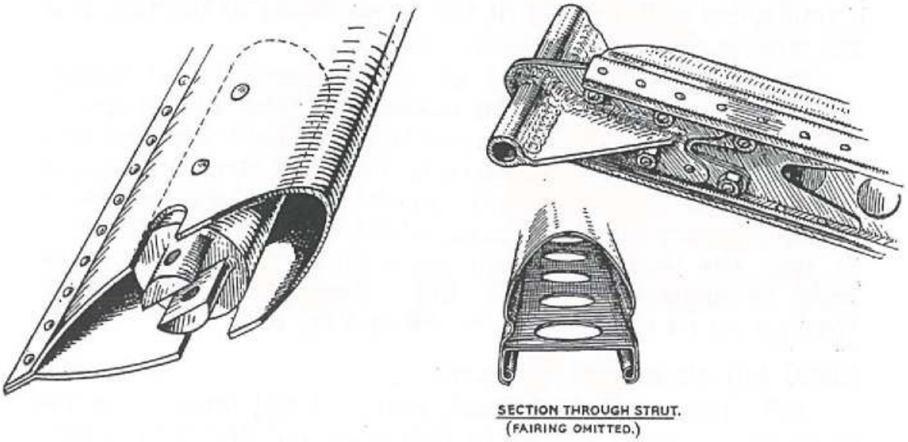

FIG. 62.—Built up metal struts.

193. The end fittings for tubular struts vary in design to some extent in accordance with the purpose for which the strut is used, but the most common type for pin-jointed structures is that of the internal or external socket shown at A and B, fig. 63, the latter being generally considered the better type, as it prevents any tendency of the tube to spread or split. Steel tube end sockets are a comparatively heavy type of fitting, and for this reason manufacturers occasionally adopt other means of making tube end attachments. The illustrations C to H, fig. 63, give some of the methods used. The bent, flattened tube types are not frequently encountered on all-metal aircraft, because, even when the tube has a liner, a fracture is apt to occur at the bend, owing to the fact that the strut is offset from its attachment.

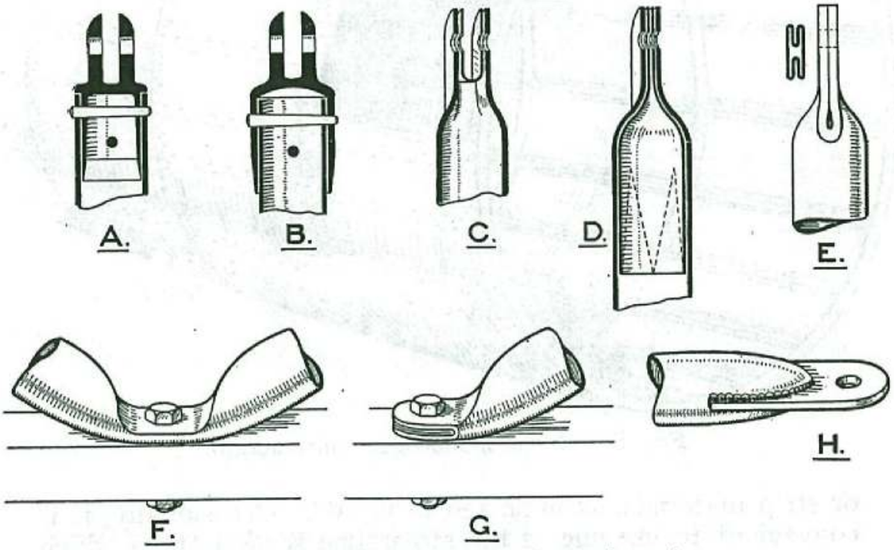

FIG. 63.—Tubular strut end attachments.

194. Fixed-ended struts are used extensively in fuselage construction, though seldom elsewhere. The advantages of fixing the ends of struts are reduction of weight and increased rigidity and lower production costs, but if the structure deflects greatly under load, then some of the benefits are lost owing to the necessity of making many of the members strong enough to take the bending thrown upon them by the fixed strut ends, as explained in para. 113. Examples of fixed-ended fuselage struts are given in fig. 59 and fig. 60.

