AEROPLANE DESIGN.

A Paper read by
Mr. H. P. Folland, M.B.E., F.R.Ae.S., etc.,
before The Institution, on 31st March, 1922.

Lt.-Col. J. T. C. Moore-Brabazon, M.C., M.P. (President),
in the Chair.

In introducing Mr. Folland the Chairman said :—

It is with much pleasure I call upon Mr. Folland to read his paper on " Aeroplane Design " to you. In the case of a written paper, except for the pleasure of looking at the reader, there is not a great difference between hearing it and reading it, but the former does afford members an opportunity of joining in the discussion afterwards. You all know Mr. Folland by reputation; his fame is well established, and I am sure that whatever criticisms arise in the discussion, he will answer them so that we feel quite small at hearing our criticisms washed aside. I hope, however, that many of you will take the opportunity to join in the discussion, and I now have pleasure in calling upon Mr. Folland.

AEROPLANE DESIGN.

The title of my subject to-night, " Aeroplane Design," is one which covers many branches of Aeronautical Engineering and Scientific Research. Each branch could be subdivided into a large number of different subjects, which would provide a paper and food for discussion for many lectures. In my paper to-night I shall only be able to touch briefly on the many subjects of General Design and Detail Design connected with such a vast and progressive new branch of engineering and science; this I will endeavour to do in a way which will appeal to the aeronautical engineer and the draughtsman.

It is to the engineer and draughtsman that I wish to appeal, for when the designer has laid down his specification, plans and schemes, the draughtsman and engineer greatly contribute to the producing of a sound commercial proposition in the detail design on an engineering basis which will go towards making the aeroplane a commercial success and a foolproof structure.

I intend in this paper to go over the preliminary design of an aeroplane, and to give rough approximations; also to draw attention to the importance of the detail design and points which go towards reliability, efficiency and an engineering structure. Wing sections in my paper are assumed to be known sections, such as R.A.F. 6, 14 and 15. For high-lift wings and slotted wings the following approximations do not apply, these being, in most cases, still in the experimental stage.

PRELIMINARY SPECIFICATION.

To produce an aeroplane as efficient as we can for a definite purpose, the designer must start by knowing the load to be carried and the cubic capacity of the load, the maximum distance at cruising speed, and the conditions under which the machine will have to operate. By conditions I mean useful load, such as military, passenger, goods, postal, etc.; also climate, landing grounds, and altitude at which the machine must operate. This is usually covered by a rough general specification stating requirements and giving these particulars.

Having this the designer can proceed to draft out a more detailed specification.

Using known wing sections such as R.A.F. 6, 14 or 15, the Air Ministry requirements for load factors, the problem is then to design a safe, reliable and efficient aeroplane. It will be wise to consider, at this early stage of design, the altitude at which the machine may have to operate. In the past machines have been designed to suit this country only; also the R.A.F. wing section 15 has been universally adopted. Often machines have been sold to the colonies and foreign countries, and have proved to be unsuitable, owing to the altitude at which they have to operate being in some cases 5,000 feet to 8,000 feet above sea level. These cases could have been covered by having different standard wings for different altitudes; these could all be the same wing area, using in wing fittings, wires and struts, but the section itself would be designed to give the equivalent landing speeds and climb for the altitude required.

With the data at our disposal and the requirements being known, it is necessary to select a suitable engine, this being selected according to performance and requirements of the specification, always bearing in mind, first, reliability and efficiency; second, low weight per horse-power, and in the case of a commercial machine low running cost per horse-power. In many cases the engine is specified, especially in the case of Air Ministry designs.

The first step towards making the detail specification is to make a rough estimate of the total weight of the machine. This can be taken on the following chart of percentage of total weights. This chart gives a fair approximation over a number of machines. (*See Slide No.* 1.)

It will be noted that about 65 per cent. of the total weight is known—the weight of engine, useful load, fuel, oil and radiator—and therefore only leaves us with about 35 per cent. load unknown. This simplifies the total permissible error. Having obtained the approximate total weight loaded, and assuming we use a standard wing section with a known lift coefficient, we can fix our load per square foot according to the requirements and type of machine to be designed. The total area of the wings, including ailerons, can now be fixed, also span, chord, gap, incidence, stagger, and dihedral.

