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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 563

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BALANCED AND SERVO CONTROL SURFACES

From The Aeroplane, February 26, 1930

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 563.

BALANCED AND SERVO-CONTROL SURFACES.\*

Many reports on various control systems are available, but the results cannot be generally applied since the effect of particular changes of surface-form and mounting are subject to variations depending, among other things, upon airfoil section and influences of airplane layout.

If these control systems are studied in detail the general principles underlying certain developments may be understood, and it is possible for these results to be intelligently applied to airplanes where certain specific changes or requirements appear desirable.

The force which a pilot can exert on the control members is strictly limited and, except for very light airplanes, it is inadequate for satisfactory operation of the control surfaces unless the system is skilfully arranged.

The problems in connection with this work have received much attention and various means have been adopted for relieving the pilot of excess loads on the control stick and rudder bar.

In a short article of this description it is only possible to make a simple analysis of the several systems in more general use.

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\*From The Aeroplane, February 26, 1930.

## Surface Balance

From a mechanical point of view the elevator, rudder, and aileron surfaces can be treated in a similar manner. Considering a simple elevator unit such as that illustrated in Figure 1: If an air load  $P$  is acting normal to the surface such that its C.P. lies at .3 of the chord from the hinge, then the hinge moment  $.3 CP$  must be balanced by a load applied at the top of the control column.

The hinge moment on such a surface is roughly proportional to the angular movement and to (area  $\times$  chord) of aileron or elevator.

It will be apparent that there is a definite limit to the load a pilot can sustain and, where the control surfaces become too heavy for the pilot's strength, assistance is provided through one of two methods: (a) balanced control surfaces or (b) servo control surfaces.

Servo control systems have received a limited application on airplanes above 10,000 pounds gross weight, but it is usual to balance the control surfaces of all airplanes with the exception of very light planes.

A reduction in the control column force can be effected by increasing the aspect ratio of the surface, thereby reducing the chord and hinge moment. While this method is perfectly sound, there are very definite limitations to this procedure,

especially for elevators and rudders.

Balancing of control surfaces is done by disposing the moving surface so that part projects forward of the hinge line, and this in effect brings the C.P. of the surface nearer to the hinge and decreases the hinge moment.

In discussing the various balance systems reference will be made to overbalancing and underbalancing, and these terms can be simply defined. Overbalancing is that condition when the C.P. lies forward of the hinge, so that the surface tends to take charge and throw over to its extremelimit. This represents a reversal of load on the control column and is a serious fault. Underbalancing, on the other hand, is not a serious matter except on large airplanes when the control forces tend to become excessive.

A very considerable reduction in hinge moment may be required on some airplanes if the controls are to be balanced sufficiently to permit of reasonable loads on the operating members. This being so, it is important to know the safe limit to which balance can be carried without overbalancing under certain conditions of flight.

### R u d d e r s

From an examination of the geometrical shape of most rudders, it is evident that the chord is generally much greater than that of the elevator because its height, for structural reasons, is

comparatively small. The longer chord increases the hinge moment and makes for heaviness on rudder control. Chiefly for this reason rudders are more often balanced than the other control surfaces and, on large airplanes, some form of servo operation is required.

It is usually found that the rotational flow of the slipstream, introduced by the propeller action, requires the use of some right or left rudder (depending on the direction of propeller rotation) to maintain straight flight with throttle open. In this case the effectiveness of rudder balance is marked, the balance holding the rudder over without much effort on the part of the pilot. Several devices have been employed for overcoming the rudder-bar force during straight flight. One method consists of a spring (usually shock-absorber cord) attached to one side of the rudder bar which produces the necessary corrective force. An alternative system which has been used with success is that of offsetting the fin.

A series of typical tail units is shown in Figure 2 and indicates some of the methods employed for providing rudder balance.

There is a scarcity of published information with respect to experimental work on tail units. The reason for this is, no doubt, to be found in the fact that no part of the airplane is so easily altered and exchanged. Unfortunately, the large amount of experimental work on this subject, done by individual

designers and manufacturers, is never published, but the results may be found embodied in all successful airplanes.