Metal tail planes and elevators.

195. The method of construction of tail units is, in the majority of cases, similar to that used for the main planes, the main differences being that the tail planes are much

smaller in span, and usually have a symmetrical section. Also, all that portion of the plane behind the rear spar is usually hinged, and so forms the elevators. The stripped tail-plane and elevator shown in fig. 64 represents one type of strip steel construction.

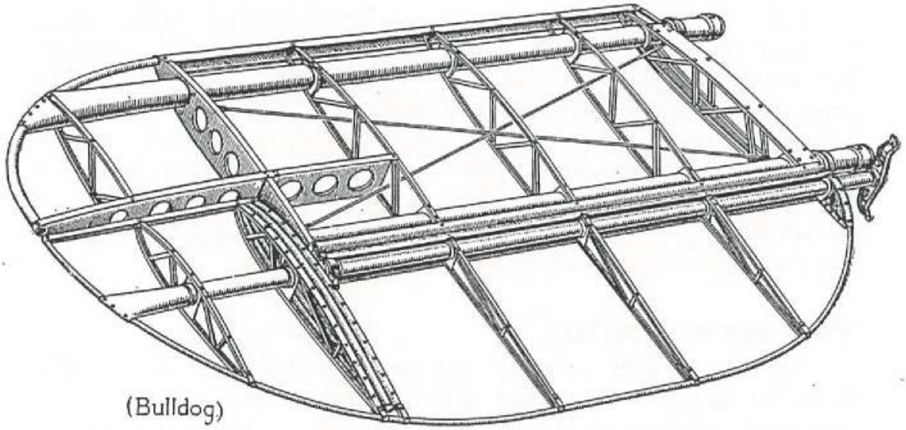

FIG. 64.—Metal tailplane and elevator.

196. Tail planes are usually provided with some form of incidence adjustment which is operable in the air. The tail adjusting gear shown in fig. 65 indicates the principle on which

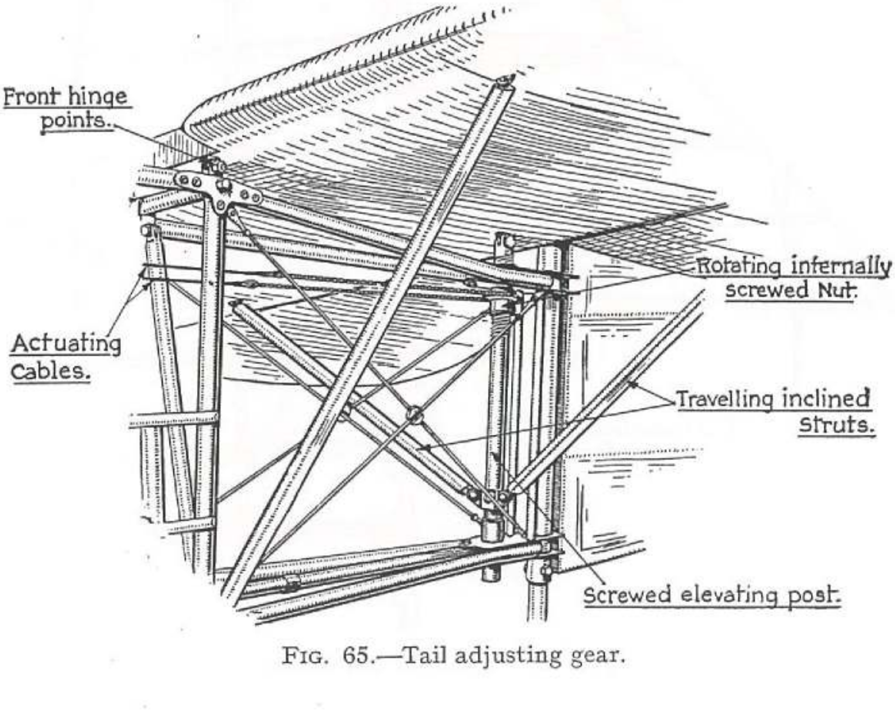

FIG. 65.—Tail adjusting gear.

the majority of these gears work. The object of the device is to give a fairly large range of adjustment of incidence for the tail plane, so that, under all normal conditions of flight and centre of gravity positions, the air loads can be to a great degree balanced, thereby making the aircraft less tiring to fly.

