Aeroplane Controls*

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MAN imposes his will on a machine by the use of a control. We are all familiar in a general way with the kind of control by which many of the machines which transport us from place to place are guided ; the most recently arrived means of transport, the aeroplane, has controls which are much more complicated in their effects than we find with earth-bound transportation. The vastly greater possibilities of movement possessed by the aeroplane can be stated with greater precision if we consider the number of degrees of freedom it possesses, and then compare it with trains, cars or ships.

A train or tram running on a straight length of line has but one degree of freedom ; it can only move along the line and it needs only a single control—that of speed. It is true that this speed control is usually shared between two controls, one of which is responsible for increase of speed and the other for decrease ; but, as on a tram, these may be combined in one handle and are essentially one control. A car has three degrees of freedom, if we consider it when travelling in a wide smooth desert ; it can move forwards, under certain conditions it may be skidded sideways, and it can be steered so that it turns about a vertical axis. The same limitations apply to a ship, if we think of a calm sea. In these two cases we find that two separate types of control are required—the speed control, which may be sub-divided as before, and the steering for controlling the direction about the vertical axis.

Coming now to the aeroplane, we find no less than six degrees of freedom. The aeroplane can move forwards, sideways and upwards, and rotate about three axes at right-angles to each other, that is to say, it can pitch, roll, and yaw.

We do not provide direct controls for each of these degrees of freedom any more than we do on a car or ship. The skidding or sideways motion of a car is controlled by special combinations of two controls, the steering and the speed. On an aeroplane four controls of the motion are provided ; we control the three rotations and, in addition, the power of the engine by means of the throttle. This last control alters the thrust of the propeller, and on all modern types of aeroplane an air brake is provided which gives negative thrust, so that throttle and airbrake are essentially one control, similar in nature to the speed control on the tram.

* From a Friday evening discourse delivered at the Royal Institution on February 17.

Unfortunately, the three rotations are not usually each controlled by a simple movement of one control. Pitching by the use of the elevator is nearly independent of the other motions, but a turn is much more complicated, as it requires a proper combination of rolling and yawing and, on a steep turn, of pitching as well ; not only this, but also the motion of pure rolling requires the application of both ailerons and rudder in due proportion, and so does the motion of pure yawing.

Coming now to the indirect control of vertical and lateral motion, we find that a pitching rotation changes the lift on the aeroplane and thus a rise or fall is obtained, though this is of course necessarily accompanied by the pitching rotation ; in other words, it is not a simple motion in a given direction. Lateral motion, or sideslip, is produced by a special combination of aileron and rudder control, and with big sideslip the elevator control comes in as well.

The control of an aeroplane thus differs from that of a car or ship primarily in the fact that a much greater variety of motions is possible, and, further, to produce many of the simple motions a certain combination of various controls is needed.

We come now to a discussion of the relation between the movements of the pilot's hands and feet and the resulting motion of the aeroplane. There are three simple kinds of control which may be used ; we may have a control of position, or a control of velocity, or a control of acceleration. To give everyday examples, the act of lifting a glass from the table to the lips is a direct control by the hand of the position of the glass ; the rotation of the steering wheel of a car is a control of the rate at which the car turns, that is, of its angular velocity, and the pressure on the brake pedal is a control of its acceleration, in the negative sense. Each of these types of control is a reasonable one, though simple experiments performed with beams of light moved successively by the three types of control indicate that the position control is the easiest to manage and the acceleration the least easy.

However, it seems probable that real difficulty arises when a control changes its type with time. Take, for example, the aeroplane elevator control ; if the stick is pulled back a little and held there, the first thing that happens is that the aeroplane has imposed upon it an angular acceleration in pitch ; this falls away very rapidly, and leaves the aeroplane with a certain angular velocity, and ultimately this dies away and the position of the stick controls the attitude and forward speed of the aeroplane.

