CONSTRUCTIONAL DESIGN OF AEROPLANES

SECTION II.

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 27th, 1922.

MR. H. B. MOLESWORTH was in the Chair, and before introducing the lecturer he read letters of regret at unavoidable absence.

MR. C. W. TINSON said:

CONTROL GEAR RATIOS.—No standard gear ratios exist for aeroplane controls owing to individual machines requiring different treatment.

A big heavy machine has a higher moment of inertia than a small one, and consequently a disturbing force takes longer to produce displacement, but having produced it more control power is required to correct it, so that a heavy machine may have its controls geared down to a greater extent.

Balancing the control surfaces would also affect the question of the selection of gear ratios.

Rudders are generally even geared, and movement of 30 degrees each side of neutral should be allowed.

In running along the ground preparatory to getting off the machine is very susceptible to directional changes, and quick control is important to enable a straight course to be maintained. Lateral stability is more or less provided by the undercarriage in the condition of getting off, and longitudinal control is more powerful than directional.

The directional control is often weak at low speeds, but very big rudders are heavy to operate at high speeds, hence rudders are commonly found to be balanced whilst ailerons and elevators are not.

Also, in seaplanes it is much more difficult to turn when taxi-ing than on land, owing to the submerged sides of the floats.

The control stick or wheel pillar cannot conveniently be moved through more than 16 or 18 degrees fore and aft, but if gearing is necessary it can be done by unequal leverages where the cables are attached at each end.

As a rule, elevator controls are practically even geared, the reason being that the 16 degrees or so in which they are efficient in controlling corresponds to the possible movement of the control stick or wheel pillar, and in a large machine the elevators will be balanced to relieve the loads. Also there is no difficulty in providing adequate area.

With stick control, the amount of movement laterally is very limited in some cases, about 18 degrees is generally the maximum which can be obtained owing to the pilot's knees.

The ailerons are frequently geared down 1½ or 2 to 1, but there is no real standard, the handwheel of a Short 184 moving through 260 degrees from full warp to full warp for a 16-degree movement of the ailerons. In this case, however, the ailerons are single acting.

As a general rule, the ailerons should be made to move through 15 degrees each side of neutral with as much stick movement as can be obtained, or if a wheel is used, with from 80 to 110 degrees on the wheel.

Wheel control is, of course, much heavier than the simpler system, but is necessary in heavier machines, to give the necessary gear ratio unobtainable with a stick.

FORCES ON CONTROLS.—It is clear that the strength of the controlling mechanism need be no greater than can be imposed by the pilot. The following figures are obtained from experiment, and a factor of safety of 2½ or 3 on these figures should be ample.

The pilot has least purchase when operating a control stick laterally and with the elbow unsupported, as is usual, the average lateral force at the control stick knob is from 14 to 18 lbs. Supporting the elbow increases it to 36 lbs. as a maximum.

Longitudinally, about 100 lbs. can be maintained fairly easily, and about the same on the rudder bar, and if the control stick or pillar be designed for this load with a small factor, using yield point and not ultimate stress there should be no danger.

If the stick be made of yellow metal quite a low factor on yield would suffice, as even if it were to bend the machine may be controlled, whereas a wooden control stick would break off, and would necessarily require a higher margin of safety.

With regard to the force that can be applied through the rudder bar—and also longitudinally through the stick, it should be remembered that the reaction comes through the seat fixings, and is twice the load per foot.

Seats and floors therefore should be capable of taking these loads satisfactorily.

The maximum load which it is possible to apply through the feet in a condition of panic appears to be about 800 lbs., that is, 400 lbs. per foot, but it is not suggested that many rudder bars are capable of taking such a load. A gymnast, however, will support 10 others on his body, proving that a strong man's leg is capable of taking about 600 lbs. as a strut.

With wheel control, the maximum torque on a 16-inch wheel is 800 inch-lbs., but this cannot be maintained, and falls to 640 inch-lbs.

DIFFERENTIAL ACTION.—In common with an aerofoil as a whole, the aileron has a maximum KL; that is to say, that if moved too far its resistance increases, but its lift falls off, and if the aerofoil is already running at its maximum KL angle it will be little use pulling down the aileron on the low side. This merely slows the wing up, which then drops still more, and a spin results.