197. The elevators are generally provided with some form of balance, and are usually directly connected together by being mounted on the same spar, but variations of this arrangement exist where the inter-connection is obtained by having a countershaft fitted with levers, positioned in the rear end of the fuselage with connecting rods to a lever on each elevator. The reason for the rigid inter-connection is to prevent the excessive tail flutter which may be produced by elevators connected only by cables.

Metal fins and rudders.

198. Fins and rudders are usually built in a slightly different manner from the main planes. The type of construction used is generally much simpler. Fig. 66 shows a

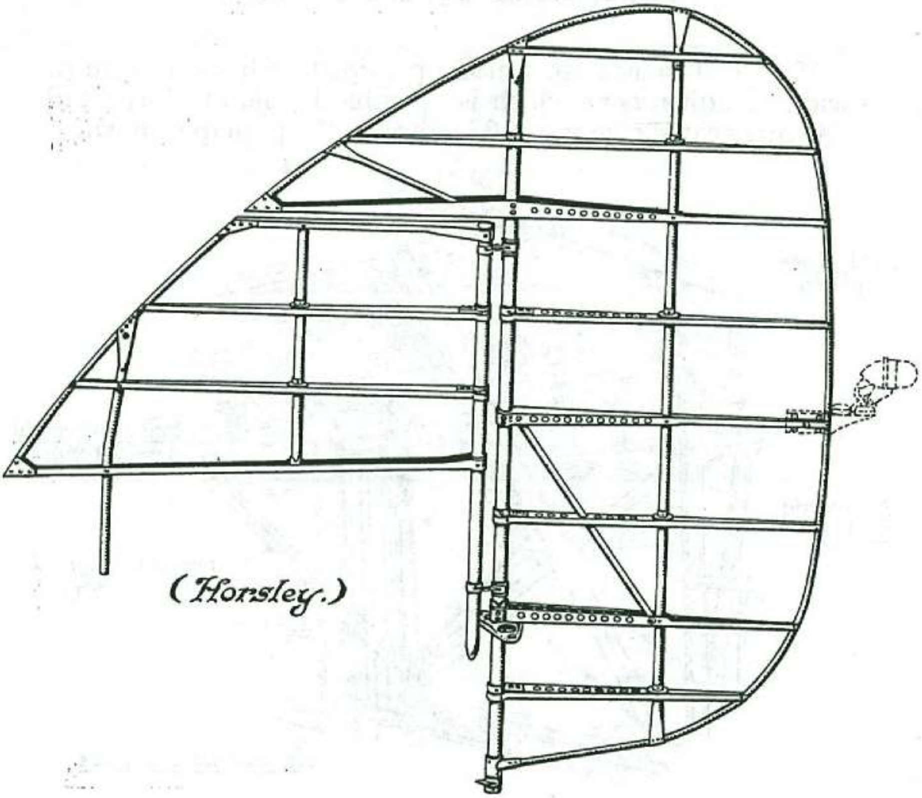

FIG. 66.—Metal fin and rudder.

skeleton arrangement of a fin and rudder employing steel tubes and light alloy ribs and boundary tubes, which is a usual type of design. As with ailerons and elevators, rudders are usually arranged with some form of balance in order to assist the pilot in actuating these control surfaces.

Metal undercarriages.

199. All the main members of an undercarriage for a modern aircraft are constructed of metal, but wooden fairings are still used for tubular axles or struts. The axles are in all cases composed of a high-grade tubular steel, specially hardened and tempered to withstand the landing shocks and also the bending stress which usually exists owing to the slightly offset wheels. In some instances the axle tube is in one continuous length, and in others it is split into two lengths, in which case the inner ends of the two halves are anchored to some point of the fuselage structure and the outer ends are set horizontally and sleeved to take the undercarriage wheels.