The use of servo controls for aircraft have been chiefly confined to rudders. Unlike the elaborate servo mechanisms used on ships the method employed on airplanes is very simple and generally consists of a small auxiliary rudder mounted aft of the main rudder. Recent instances of the use of such devices are to be found in the Boulton and Paul Sidesstrand, the Short Singapore and Calcutta, and the Beardmore Inflexible.

The principle of operation will be briefly outlined in conjunction with the diagrams shown in Figure 3. The only forms of servo rudder used on aircraft have been of Flettner type, or variations of that type. This system depends upon the action of a small trailing flap carried by a balanced rudder. The main rudder is quite free to swing in any direction, the pilot only controlling the auxiliary flap. Figure 3A shows the control unit in a neutral position, Figure 3B shows that a disturbance has started the rudder to swing without any movement of the rudder bar, as it is free to do, and the mounting of the controls to the auxiliary flap are such that they start the flap moving in the same direction as the main rudder, but at a greater rate. This applies a corrective moment which returns the rudder assembly to its neutral position. The position at Figure 3C indicates that the pilot has moved the rudder bar over and rotated the flap. It is applying a turning moment to the main rudder

and Figure 3D shows the position of equilibrium following the movement at 30. When the servo rudder is moved over, the main rudder will move through such an angle that the moment of the forces acting on the complete system about the main rudder hinge, is zero.

There is no difficulty in ensuring that the servo rudder hinge moment shall be sufficiently small to give reasonably light loads on the rudder bar. The main difficulty is, in fact, to make the moment sufficiently large to give a reasonable feel to the control.

The aerodynamics of a simple servo rudder has been the subject of R.& M. No. 1105.\* This system consists of a rectangular rudder and servo rudder of the same span hinged to its trailing edge. The arrangement is illustrated in Figure 4. The two graphs accompanying this figure show the relationship between the angle of servo rudder for different positions of the main rudder hinge when the main rudder is set over at 10 and 20°. The position of the main rudder hinge is given in terms of rudder chord and represents the position of the hinge in front of the position corresponding to full balance on the main rudder. It can be seen from inspection of the graphs that the servo rudder angle required, to hold the main rudder over to a definite angle varies comparatively little with change in size of servo rudder.

It follows, therefore, that there is no advantage gained by in-

\*The Aerodynamics of a Simple Servo Rudder System, by H. M. Garner and C. E. W. Lockyer. British Aeronautical Research Committee Reports and Memoranda No. 1105, 1927.

creasing the servo rudder above a certain definite size and these tests indicate that an economical ratio for rudder area to servo area is possibly between 1 : .15 and 1 : .20.

### E l a v a t o r s

Five methods for balancing elevators are shown in Figure 2. The tail units illustrated are (A) Dornier Do.X, using Dornier balance; (B) Short Singapore with horn balance; (C) Hawker Hart with inset balance; (D) Blackburn Dart with tapered inset balance; and (E) arrangement with Frise type balanced elevators.

The object of elevator balance is to secure a close approximation to zero hinge moment under all possible conditions but without risk of overbalance on the one hand or of inadequate provision, with unduly heavy loads, on the other.

The Dornier system, used for elevators, rudder and ailerons, is a completely new departure. In appearance it looks somewhat like the Avro balance, but its action is quite different. There is no published information regarding its efficiency in comparison with other known types, but there can be no doubt regarding its efficiency in view of its successful application to the world's largest flying boat.

Figure 5 shows the method of balancing in closer detail and, it will be noted, a small balance plane is mounted on struts which are anchored to the fixed portion of the wing (or the fin in the case of rudder balance). These supporting struts are ad-

justable in order that the height of the balance plane can be varied. The balance is operated through a rod, pivoted to an extension of the balance plane, and connected to the control surface at a point some distance behind the hinge.

Movement of the balance plane, following displacement of the control surface, can be readily followed without further explanation. The arrangement is ingenious since the balance plane can be easily removed, and area modified, the hinge position and incidence angle altered at will. Such advantages are not possessed by any other system. In the case of rudder control, a small balance plane is located on each side of the rudder. The controls are operated through the usual levers and torque tubes.