These considerations lead us directly to a discussion of what qualities in a control are responsible for its being described as *pleasant*. I hold that we should go to great lengths to give pilots the easiest and most pleasant controls that we possibly can, so that by relieving their minds and bodies from all avoidable strain, they may be able to concentrate more fully and effectively on their other duties. A pilot coming to fly an aeroplane which is good on the controls will learn to fly it in the shortest possible time, undoubtedly a matter of tremendous importance in these days; when he knows it well he will love to fly it and will feel at one with his machine, and surely he and his mount will be a more effective combination for either peace or war than the pilot with poor controls, disgruntled, tired and at odds with his craft.

If we are agreed that it is worth while devoting time to a study of the characteristics of a pleasant control, we must admit straight away that while a test pilot, for example, has a very clear idea when he flies a new aeroplane as to whether the control is pleasant or not, he is in great difficulty in defining the quality he observes. While the pilot may describe the control as light, firm, crisp or free from lag, the designer always wants to know *how* light, *how* firm, and so on; in other words, he wants a definite answer in figures, and for all practical purposes so far he has been unable to get any figures which he can interpret usefully.

We are now entering upon dangerous ground, for in addition to studying the characteristics of the aeroplane we have to link up with those sensations that pilots like and dislike; the ancients thousands of years ago were well aware of the perils of attempting to argue about personal taste, but my view is that it is the greatest possible mistake to let this frighten us off the field, and aeronautical research should grapple boldly with these problems, even though they have been aptly described as being "not quite aerodynamics".

Experimental work is now in progress in Great Britain from which it is hoped that a foundation will emerge on which the designer may build up the control qualities of his new design with much greater precision and confidence than is possible to-day. An attempt will be made to codify a pilot's likes and dislikes, not only in general terms but also on a quantitative basis.

The ultimate object of the use of the controls of the aeroplane is to produce the flight path which the pilot desires, and in any quantitative study it is no good measuring the forces and couples which the controls apply without a knowledge of what has to be overcome by those forces and couples.

The functions of the controls may be regarded as four-fold, namely: (i) maintaining balance, or trim, in steady straight or curved flight; (ii) overcoming inertia when starting and ending a manœuvre; (iii) overcoming air damping, which usually resists motion, but in some important cases assists it in an undesirable way; (iv) overriding the natural stability or instability of the aeroplane.

The first function is well understood, because it is relatively simple to analyse steady flight conditions, and it is fairly easy to make measurements, both on models and also in flight, where there is plenty of time available for taking readings.

The second function of the controls concerns the relation of their power to the inertia of the aeroplane, and the effect of inertia depends of course on the rate at which manœuvres are carried out, and on absolute size, or size relative to the pilot, whose size is constant. These effects are familiar if we think for a moment of ships of different sizes and study their manœuvres. Small yachts turn quicker than large ones, and yachts turn about as quickly as aeroplanes of the same size, though of course the forward speeds of the aeroplanes are something like thirty or forty times as great.

It is not, however, in the steady rates of turn, but in the entering and checking of the turn that inertia shows its effect, and although large craft turn slower, inertia effects are greater than on small craft. On a liner, for example, it may take nearly half a minute to check the swing by reversing the helm on a steady turn, and it is this great time lag in the control which makes the operation of bringing a large liner alongside a quay under its own power a very tricky operation. A lag of even as little as a tenth of a second can be noticed in an aeroplane control, and bearing in mind that most aeroplanes have to be brought into relatively gentle contact with the ground at the end of each flight at speeds of the order of sixty miles an hour, lags of much more than a tenth of a second are quite unacceptable to the aeroplane pilot.

The third function of the controls, the overcoming of the damping of the fixed surfaces of wing, tail, etc., provides the general guide to the power required from the control organs; thus the movable elevator, which causes pitching, may be about half the size of the fixed tailplane, which resists or damps pitching motion. Proportions such as this have been reached as the result of long experience, but the harmonizing of the three controls, elevator, ailerons and rudder, still gives rise to a great deal of experiment of the hit-and-miss variety on new types, before they can be regarded as satisfactory.