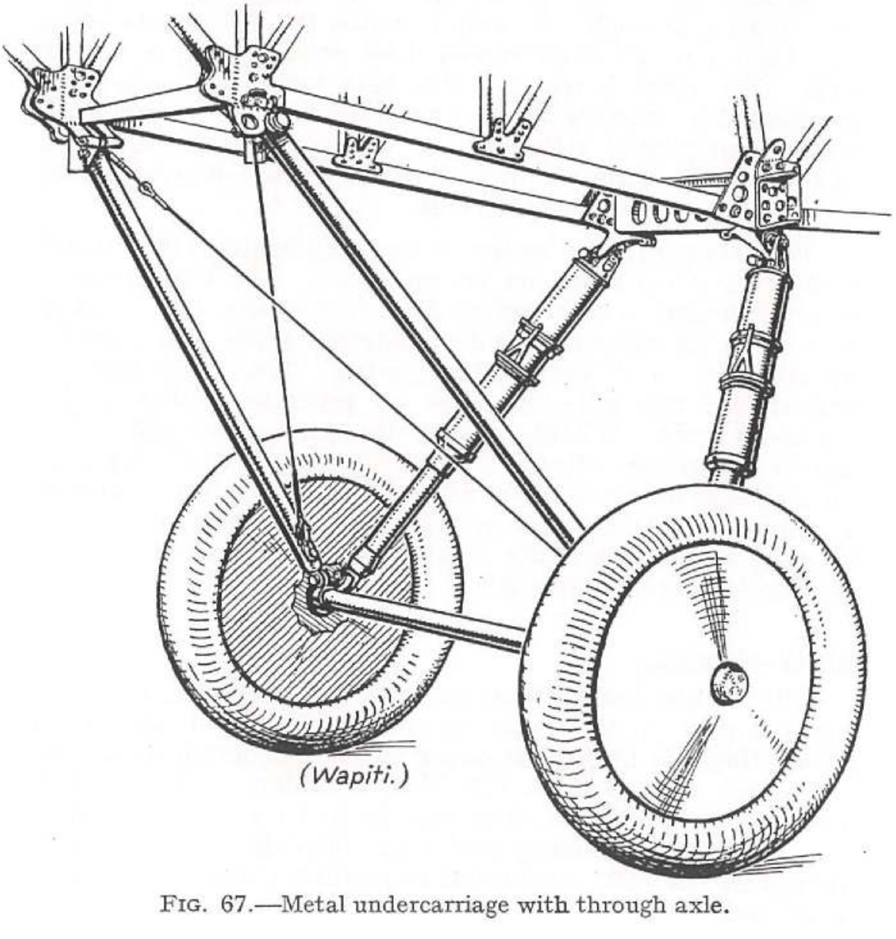

FIG. 67.—Metal undercarriage with through axle.

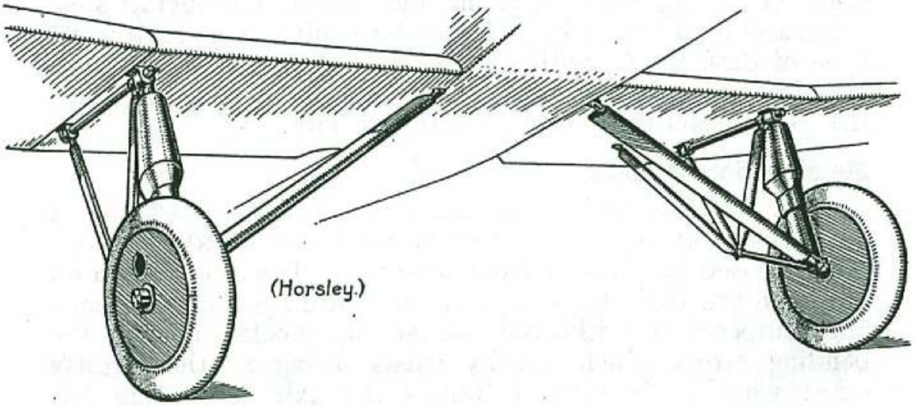

FIG. 68.—Metal two unit or divided undercarriage.

