# CONSTRUCTIONAL DESIGN OF AEROPLANES.

## SECTION I.

**Abstract of Paper read by Mr. C. W. Tinson, A.F.R.Ae.S., Member, at a meeting of the Institution held at the Engineers' Club, W.1, on October 13th, 1922.**

MR. H. B. MOLESWORTH, Chairman, in introducing the speaker, said that owing to activities at Itford, the attendance at this first lecture of the session was not so high as could have been wished, and read letters of regret from those who were thus unavoidably absent.

MR. C. W. TINSON said:

The notes comprising this paper are intended to refer mainly to the points of more practical interest in the design of an aeroplane, as distinct from purely aerodynamic considerations, and that part of the work, such as the prediction of performance, which precedes the actual work of structural design.

The following, while particularly dealing with the design work subsequent to an order for construction having been placed, also touches on the general questions involved in some cases, as of course is inevitable since aerodynamic considerations govern and largely affect the general arrangement of components.

It is customary in submitting a design in the first case to include a sectional arrangement on a large scale to indicate more or less completely the disposition of the main essentials, and in making this the designer will have decided to some extent on the type of detail design of various components, and with previous experience to guide him, will have so disposed these components in relation to the engine and the remainder of the machine so that the centre of gravity when loaded will occur at the correct place for proper balance.

In the lay-out of the fuselage, the struts will have been arranged so that, as far as possible (1) they space out nicely to get the bracing wires nearly parallel; (2) they then give the minimum number of unbraced bays; and (3)

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that they occur in the most convenient positions to support parts of the structure directly attached to them.

PARALLEL WIRES.—From considerations of stresses it is advantageous to space the bays in such a way that the side wiring is more or less parallel, and as a starting point we take the bay of the wings. Choosing a reasonable fuselage depth, and endeavouring to obtain an angle of 45 degrees as nearly as possible for the side wires, we project this angle from top to bottom longeron, marking off the strut positions at the intersections.

The position of our live loads, however (pilot, observer, etc.), is fixed by other considerations, hence at the cockpits the struts may not be convenient, and we must therefore carefully review the other considerations.

UNBRACED BAYS.—If it were possible to completely brace the top of the fuselage as well as its sides and underside, the bracing in cross section would be redundant except for "wires cut" condition.

Unfortunately, this is rarely possible owing mainly to the cockpits, so that it is essential for rigidity to carry the section bracing right through if possible.

From this it is clear that we must endeavour to dispose the struts in way of the cockpits in such a way that sectional bracing is as complete as possible, but as the length for accommodating a pilot must be 3 feet 9 inches or thereabouts, there will probably be a side strut somewhere about half-way in this length, and of course no section bracing can be incorporated here.

SUPPORTING OTHER PARTS.—The third consideration to be borne in mind in fixing the side struts is purely a practical one, but some extra weight may be involved if the question is not carefully considered.

Essential parts of the aeroplane are its seats, controls, and tanks, all of which must be supported on or in the fuselage, and if the lateral bearers for them do not conveniently occur at struts, longitudinal bearers will have to be added, or such longitudinals as are essential must be extended to the nearest strut.

It follows that it may be economical to space the fuselage bays in a less efficient manner (regarding the fuselage as a girder), in order to cut out some of the minor internal structure which would otherwise be required.

Further there is the undercarriage to consider.

It is of course essential that the wheels should be a few inches ahead of the centre of gravity when the fuselage is level.

Now in a machine having an ordinary vee type of undercarriage it is desirable to have the two legs of the vee diverging at approximately the same angle, in that way getting the full value of both legs, and by doubling the bearing area on the longerons, reducing the tendency to crush them in a heavy landing.

If there is any choice of stagger this may be achieved.

CENTRE OF GRAVITY.—The "tolerance" allowable for the centre of gravity is relatively small, say plus or minus 0.03 chord, so that to get within this limit we must be very careful with our estimate of its position.

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From compiled data, the weights of most of the components can be obtained very closely, and their respective centres of gravity decided by inspection but the fuselage itself is difficult.

It always weighs more than has been estimated, and generally there is a distinct tendency to guess the position of its centre of gravity too far forward.

Considered as a solid body the centre of gravity of the fuselage would naturally be about one-third of its length from the fore end, but it must be remembered that cowling and decking are usually reckoned separately, but the fabric covering, stringers and formers, and a host of items not otherwise accounted for will bring the centre of gravity back considerably, and it is usually safer to estimate it at from 0.4 to 0.45 of the length from the fore end.

CALCULATING THE POSITION OF CENTRE OF GRAVITY.—For finding the position of the centre of gravity, select any vertical line as an axis for moments. Then, having tabulated the estimated weights, the distance of each item from this axis is measured and noted in a column headed L by the side of the weights W. Multiplying the several weights by their length from the axis gives us the moment of each about that axis, the sum being the total amount.

Dividing this by the total weight will give a figure representing the distance of the centre of gravity from the axis in the units of length chosen.

As a check, moments positive and negative may be worked out, using a vertical line passing through the point just found the sums of them being equal unless some error has crept into the calculations.

The vertical height is found by taking a horizontal line as axis for moments.

ELLIPSE OF INERTIA.—To obtain a comparison of the manœuvrability of a machine, the ellipse of inertia may be required.