Thus it often occurs that the landing speed is governed by the ineffectiveness of the aileron control, which is more marked than either longitudinal or direction control.

It is probably better therefore to employ single acting ailerons moving upwards only than double-acting ailerons giving similar angular movement up and down.

A system has, as is well known, been tried with excellent results, in which the upward moving aileron passes through a greater angle than the downward moving one, and this is known as differential aileron control. It has the advantage over single-acting ailerons moving upwards only in that the increase in drag is practically balanced on each side of the machine, so that less rudder is necessary when using the ailerons, and it also gives an exceptionally light control in operation.

SEATS AND FLOORS.—As has already been noted, the seats should be designed with a view to taking the reaction when pressing hard on the rudder bar, the worst load probably being due to turning on the ground or on the water.

The maximum load on the rudder bar need not be taken by the seat, however, as this occurs in manœuvres in which a good deal of the actual weight of the pilot is taken direct on the rudder bar, such as in coming out of a nose dive.

Vertically, the seat bearers require a factor of at least 4½, as in looping quickly this has been registered, and seats have been known to fail in such circumstances.

The same applies to a floor which actually carries the weight of a man, such as in a gunner's cockpit.

It does not, of course, apply to the pilot's "floor," which is really merely a heel rest.

FUSELAGE.—The layout of the fuselage has already been referred to in Part I., and is a component about which it is difficult to generalise. Every design has its own particular fuselage problem; every engine requires separate treatment, and so on.

Generally, however, the fuselage consists of three parts: (1) that part from the nose to the front wing spar; (2) that part to which the wing spars are attached, and to which the undercarriage struts are usually connected; and (3) the portion connecting the empennage, and carrying all or a part of the crew.

Respecting the forward portion little can be said, as it is governed by the particular engine it has to carry and by the dimensions in cross section which it must be at the wings.

In designing the engine mounting, however, the forces due to torque must be watched, as in some cases they will be of very great magnitude owing to high engine power at low airscrew revolutions.

In the Napier "Cub," for example, weighing 2,340 lbs., or about 2,400 lbs. with water and oil, we have 1,200 lbs. dead load per bearer, but as the torque is 7,050 foot-lbs., there is plus or minus 3,115 lbs. per bearer due to torque; that is, over two and a-half times as great as the static load.

The effect of torque, in passing, is to cause the machine to fly with one wing slightly down, and consequently in a curved path. To correct this one wing is usually rigged with a slightly different angle of incidence to the other; in the case of one flying boat the engine was inclined in plan view so that the thrust acted obliquely to the line of flight, thus directing the slip stream on to one side of the fin.

Other methods are to rig the fin at an angle, to offset the engine in the fuselage, so that the centre of gravity is not on the centre line of the machine, and to load the cable to one side of the rudder with a spring.

Reverting to the fuselage, the portion between the wing spars needs to be as rigid as possible, and it is important to arrange for adequate bracing, to prevent the engine torque twisting the fuselage, to eliminate vibration, to stop the top wings shifting bodily sideways when unequally loaded, and to take lateral loads from the undercarriage.

For the third reason it is essential to have adequate cross bracing in the centre section and the top of the fuselage, at least in way of one pair of centre section struts, and this is sometimes difficult to arrange because of the petrol tanks, especially in staggered machines.

From behind the wings to the sternpost the fuselage on aerodynamical grounds requires to be tapered both in side and plan views to give an efficient form for air resistance, but for practical reasons the first bay ahead of the sternpost should be of reasonable width and depth to give torsional resistance.

Otherwise the tail plane will shape excessively due to lack of rigidity, although the fuselage members are quite up to the loads imposed in flight.

Turning on the ground also imposes severe side loads on the fuselage resulting in torsion, especially if the tail skid is not articulated laterally.

The last bay of the fuselage at the sternpost end is, as a rule, a triangle with curved sides in plan. This figure geometrically is difficult to brace, but at the same time lacks the rigidity of a triangle proper, and in wood fuselage construction a gusset of three-ply should be screwed on top and bottom to give the necessary rigidity. Otherwise short struts can be incorporated in top and underside to split the bay into two, the triangle then becoming much smaller.