200. Figs. 67 and 68 show typical examples of both forms of undercarriage. In fig. 67, the undercarriage is of the oleo type with a through axle and V-struts, the rear struts being oleo legs, and the cross braced front struts acting as radius rods. The cross bracing in this case takes any side loads imposed. Fig. 68 shows a two unit or divided undercarriage, in which triangulated strut pylons take the fore-and-aft drag of the wheels, acting through short universally-jointed struts, and the axle takes the side loads.

Both these types of undercarriage may be fitted with wheel brakes, of which there are several types. The brakes are in most cases similar to those used for motor cars, that is, they may have an external band or internal shoes and may be operated by hand lever or foot pedals. The power may be transmitted indirectly by oil or air pressure or directly by cables or rods. Whatever form the mechanism takes, the brakes are usually arranged to operate on all wheels together or each side independently, as desired. The adjustment and maintenance of the various types are usually given in the Rigging and Maintenance Notes, or the Handbook, of the particular aircraft concerned.

Shock-absorbers.

201. If shock-absorbers are properly designed, they are efficient over all the conditions of loading of the aircraft to which they are fitted, but owing to the restriction on weight and range of movement this ideal is seldom realsied. It is not uncommon for shock-absorbers to be so designed that their maximum efficiency is obtained near the full load condition of the aircraft ; this tends to produce harsh action under light loads.

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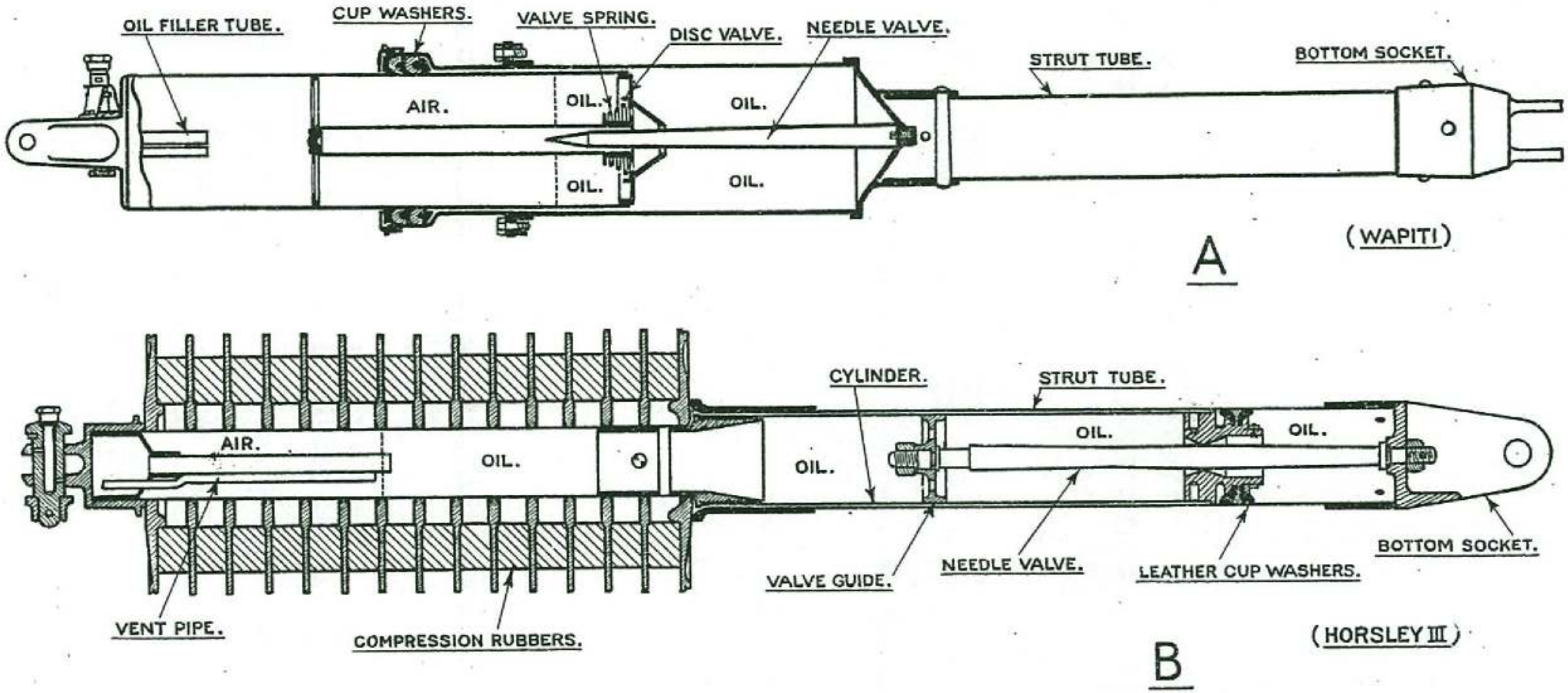