If several masses are in relative motions about a point, the result can be measured by imagining a single mass to be operating at a certain distance from the common centre of gravity, and the inertia of this single mass will have similar effects.

Now when we require to find the moment of inertia of a section for strength, we split it up into a number of small sections, and multiply each area by the square of the distance from the neutral axis, which latter passes through the centre of gravity of the section.

Similarly, if we take the various detail weights, and multiply them by the square of the distance of the part from the centre of gravity of the machine, we shall, by adding the products and dividing by the total weight, obtain a distance (squared), the root of which is the radius of gyration.

The characteristics of acceleration would then be identical if the total weight were concentrated at this point.

An aeroplane can rotate about three principal axes, so that the radius of gyration should be found in side elevation, front elevation, and plan, the three points marking the boundary of an oblate spheroid from which any combination of angular movements can be referred to the centre of gravity.

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Generally, the smaller the ellipse in any view, the smaller will be the effect of inertia about an axis perpendicular to that view.

CONTROLS.—The controls are often difficult to design for simplicity, and unless the arrangement of them is well thought out when the machine is first laid down, the installation may be far from ideal, the ideal control set being that comprising the minimum number of parts.

In small single seaters, in which there is no obstruction behind the pilot, and in which the tail plane is usually very little higher than the pilot's seat, it is generally possible to run both elevator and rudder cables clear out of the cockpit, passing under the seat, and clearing all fuselage struts and wiring aft to the elevators and rudder respectively, and at the worst a short countershaft will be all that is required to start the aileron controls off in a convenient place for them to run out along the back of the front wing spar.

This is an ideal difficult to realise in larger types, but every effort should be made to reduce the number of fairleads, pulleys and other working parts.

With folding wings, the difficulty is intensified by reason of the aileron controls having to pass behind the hinge, partly by the difficulty of operating them by means of a cable behind the rear spar, and partly by the fact that unless the cable passes very close to the hinge pin, and is retained by some means at this point, it will slack off on folding the wings, and allow the ailerons to drop and flap about if the folding is carried out in the open.

No really satisfactory system has been evolved for dealing with this problem unless the control cable is entirely outside the fabric.

In order to get the control cable behind the rear spar, when external cables are not objected to, a strut coupling the ailerons is employed, and from the points of attachment of the strut ends cables are taken to pulleys bracketed off the rear spars.

Apart from the additional resistance, the system is not ideal owing to the large travel of the cable in operation, necessitating coupling it up fairly high on the control pillar. This disadvantage, however, can be overcome by attaching the cables to the aileron stiff rib midway between the interconnecting struct and the aileron hinge.

A preferable scheme, easily applicable when the aileron spar is not directly behind the rear spar, as in the Handley Page balanced aileron, is to couple up the leading edges of top and lower ailerons by a length of cable, and similarly couple them up at points behind the hinge spar. The operating and return cables can then be shackled on to the forward connecting cable, and the pulleys can be behind the rear spar and concealed in the wing section.

When the aileron spar cannot be placed in this way cranked horizontal levers may be used for operating the ailerons, as has been done on certain German types.

Coupling up the elevator and rudder controls is not difficult, but in laying out the elevator and rudder the levers should be placed if possible so that straight connections can be made without fairleading to clear fuselage struts or wires.

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The only really important point to watch in setting out the controls is the amount of give and take in the cables which results from levers of uneven lengths—and hence, from trying to get a gear ratio with levers, or from leading a cable on to a lever at an angle other than 90 degrees.

This trouble is caused by one cable moving more nearly parallel to itself than the other, and is particularly noticeable in elevator controls where the cables are usually crossed. If the cable be tightened up so that there is no backlash in neutral, it will slack off when the control is fully over, and if then tightened up, will be very much too tight in neutral.

When wheel control is used, and the cables have to go a certain distance fore and aft before branching out to the wings, it is necessary virtually to crank the axis tube of the column in order to arrange for the cable to intersect the axis about which the control pillar rotates. Otherwise, moving the pillar fore and aft will tighten and slacken the aileron cables.

Short of making every lever a quadrant, there does not seem to be any way of avoiding backlash with levers, but with care it can be restricted to a negligible amount.

It should be possible to take out and replace any cable without cutting it or making a slice in position.

The speed of erection is governed largely by the number of men who can work on the machine, and it is no use getting too many on, or they merely get in each other's way. Therefore, if for no other reason, such as replacements which are practically necessary, we should eliminate splicing on erection, and all that is necessary to do this is to so design fairleads and pulley boxes that the cable can be removed intact.

Where the cable passes through such a part as an end rib, the hole should be large enough to pass the splice.

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## DISCUSSION.

Mr. H. B. Molesworth (Chairman).—I have listened with the greatest interest to this very instructive paper, and should like to make a few remarks on a certain point which has struck me, not necessarily in regard to aeroplane construction, but concerning cross-bracing. Some years ago I was inspecting the construction of viaducts for the Uganda railway, the piers of which consisted of four heavy uprights braced together, these being cross-braced at the intersections of the struts and ties with the uprights. There was some difficulty with regard to the horizontal cross-bracing, as to holding it up. The cross-braces were very long, and I wrote home and suggested that the cross-braces should be entirely omitted, because when you get four sides all braced, it is unnecessary