SPAN AND CHORD will depend on the required aspect ratio, and are sometimes controlled by the most economical spacing of the wing struts and spars. The average aspect ratio being 5.5 to 7.5 to 1 for the best all-round efficiency, it is not wise to go below 5.5 to 1.

ANGLE OF INCIDENCE will depend on the altitude at which the best performance is required. For a fighting machine incidence can be taken between 1½° to 3°, and for a commercial machine 3° to 5°.

THE DIHEDRAL will depend on the degree of lateral stability required. This can be taken between 3° and 5°.

STAGGER.—For a biplane stagger will greatly depend on the requirement of the machine, visibility, efficiency, etc. Stagger is also useful as a means of correcting the relation of the elusive centre of gravity to centre of pressure. For structural reasons it is not wise to stagger more than 25° in either direction.

GAP.—For efficiency of a biplane the gap chord ratio should not be less than .85 to .95 of chord. This is a good figure to work to. Wind tunnel tests show that a gap chord ratio of 1.2 to 1 is more efficient, but taken in actual practice, it is very doubtful whether the extra head resistance, due to longer struts and wires, also the extra weight, warrant one taking the advantage of the extra efficiency.

AILERONS.—Total area of ailerons can be taken as:—For a fighting machine, where quick manœuvrability is required, 13.5 per cent. of total wing area, and for a load carrying military or commercial machine, where quick manœuvrability is not required 13 per cent. can be taken of total wing area. For good control the chord of aileron should be .25 mean chord of wing.

TAIL PLANE, COMPLETE WITH ELEVATORS.

Total area of tail plane and elevators can be taken as :—

Scout $\frac{10.75 \times A}{100}$ 2-Seater Fighter $\frac{12.25 \times A}{100}$ Commercial $\frac{13.5 \times A}{100}$

The distance of tail plane leading edge from centre of gravity of aeroplane can be taken as :—

Scout 2.2 x Mean Chord. 2-Seater 2.7 x Mean Chord.
Commercial 2.9 x Mean Chord.

The percentage of tail to elevator gives good controlability at 65 per cent. tail and 35 per cent. elevators for Scout; for Commercial Machine 60 per cent. tail and 40 per cent. elevators. Aspect ratio of elevators to give good fore and aft control can be taken as 3.3 to 1.

RUDDER AND FINS.

Total area of rudder and fins.

Distance of leading edge of rudder from centre of gravity of machine will in most cases be controlled by the position of the tail plane.

Total area of rudder and fins = $\frac{4 \times A.}{100}$

51 per cent. movable, 49 per cent. fixed.

Aspect ratio of rudder to give good control should be 2.6 to 1. A in each case being total area of wings.

PRELIMINARY DESIGN.

Having obtained total weight, wing area, and controlling surface areas, we can now proceed to lay out a preliminary design to meet the required specification.

It is necessary in the preliminary design stage to bear in mind the important points which go to make the best all-round machine from a service or commercial point of view. Wherever possible the following points should be borne in mind as most desirable :—

(1) Simple but adequate petrol system; wherever possible a gravity system should be used.

(2) Accessibility to engine, especially filters; also easy replacement of engine.

(3) Accessibility to flying and engine controls.

(4) Deletion of control pulleys and cables in favour of bell cranks and rods.

(5) Fireproof bulkheads.

(6) Adequate bearing surfaces for moving parts, and adequate means of lubricating same.

(7) Visibility in all directions, especially forward and down.

(8) Quick-detachable small units, to facilitate easy replacement.

(9) Comfort of pilot and passengers. (Ventilation, seating, view, etc.).

(10) Initial cost.

It is at this early stage in design that these items can and should be considered, and bearing this in mind we can proceed to draw out the arrangement of the machine. The best method to adopt is to draw the fuselage with engine, tanks, pilot, armament, or, in the case of a commercial machine, the passengers' cabin, controls, etc., in fact, everything for the complete fuselage and cabin.