FIG. 69. OLEO LEGS.

P.9882.

202. Shock-absorbers for aircraft may take the form of rubber in tension or compression, or they may employ a steel spring or an oleo damping cylinder. Rubber in tension undoubtedly makes the lightest form of shock-absorber, but its behaviour under extreme climatic and atmospheric conditions precludes its use on modern service aircraft. Rubber in compression is also affected by like conditions, but with less serious results. Steel springs are usually durable, but generally they only reach their maximum efficiency at the one load at which they are designed to operate. Oil and air oleos can be made to operate efficiently over a large range of loading, and are to a large extent unaffected by climatic conditions.

203. An oleo leg of the type shown in fig. 69B has an oil dashpot which is used in conjunction with compression rubbers. In operation the oleo leg extends to its full length whilst the aircraft is in flight, due to the weight of the wheels and axle. Upon alighting, a compression load is applied to the leg which forces upward the lower sliding tube. By this action the oil is forced at high pressure through a restricted orifice, which delays the displacement of the oil, and consequently gives a comparatively gradual telescopic motion to the leg. If, after all the oil has escaped through the orifice, further compressive loads are applied to the leg, then the compression rubbers come into operation. Thus, the oil oleo operates only during the first actual landing contact, whilst the compression rubbers take any subsequent shocks, such as those due to taxying. When considering the shock absorption of an undercarriage, the effect of the large pneumatic tyres fitted to modern aircraft must not be ignored, as these are capable of absorbing all light shocks and a considerable proportion of the heavier ones.

204. The oleo shown in fig. 69A is similar in principle to that shown in fig. 69B, but it has an air cylinder instead of the compression rubbers. In this type of oleo the air in the cylinder has to be maintained at a pressure, varying with the type, of between approximately, 150 to 500 lb. per square inch. In operation the oil is forced through a variable orifice from the lower to the upper chamber, thus absorbing the landing shocks, and the air provides a cushioning effect when a subsequent load is applied, such as that due to taxying. For this type of oleo leg, special forms of hand air pumps are provided, Stores Ref. 4/257 and 27A/480. The maintenance and adjustment of the various types of oleo legs is fully dealt with in the aircraft handbooks and A.M.T.O's.

Metal tail-skids.

205. Metal tail-skids are very similar in action to those used on wooden aircraft, but the adaption of an all-metal

construction usually allows greater facilities and therefore the types vary to a greater extent. Fig. 70A indicates a typical tail-skid using rubber in compression, fig. 70B shows a type employing a steel spring, and fig. 70C a type utilising an air oleo.

Metal Airscrews.

206. Metal airscrews of two types are at present in service, the solid duralumin twisted sheet type and the hollow mild steel variety which is adjustable in pitch. The former is made from thick duralumin sheets and after being milled to shape the blades are twisted to give the required pitch. The bosses are constructed in two halves of either wood or metal; if the former laminated oak is used, if the latter then hollow aluminium castings are employed. In both cases the two halves are bolted to the blades.

207. The steel airscrew consists of a central hub which is provided with sockets, into which the detachable blades are fitted and clamped. The hollow blades are built up from laminations which are pressed into shape in a die, and edge-welded. There are generally four laminations, the innermost being shortest and the remainder increasing in length until the outside sheet forms the complete blade shape. The blades are welded to cyclindrical butts, which are machined to suit the sockets on the hub. The blades can be adjusted to give any pitch desired; the method to be adopted and the angular setting for certain aircraft is described in Air Ministry Technical Order 128 of 1927.