Then finally, there is the relation of the natural or inherent stability, or instability, of the aeroplane to the power of the controls. I propose to illustrate this point by a homely example. In the case of a cyclist riding at a good speed, so long as his craft is endowed with good stability by virtue of its speed, the control movements of his handlebars are very small, but as the speed falls, so he has to work harder and harder in moving his handlebars more and more violently from side to side, until at last his fullest powers of control are inadequate and he crashes. Now this has a close parallel in the air, where stability deteriorates as the speed falls, just as on the bicycle, and it is always for the slow end of the speed range of the aeroplane that it is difficult to provide adequate control surfaces, particularly when it is borne in mind that these surfaces must also be capable of operation at the high-speed end of the speed range.

It is not possible to discuss questions of stability here in detail, but the intimate connexion which must always exist between stability and control can never, in my opinion, be too strongly emphasized.

This brings my discussion of the general considerations surrounding control problems to a close, and I would now like to refer to the results of some new experimental work and their bearing upon particular difficulties which have arisen from the great increase in performance of aeroplanes in recent years.

The trim and stability of a glider, or of an aeroplane gliding with its engine shut off, present no great difficulties to the experienced designer. When the aeroplane is flying under power, the slip-stream from the propeller passes first over the wing and later over the tail-plane, changing the air forces on any surface with which it comes into contact. Experiments with models show that the slip-stream from each propeller, by the time it has reached the tail-plane of a representative modern type of twin-engined aeroplane, has a nearly flat under-surface. This provides an explanation of why two different types of aeroplane, which may look very similar, behave quite differently in flight. In one case it may be that the tail-plane is below the bottom of the slip-stream, and thus experiences only the air pressures arising from the normal speed of the aeroplane through the air; in the other case, with the tail-plane just in the slip-stream, the air forces may be more than twice as great and the upsetting effect of this on fore and aft balance, or trim, is obvious.

The sizes and speeds of aeroplanes are rapidly increasing as the years go on, and the reason that the aeroplane pilot has not yet found salvation in a power-assisted, or servo, control is to be found in the danger involved if there is lag in the mechanism. The very minute degree of lag which is tolerable has already been referred to, and by a continuous exploitation of the possibility of aerodynamic balancing of the control surfaces, it has, up till now, been possible on even the biggest types to avoid the need for a servo-mechanism at all. But yet closer aerodynamic balancing will be needed in the future, and a new system has recently been invented by several people in different countries almost simultaneously.

The control flap has its hinge situated well behind the leading edge in the familiar way, but that part of the surface in front of the hinge is entirely shrouded by curtains formed by extensions of the top and bottom surfaces of the main wing, extending back almost to the hinge, with a small gap or vent at top and bottom between their extremities and the moving control surface. The front part of this surface thus works in a kind of box, and the pressure on top of it is controlled by the air pressure existing outside the wing at the position of the top vent, and similarly for the under side; the essential point is that the box is divided into two parts, sealed from each other by

Fig. 1.

the nose of the control surface, which touches at all points in its travel the curved back of the main wing (Fig. 1). The absence of any air flow through the gap which usually exists between control surface and wing is found to avoid the undesirable pressure changes which usually arise on the nose of the control surface as it moves, thus spoiling the balancing over anything but a small angular range. Irving, of the National Physical Laboratory, has been one of the co-inventors, and the results of his first experiments are most promising.

Another development which, like the tricycle undercarriage, is a revival of an old idea and goes back, to my knowledge, to 1904, when it was embodied by the Wrights in one of their patents, is what is known as the *two-control system*. The standard system of to-day, with the three controls, elevator, aileron and rudder, is universal in all countries; at various times attempts have been made to abolish either the ailerons or the rudders. It seems, however, impossible in the light of modern knowledge to design an aeroplane which can carry out perfect turns at all speeds with either a rudder only or ailerons only, and an interesting new arrangement is being tried by a well-known American aeronautical engineer, Weick, of the Engineering and Research Corporation, of