Having this, we can then find the weights of the structural parts, etc., from the table of percentage of weights, allocate the weights over the fuselage approximately where the centre of gravity of the masses comes, then find the centre of gravity of the fuselage complete. Having found this we can make a sketch of the wings with the centre of pressure marked on the mean chord line. The centre of pressure in relation to the centre of gravity of the machine can be taken as .3 of the mean chord. This sketch can be placed over the fuselage with the centre of pressure on the centre of gravity and traced on to fuselage. (*See Slide No.* 2.)

The next step is to add the undercarriage. This can be done by striking a line through the centre of gravity of the machine 16° to the centre line of the fuselage. The wheel can then be put in, making allowance for adequate taxi-ing angle and propeller clearance. 16° for position of the landing wheels to the centre of gravity is a safe figure to take. The taxi-ing angle of machine, with skid on the ground, should not be less than 14° to ensure quick pulling up of the machine after touching the ground.

With the exception of the added weight of the wings and undercarriage, we have a fairly accurate centre of gravity. By this method a lot of time will be saved over drawing the complete aeroplane, and then moving the weights or components about until the centre of gravity comes correct in relation to the centre of pressure of the wings.

Providing the wings come in a position for good visibility, etc., and the general layout is to the satisfaction of the designer, the design can be adjusted and the centre of gravity re-taken, horizontally and vertically, at the same time correcting for the additional weights of wings and undercarriage.

A mock-up of the front portion of fuselage, and in the case of a commercial machine the passengers' cabin, should be made in rough wood with dummy controls (engine and flying) and seating accommodation. From this visibility, leg-room, position of controls, accessibility to engine controls, switches and instruments can be checked : positions for wireless, bomb sight, camera, oxygen apparatus, can also be rigged up and approved. Alterations can be made in a rough manner, and the design modified, if necessary, at an early stage. This saves a great amount of scheming and drawing in the Drawing Office, and incidentally prevents a large amount of modifications being issued to the shops at a later date.

The time and expense of this mock-up is therefore often saved many times over.

COMPLETE SPECIFICATION.

When the final design is approved, the component weights can be finally checked, centre of gravity re-taken, and a final specification drawn up for use in the drawing office, giving detailed requirements of each component of the machine.

FINAL DESIGN.

With this final specification set out and the scheme approved, it can then be issued to the drawing office, and each component of the aeroplane allocated for large size schemes of components, to determine the best method of construction and detail design.

We have, for choice of construction, three different types :—

1. All wooden structure.
2. All metal structure.
3. Metal cum wood structure.

These can again be subdivided as follows:—

1. (a) Monocoque wooden structure.
   (b) Wire braced ,,
2. (a) Tubular steel structure.
   (b) Built-up steel structure by special sections.
   (c) A combination of the two; this can be made in duralumin or aluminium.
3. (a) Steel tubular main structure, such as fuselage, wing spars and compression struts, undercarriage and wing struts, the ribs, leading and trailing edges, fairings, etc., being in wood.
   (b) Metal built-up main structure of special sheet sections, such as fuselage, wing spars, compression struts, undercarriage and wing struts, the ribs, leading and trailing edges, fairings, etc., being in wood.

Slide No. 3 shows special construction of a body of a large bomber built during the latter end of the war, construction of low grade wooden planking on side 3/16 in. and ¼ in. thick grooved and tenoned into each other, nailed to longerons and struts with copper nails, and nails bent over on inside. The planking was also sewn to stiffeners with brass wire, corners of transverse members were fixed by fitting 3-ply gussets, and corner chocks, glued and pegged with hard wood pegs. Slide No. 4 shows the details of planking and jointing. Tubular rivets were used in almost every case where fittings were attached.

The choice of construction will depend on:—

1. Cheapness of construction.
2. Number of machines to be constructed.
3. Weight-saving.
4. Robustness of construction.
5. Delivery and ease of obtaining material.

The merits of each type could be described briefly as follows:—

WOODEN STRUCTURE.—This is the cheapest and simplest form of structure. For a small number of machines the initial cost is low, with minimum weight.