In covering the fuselage, the last bay should have a separate "stocking," laced on to the main cover to allow inspection of the tail skid rubbers without having to peel back the main cover, or an aluminium door can be sewn on to the fabric for this purpose.

Coming back to the main portion of the fuselage, no general remarks can be made respecting fittings, as, at any rate from the nose to the rear of the seating accommodation, each fitting must be specially designed, and more or less the same applies from the front spar of the tail aft.

This leaves comparatively few bays in which to standardise a fitting, but the fittings whether similar or not should permit the longeron to be removed without upsetting all the rest of the structure.

Damage to longerons does not happen frequently, but when it does occur a great saving in time and money will be effected by being able to remove a longeron by taking out the fitting attachment bolts only, leaving all wires in place. No re-trueing is then necessary after replacements, each joint being stabilised by the four or five wires connected to it.

Finally, the longerons should all be straight lengths spliced or butt jointed where necessary, then each section can be made lighter than would be the case if it were curved, as its loading as a strut is not eccentric.

TAIL ADJUSTMENT GEAR.—The object of altering the angle of incidence of the tail plane in flight is to enable the machine to be trimmed so that there is no load on the control at any desired speed, and to compensate for the effect of the slip stream, which is sometimes serious with single engines of high power.

The tail plane is generally pivoted about the front spar, the rear spar being moved up and down by means of a tube inside the sternpost and finpost, having on it a thread operated by a chain sprocket internally threaded to suit.

A length of chain passing round the sprocket is coupled to a handwheel in the cockpit by cables.

The sternpost and/or the finpost (according to the tail-plane bracing employed) is slotted, and lugs which are attached to the sliding internal member project through the slots and take the bracing to the rear spar so that it moves in unison with the spar.

The sternpost must be vertically cut in two parts by the sprocket casing, as the diameter of the sprocket will be greater than that of the sternpost, and the casing must be designed with due regard to the continuity of strength and rigidity. In order to assemble, the slots will have to run out at the ends of the tube and should be capped by a fitting having a circular groove in it to receive the end of the tube so that it is firmly held in position in such a way that contraction as well as expansion is prevented.

The halves of the sprocket casing locate the sprocket so that it turns the shaft instead of screwing itself along it, and the bearing area should be adequate so that wear does not take place quickly and allow backlash to develop.

The advantage of pivoting the tail about the front spar is that it is then partially balanced, and for that reason should be lighter in operation than a tail pivoted on the rear spar.

It is necessary however to take the cables from the elevators through the plane of the hinge axis of the tail, as otherwise they become tight and slack when the tail adjustment is operated.

If the tail is pivoted on the rear spar a system of bell crank levers can be used instead of a worm, but is not irreversible, and if operated by a lever instead of a handwheel requires a toothed quadrant to locate the settings.

Operation by lever and bell cranks has the advantage over the worm system in that it is much quicker, and of course a worm, even with double or triple starts, requires several revolutions to effect the change of incidence required.

DISCUSSION.

Mr. W. O. Manning.—I have listened to this paper with very great interest, and have found the lecturer's problems somewhat different from those I usually have to deal with on controls. I have found it very convenient to consider such things as aileron controls on an energy basis, rather than on the more usual moment basis. The aileron that takes the least energy in producing a given effect on a machine is the best, measuring the energy from no angle to angle required.

I have a considerable objection to balance where it can be avoided. I have found it possible to use unbalanced ailerons in machines up to 12,000 lbs. I agree that rudder balance is advisable in any case, as it is easy to carry out, and has no disadvantages.

The lecturer's remarks on engine-bearers are very useful. He did not mention landing loads. It will usually be found that if the bearer is strong enough to stand a landing with the usual factor, it will be strong enough to stand the engine torque.

Tail jacks of the worm-gear type are, of course, common, but one does not feel quite sure that they will not turn under vibration if the wires are cut.

His remarks with regard to fairing are excellent, and much more attention should be paid to this subject than is the case to-day. It certainly pays to fair to a considerably greater extent than is usually done, and I am inclined to think that in this respect some modern designs compare unfavourably with machines built in 1913.

With regard to the diagram, the question of the protection of the gunner from the slipstream needs remark. I think aeroplane designers will be forced to some sort of turret for protection of the gunner.

In conclusion, I should like to thank Mr. Tinson for a most interesting paper.