Washington, D.C. Weick connects up both the ailerons and the rudder to a single control wheel, the rotation of which operates them both in a pre-arranged proportion. By this means it is possible to make nearly perfect turns at one speed and very satisfactory turns at all speeds. Encouraging results have attended the early trial flights, in which an experienced test pilot observed that he got smoother riding in bumpy weather with the two-control system than with the standard three controls. If the early promise of this experiment

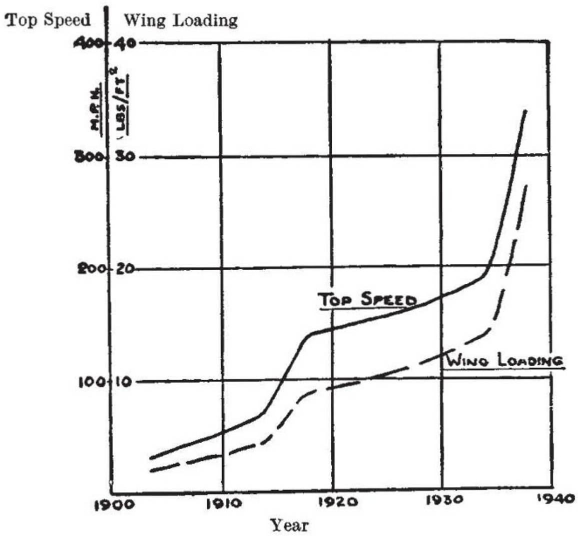

Fig. 2.

is fulfilled, a real advance in simplification of control will have been made, and with the increasing complication of everything connected with the aeroplane, a fundamental step in the opposite direction, such as that proposed by Weick, will be most refreshing to the hard-pressed pilot.

In order to minimize the very real danger of the first test flights on large new types, there is a procedure which has been adopted, notably by one firm in Great Britain, Messrs. Short Brothers, which consists of building a *flying model* of the large aeroplane. This flying model may be something like half the size of the projected type, and its weight would then be only one-eighth ; the control forces are in that case reduced to one sixteenth, and the pilot thus has no difficulty in managing his model. It is of course far quicker and cheaper to modify the model to correct any faults in trim and stability, and it is possible to ensure that the control forces on the full-size aeroplane are within the capacity of the pilot's strength. Then minor modifications should suffice to harmonize the controls and achieve the high standard which we know is possible of attainment.

The large types built by Shorts, just referred to, are the "Empire Boats" and their Service counterparts the "Singapores", and the flying model was known as the "Scion Senior". Although this latter type was fitted with floats, nevertheless the wings and tail, including all control surfaces, were used as the basis for the design of its larger counterpart ; the flying model must take its fair share of credit for the remarkable ease of handling in the air which is characteristic of these fine boats.

The thought may perhaps arise that I am exaggerating the importance of the role taken by stability, and particularly by control, in the advance of the science and art of flight. I have prepared a diagram (Fig. 2) showing the rise in speed, the common criterion for judging progress, and also in wing loading, showing what has been accomplished in the last thirty-five years. It will be seen how speed and wing loading have risen together in such a way that it is impossible to dissociate one from the other, and I hold that it is only through improvement in stability and control that we can now attain the speeds we do by flying safely with wing loadings twenty and thirty times as great as those of the most famous aeroplane of all time—that in which the Wrights made their first flights in 1903.

The Ordnance Geological Survey: Its First Memoir, 1839

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IN the spring of 1839, R. A. C. Godwin-Austen commenced a letter to H. T. de la Beche with the following words : "I am not much in the habit of buttering my friends, but in the present instance you must not complain at being compelled to pay for a shillings-worth of that commodity". (A shilling was the postage charge for a letter from Newton Abbot to Swansea.) The writer then described his efforts to secure a copy of de la Beche's "Report", and continued, "I read it before dinner and after : I dipped in it with my tea, and went on devouring it until the 'dead hour'. I was at it again this morning. . . ."

The reference was to the "Report on the Geology of Cornwall, Devon, and West Somerset" —the first volume to be published on behalf of the newly founded Ordnance Geological Survey. It was de la Beche's own idea to supplement the