METAL STRUCTURE.—With the metal structure we have a large variety of metal of different tensile strengths to choose from. (With wood we have only two approved timbers—ash and spruce—with a tensile strength of 5,500 lbs.

per square inch.) With metal a weight strength ratio can be obtained equal to wood. It is not subject to atmospheric and climatic conditions, providing it is adequately protected; in the case of steel, this can be done by electro-galvanising or other approved methods. This type of structure does not warp or affect interchangeability. For a small number of machines the initial cost is invariably higher.

METAL CUM WOOD CONSTRUCTION.—With this type of construction, the bare fuselage would be made of metal, also the main spars, compression struts, wing struts and undercarriage. These form the main structure of the aeroplane for strength and resistance against atmospheric and climatic conditions, also against warping, and ensure perfect interchangeability. The subsidiary structure, such as ribs, leading and trailing edges and fairing for fuselage, can be made in wood, thereby saving expensive metal construction for ribs, fairings, etc.

Great difficulty is now being experienced in obtaining good spruce for aircraft work; the requirements of the war have made a marked effect on the supply of good spruce. We can only hope that this will hasten the steel construction.

I am personally all out for the all-metal aeroplane, but I maintain that the evolution of wood construction to metal construction must be done in stages, and I recommend the metal cum wood construction as the first stage, and I consider the tubular structure the best form at present, as tubes can be bought from stock at a short notice, also at a low cost.

With the tubular structure a machine can be constructed for the same weight as a wooden structure, and for very little extra cost. We are, in this country, constructing all-metal experimental aeroplanes, and developing the built-up thin high tensile sheet metal structures. This is a trend in the right direction, but the initial cost of dies, tools, jigs, etc., for manufacture is extremely high. With the few orders available at the present time, it is impossible to construct commercially and competitively on these lines. No doubt, when large orders are placed, this type of construction will compare very favourably with the wooden structure.

Having decided on the type of structure to be used, the schemes of components proceed, and a preliminary estimate of the loads in the structure can be calculated. Also model tests for stability, etc., are being carried out.

When the component schemes are approved, and the structural loads are completed, the detail design can be put in hand.

LOAD FACTORS.

Before getting into the subject of detail design, I would like to touch on the question of load factors required; these will vary according to the type.

For fighting types, where high speed combined with quick manœuvrability is necessary, the load factor should be as follows:—

WINGS.—Load factor front truss 7.
,, ,, rear ,, 5.
,, ,, centre of pressure forward, with any lift wire broken 4.2.
,, ,, centre of pressure back with any lift wire broken 3.
Travel of centre of pressure taken for R.A.F. 15 wing section .28 to .5.

AILERONS.—20 lbs. per sq. ft. should be taken as failing load on the ailerons. Load assumed as coming .3 of chord of aileron.

TAIL PLANE AND ELEVATORS.—Tail plane taken for worst condition, that being nose diving case,

$$\frac{W.C.}{L.} = \text{load on tail.}$$

Where W = total weight of machine.
C = chord of main plane.
L = length from centre of gravity of machine to centre pressure of tail plane.
C.P. = .33 chord of tail and elevators.
Factor of safety to be 1.5.

RUDDER.—20 lbs. per square foot should be taken as failing load of rudder, load taken with centre of pressure .3 of mean chord.

FINS.—20 lbs. per square food should be taken as failing load of fins, load taken with centre of pressure .3 of mean chord.

FUSELAGE.—Four cases should be taken as follows:—

(1) Landing over centre of gravity of machine, load factor 5.
(2) Landing on wheels and skid, load factor 5.
(3) Flying top speed, load factor 5.
(4) Terminal dive load on tail, factor of safety 1.5.

CONTROLS.—For elevator controls 100 lbs. should be taken on top of control stick.

For aileron controls 50 lbs. should be taken on top of control stick.

For rudder controls 75 lbs. should be taken on rudder bar.

The loads quoted are considered the maximum loads a pilot could exert on stick or rudder bar, and therefore the controlling surfaces must be designed so that the load to be operated comes within the above figures.

A factor of safety of 1.5 should be given.

REAR SKID.—Load factor 4.

UNDERCARRIAGE.—Load factor of 4 for conditions as follows :—

(1) Landing on both wheels, tail above horizontal.