208. The light alloy airscrews have identification marks similar to those of wooden airscrews, but, for the detachable-bladed steel airscrews, the blades and the hubs are all given identification marks again similar to those described for wooden airscrews, but with the exception that the pitch and the name and series of engine are omitted. The protective covering of the light-allow airscrews usually consists of varnish, whilst the steel airscrew blades are stove enamelled.

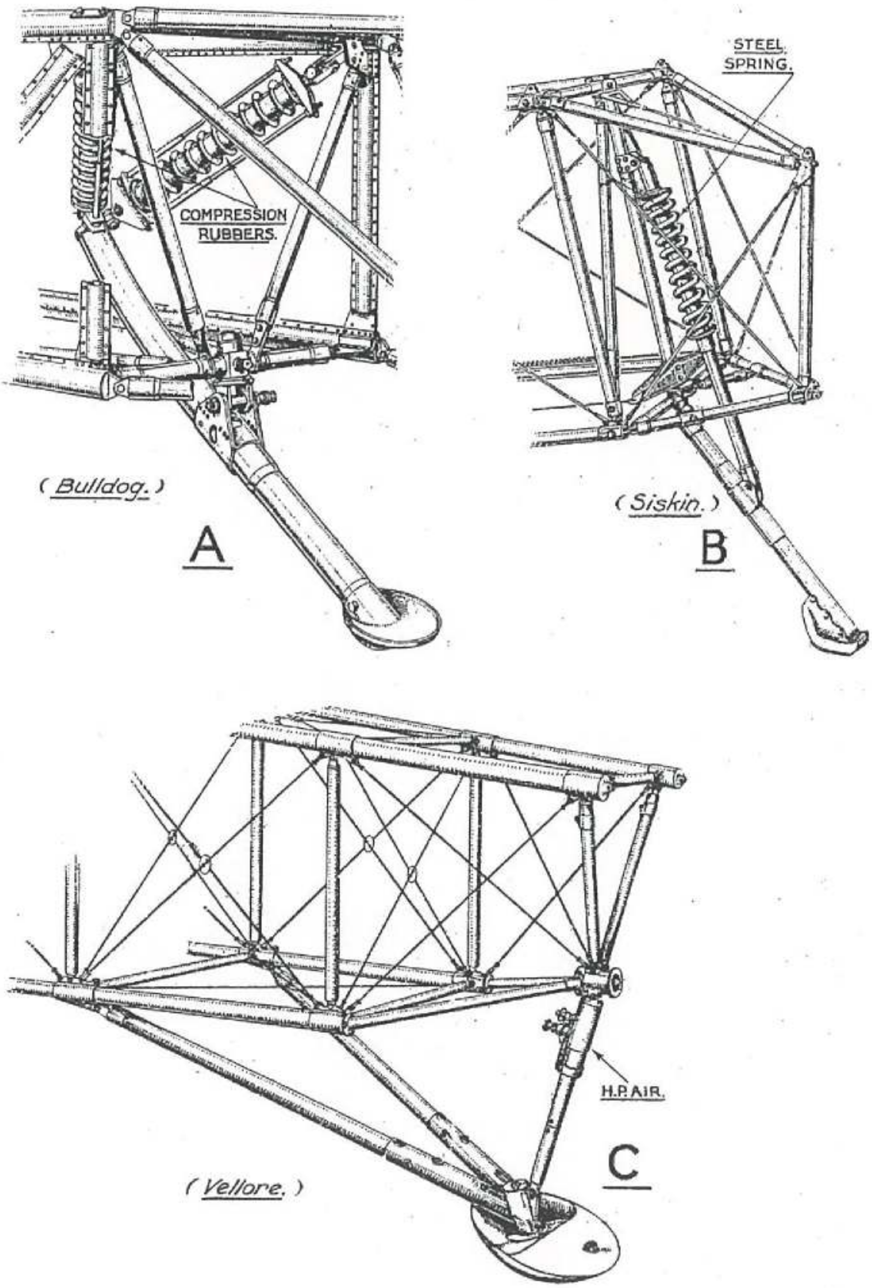

FIG. 70. METAL TAIL SKIDS.