(2) ,, ,, ,, ,, ,, horizontal.

(3) ,, ,, ,, ,, and skid.

(4) ,, ,, one wheel, machine horizontal.

For load-carrying military and commercial machines, where manœuvrability and stunting are not required, the load factors should be as follows :—

WINGS.—Load factor, front truss 5.
,, ,, rear truss 4.
,, ,, centre of pressure forward, with any lift wire broken 3.
,, ,, centre of pressure back, with any lift wire broken 2.4.

Travel of centre of pressure for R.A.F. 15. Wing section taken .28 to .5 chord.

AILERONS.—16 lbs. per sq. ft. as failing load of ailerons. Load assumed to come .3 of chord of aileron.

TAIL PLANE AND ELEVATORS.—Tail plane taken for worst condition, that being nose-diving case, $\frac{\text{W.C.}}{l}$ = load on tail.

Factor of safety to be 1.0.

RUDDER.—16 lbs. per square foot as failing load of rudder. Load assumed to come .3 of chord of rudder.

FINS.—16 lbs. per square foot as failing load of fins. Load assumed to come .3 of mean chord of fin.

FUSELAGE.—Four cases should be taken as follows :—

(1) Landing over centre of gravity of machine, load factor 5.

(2) Landing on wheels and skid, load factor 5.

(3) Flying top speed, load factor 5.

(4) Terminal dive load on tail, factor of safety 1.

CONTROLS.—For elevator controls 100 lbs. should be taken on top of control stick.

For aileron control 50 lbs. should be taken on top of control stick.

For rudder control 75 lbs. should be taken on rudder bar.

A factor of safety of 1.5 should be given.

REAR SKID.—Rear skid, load factor of 4.

UNDERCARRIAGE.—Load factor of 4 for conditions as follows:—

(1) Landing on both wheels, tail above horizontal.
(2) ,, ,, ,, ,, ,, horizontal.
(3) ,, ,, ,, ,, ,, and tail skid.
(4) ,, ,, one wheel, machine horizontal.

Whilst dealing with the question of load factors, it should be taken that these represent the minimum load factors and not the maximum; there are cases on an aeroplane where load factor alone is not sufficient, and a factor of safety over the load factor is necessary to cover, for example: loads due to vibration, trueing up wings, trueing up fuselage, and also handling.

VIBRATION is a big enemy to an aeroplane structure, especially to the wing structure and the engine structure. In the case of the engine structure care should be taken to make all pin joints of a robust size, keeping bearing pressures low, and where calculated for the required load factor an additional factor of safety of 2 should be added.

Slide No. 5 shows a direct pull type of fitting, although up to strength by calculation and test, the lug continually broke, due to vibration and sudden change of section from lug to main body of fitting. This is a detail point in design to have careful attention.

The wing structure to my mind is the premier part of the aeroplane; it is the wing structure chiefly which bears the brunt of all the bad weather conditions and vibrations of a badly running engine. It is comprised, in most machines, of a flexible structure by reason of the long span between struts, and long lengths of wires, and is continually subject to reversal of loads due to bumpy weather.

The lift wires, anti-lift wires, and their attachments to my mind call for special attention, and to cover reversal of loads due to bumpy weather and vibration. The flying wires and their attachments should have a factor of safety of 1.25 over the load factor.

Handling and loads due to trueing up must also be carefully considered. In the case of handling, special hand holes and grips should be arranged for, thus avoiding damage to the machine when same is being hauled about at the aerodrome.

Loads due to trueing up also require special attention. In a force diagram of a fuselage or wing structure it will often show that certain members are redundant, and in others only a very small load. In these cases it is wise to ignore the small load or redundant member, and to assume that an initial tension may be put in the bracing wire of 75 per cent. of the breaking load of the wire; take the resultant load on to the member in question, and design accordingly. It is possible, by bad trueing up, to stress a member to a greater load than shown by calculation. Slide No. 6 shows an example of initial tension being put on wires, causing strut to bow. The strut in this case has a load factor of 30.

Another point to be borne in mind when using standard tie rods, R.A.F. wires or wiring plate sizes is, that if the calculated load in a wire comes just over the border line of a standard size wire, do not always be tempted to use the wire which is slightly under, but go for the next size. All designers are optimistic when estimating the weights of machines. I do not think a machine has yet been designed under estimated weight which would pass Air Ministry. Also, if the machine is for the Air Ministry, it seldom gets through its teething troubles without two or three changes of engine or requirements, which increase weight and reduce the initial load factors.

I do not lay these points down as rigid rules, for a machine with the required load factors would obtain its required airworthiness certificate, but a large proportion of service troubles and failures can be traced to lack of attention to the points raised.

Detail Design.—With these remarks on load factors we can go back to the question of detail design. Having decided on the type of structure, wood, metal, or metal-cum-wood, it is best to decide on the type of the main joints to be used, whether joints made of bent plates, or joints with direct pulls. For an engineering job the direct pull type is the best. (*See Slides Nos.* 7, 8, 9 and 10.) It will be seen that with the bent lug type, the plate is always tending to find the path of least resistance, and unless the bend comes close up to the head of the bolt, or the lug is reinforced against bending, the wiring plate lug will lift and allow the structure to get sloppy. A great deal of unnecessary trueing up after flights and landings would be avoided by use of the direct pull type of fitting. This applies chiefly to wing and fuselage joints.

The question of detail designing with the minimum weight must also be considered at this stage, care being taken to save every fraction of an ounce without being detrimental to the strength of the detail. In an aeroplane we have hundreds of parts, and a fraction of an ounce saved on each part means pounds on the total weight. The use of tubular rivets instead of bolts saves quite a useful amount. In a scout machine, it is possible to save 15 to 20 lbs., and in a machine weighing 8,500 lbs. 75 lbs. The next slide (No. 11) shows formulas and loads permissible for different sizes of tubular rivets; also the following slide shows method of manufacture. Slide 12 shows a small Bliss power press, adapted to manufacture on head of the rivet. A revolves in direction of arrow; B, pieces of tube to be headed; C, 1, 2, and 3, punches. The first puts a Vee in tube, second larger Vee, and third completes head. D, pivot; E, operating ratchet; F, operating rod; G, cam and lever.

A further point to consider is the method of attaching one plate to another, or, in the case of metal constructions, the method of attaching fittings. This can be done by brazing or soldering; welding should always be avoided.

Brazing is also troublesome and is likely to cause unseen fractures.

Fittings brazed require annealing after brazing.

Soft soldering should be used wherever possible. The temperature required is low, and is not likely to affect the strength or quality of the metals; also it does not require annealing afterwards. With properly designed fittings or joints there are very few cases in which soft soldering could not be used. I recommend the use of soft soldering wherever possible.

FUSELAGE.—The question as to type of main joints has already been mentioned, and care should be taken to make allowance for fitting accessories, etc. This can be incorporated in the detail design stage, and prevents little fittings being slipped about the fuselage, and extra holes being drilled at a later stage.

The undercarriage joints on fuselage should be given careful attention, and universal joints should be fitted; this gives longer life to the fuselage and undercarriage. In case of a broken undercarriage the fitting on the fuselage is not damaged, and a new one can be fitted in a short time. If the undercarriage fitting is bolted direct to the undercarriage a crashed undercarriage then means a replacement of fuselage fittings, and probably broken longerons. The extra cost of incorporating universal joints would be saved on maintenance. (*Slides Nos.* 13 *and* 14.)

The fuselage can be made in three units, viz.: Engine housing, front portion, including cabin, and rear portion. This would greatly assist replacements and transport by road.

UNDERCARRIAGE.—Three types of undercarriage are chiefly used:—

(1) With rubber shock absorbers.

(2) With Oleo type.

(3) With Oleo and rubber.

The rubber shock absorber is used more largely owing to cheapness of construction and replacement. For an engineering construction the Oleo type, comprising oil, air, and springs, is the best type. The rubber shock absorber type, with the rubber bound round the axle should be avoided, as it is difficult to replace; also, if one strand goes the whole binding gives way. If rubber shock absorbers are used, the special rubber rings should be called for. This enables easy replacements to be made of one or more rings. (*See Slides Nos.* 15 *and* 16.)

It is well to incorporate a form of damping device to prevent the machine bouncing after touching the ground. Ease of changing axle and wheels should also be carefully considered. Inspection holes in strut ends should be made. This allows one to see that the aluminum block beds on to strut. (*See Slide No.* 17.)

FLYING CONTROLS.—Flying controls call for careful attention, and a great deal can be done to design them on more engineering lines. It is an advantage to design controls in easily detachable units, such as control stick, complete with control stick housing, rudder bar, and housing. Facilities for adjustment should be made to allow for length of pilot's leg and position of stick; also, arrangements should be made for lubricating the moving parts. (*See Slide No.* 18.)

WINGS.—The type of joints have already been mentioned, and it is recommended that the direct pull type of joint should be used. This tends towards maintaining a true braced wing structure. The question of wing attachment to top and bottom centre sections is a point to watch. This is done in most machines by using fishplates bolted to centre section and wing. This type requires careful handling to prevent straining spars when rigging. A universal joint at these points facilitates ease of erection, and makes a foolproof joint. (*See Slide No.* 19.) Inspection holes for strut ends should be made as mentioned in undercarriage subject. (*See Slides Nos.* 20 *and* 21.)

REAR SKID.—The rear skid is a component of the aeroplane which has not been given sufficient attention. The skid has to take more wear and tear on the ground than any other part of the aeroplane. Due to contact with the ground the skid end wears away very quickly, and, in many cases, excess wear means fitting new skid. With a little care in design a quick-detachable shoe can be designed, so that a worn shoe can be replaced in a few minutes. Care should also be given to the moving parts, and adequate bearing area should be allowed.

FUEL AND OIL TANKS.—In many machines the tanks are placed in such a position that should a petrol tank leak, half the machine has to be taken to pieces to get at the tank. In service, or commercially, it is important to place the tanks in such a position to allow of quick detachability and easy repair. This can be done by placing tanks on top of the fuselage, on the sides of fuselage, or on the wings. Wherever possible the tanks should be placed on the centre of gravity of the aeroplane, so as not to affect trim when the tanks are empty.

PETROL SYSTEMS.—The three types in use are:—

(1) Pressure feed.

(2) Feed by means of petrol pump.

(3) Gravity.

No. 1 should be avoided, as it introduces a large number of joints likely to cause failure.

No. 3, gravity system, is the most foolproof, and should be adopted, especially for commercial machines.

MISCELLANEOUS.—Provision for handling the machine on the ground should be carefully considered, and adequate arrangements made; also the points for handling clearly marked on the machine. Holding-down rings should be used for holding the machine in the open, and towing rings in the case of large machines.

Covers should be provided for engine and cockpits, in case of forced landings.

This concludes the chief points covering the *précis* of the title of my paper. I should like now to mention one or two points relating to commercial machines and racing types.

COMMERCIAL MACHINES.—I have in my paper already drawn attention to many points in connection with the design of this type, and would like to add a few remarks about the goods carrier. This type varies very little from the passenger type in general outline. Speed is not so important, the interior and external finish need not be so elaborate, but it must be designed to take large and bulky goods, equal to that of a railway truck or a large modern motor van. For structural reasons it is impossible to have side-doors large enough to accommodate goods of large dimensions. The only way is to make a provision to open the fuselage. I will show you a slide of the Gloucestershire goods type, designed to take such goods. You will see that this scheme offers the facilities of a railway truck or motor van. (*See Slide No.* 23.)

RACING MACHINES.—The question of racing machines can be divided into two classes :—

(1) The machine designed for the maximum high speed, irrespective of safe landing speed.

(2) The machine designed for the greatest speed and reasonably slow landing speed, also a sporting chance for the pilot in case of a forced landing.

Case 1 is the practice chiefly adopted for continental racing machines, and, although giving good results in the way of top speed under racing conditions, the resulting machine is purely freakish, inasmuch as it can only be flown by special pilots who are trained exclusively for racing, and then only at great risk. This can easily be understood when it is realised that such machines often land at speeds above 100 m.p.h.

Case 2 is the method generally adopted in this country, and, whilst giving the pilot a greater degree of safety, the machine is also capable of being utilised for some other useful purpose, such as a scout or high-speed postal machine. The question of landing grounds also concerns this point, as those existing in England are generally much inferior to many on the Continent. It will be realised that the question of landing speed is important, since generally a machine with a higher landing speed will have a higher top speed, and therefore a machine with the maximum top speed will not necessarily be the most efficient, and it is desired to point out here that the real criterion of speed on a racing machine is not the maximum speed, but the difference between the maximum and minimum speeds of the machine under any specified conditions.

The next important item in racing machine design is the wing section. This, of course, is mainly a matter for experiment, and the type of section to be aimed for is that having high values of L/D at very small angles of incidence.

Having determined the landing speed required and the wing section most suitable, the remainder of the points to consider for reduction of head resistance may be taken as—

(1) Clean and shapely lines to the fuselage.

(2) Parts merging into or out of fuselage should be arranged to do so gradually; in other words, all sharp corners should be avoided.

(3) All external fittings should be faired off.

(4) The undercarriage should be carefully considered, with a view to avoiding air pockets and congestion of parts. A fairing fitted to the rear of the wheels is a very valuable item when it is realised that an increase of about four miles per hour is possible with such fairing. (*See Slides Nos.* 24, 25, 26, *and* 27.)

CONCLUSION.—In conclusion, it is hoped that the points mentioned will be of use to the engineer and draughtsman. The points raised and approximate data given are the results of experience over 30 different designs, ranging from small scouts to large twin-engined machines. If these points are carefully considered, and aeroplanes designed on a more engineering basis, the result will be longer life, greater efficiency, and a greater commercial success; this in turn will tend to reduce insurance rates, and encourage the general public to use aircraft; at the present time the man in the street looks upon aircraft as being built up of bits of wood, string, nails, fabric, and hoop iron.

There have been many valuable draughtsmen and engineers lost to the industry due to the drastic cuts in the designing staff under the guise of economy, but it is hoped that this paper may be some means of keeping them in touch with the present-day requirements and methods of aircraft design. It is not generally realised that other countries are making more rapid developments in aircraft, both in war and commercial services, and that a time will come when this country will suddenly realise that they are very much out of date and behind. I appeal to those who have been in the aircraft industry to keep in touch with progress, so that when the time comes they will be in a position to assist in what will probably be a national emergency.

When the ban on German aircraft is lifted in May, there will be no reason why Germany should not produce fighting machines in large quantities, as, although they will be limited to horse-power and duration, there is nothing to prevent them designing for high horse-power and duration, then fitting a small horse-power engine to come within the restrictions imposed by the Peace Treaty.

The recent air raids appear to be now almost forgotten, and it does not seem to be realised that they could be repeated almost without warning and with more disastrous results.

We should at the present time be converting coastguard stations into air-guard stations, linking up the whole of the coast line; also designing and constructing special types for use in the East; existing types are obsolete, and should be replaced by machines suitable for the work.

△ △ △

At the conclusion of the reading the Chairman said:—

This is a paper that will stand out in my memory for a long time as being a particularly comprehensive one, and I feel I could go off and design a good aeroplane straight away. There are one or two points I should like to touch upon, but before doing so I will ask others to say a few words.

DISCUSSION.

DR. THURSTON: I came here this evening expecting a very great treat, and I have certainly not been mistaken. It seems to me this paper is of the greatest possible use, and sums up the massed experience of the war. I hope you will be able to publish this paper in its entirety, and the illustrations and charts are all so good that I hope they will be published as well.

The point that strikes me this evening is this—here we have put in a simple and clear way the concentrated essence of the science of aircraft design, without any complicated mathematical formulæ or theories, and it shows how simple things are to the ordered mind. It brings one to Milton's way of putting things:—

"It is not to know at large of things remote from use, obscure and subtle, but to know that which before us lies in daily life; is the prime wisdom."

That strikes me as being the essential point of this paper—the remarkably simple way in which Mr. Folland has chosen to bring forward the essential things in aircraft design.