The Horn type of balance shown in Figure 2B is at some disadvantage at large angles of attack in that part of the elevator does not lie behind the fixed portion of the tail and forces and moments on the two moving portions can change differently and rapidly, giving rise to comparatively sudden loads in the controls. This aspect will be discussed more fully under another heading.

The types shown at (C) and (D) are in some respects similar. The chief objection to these systems is to be found when the elevator movement is such that it opens up a gap between the two parts of the tail because there is considerable loss in control power. Under similar conditions difficulties have been experienced with vibration of the elevators due to passage of air between the stabilizer and elevator. This has changed the nature

of flow and the distribution of forces, causing flutter of the elevator between positions corresponding to the different types of flow. This trouble should not arise on tails with thick sections because the air flow will not pass between the gap except at extreme elevator angles.

The application of the Flettner servo principle to ailerons has been suggested and a recent R. & M. No. 1262\* deals with this subject.

The study of different tail units, with their action and influence on controllability, is a complex matter and one which has been confined to full scale tests on few airplanes. In order that definite information can be obtained it is necessary for each airplane to be equipped with the special apparatus necessary for the measurement of reactions and changes of attitude due to various control movements. It is found impossible to make such investigations for every airplane and, in general, an easy course is adopted and the test pilot's report accepted. Modifications are carried out in accordance with such a report. It is well known that two pilots flying an identical airplane may report quite differently regarding the merits of controls. Even the best reports are only statements of opinion and, as such, cannot be tabulated, compared, or analyzed.

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\*The Application of the Servo Principle to Aileron Operation, by A. S. Hartshorn, 1929. British Aeronautical Research Committee Reports and Memoranda No. 1262.

## A i l e r o n s

When dealing with ailerons we are treading on somewhat firmer ground, for none of the other control surfaces have received so much attention from investigators and, in consequence, there is no lack of reliable data.

It has already been pointed out that high aspect ratio is an advantage because, for a given controlling effect, it serves to reduce the hinge moment. On the other hand, it is at some disadvantage as its inner portion is working at a small arm and therefore produces a correspondingly small rolling moment. For some reasons it would be desirable to place all the area at the wing tip because the aileron would then be working on a maximum arm and the size of surface could be reduced to a minimum. In fixing aspect ratio there are two extreme courses and it is usual to strike a compromise between these, as experience or conditions dictate.

It has already been stated that the object of rudder and elevator balance is to secure an approximation to zero hinge moment, but ailerons must be viewed in a different light. In this form of control there are two sets of surfaces operating differentially and the load on the control column is only that of the algebraic difference of the hinge moments on the two ailerons. It is always found desirable to leave a certain amount of "feel" for the pilot and this is generally provided in such a manner

that the aileron which is "up" gives a slightly increased moment over the "down" aileron.

Reviewing various forms of aileron balance, there are illustrated three general types: backward hinge, horn, and Avro. Typical hinge moment curves are shown plotted directly below the systems to which they refer. These results have been collected from various sources and, in most cases, they are not strictly comparable one with another, as the tests have been made on different airfoil sections. In the case of the backward hinge and Avro systems, a record is given of the same system without balance and the effectiveness of balance can be readily seen.

It is interesting to note that for an unbalanced surface the hinge moment is practically independent of the airfoil angle of attack and the value of hinge moment becomes steadily greater as the aileron angle is increased.

The backward hinge system, shown in Figure 6a is perhaps the best type from an aerodynamic standpoint. The aileron is mounted on arms built out from the rear spar and the aileron is cut away in order that the arms, carrying the hinges, may extend some distance behind the leading edge. For conditions of perfect balance it would be desirable to mount the hinges so that the axis of rotation of the aileron coincided with its center of pressure. Unfortunately, the center of pressure is not quite stationary and, furthermore, in practice, if too near an approach is made to complete balance, the ailerons will, under certain

conditions, become overbalanced, and "take charge." This remark applies with equal force to all types of balance. When using the back set hinge balance it is usual to shape the nose in a similar manner to that indicated, to prevent any part of the aileron projecting above the wing. This shaping of the nose portion gives more uniform balance. A series of tests on a biplane with airfoils of R.A.F. 15 section are recorded in R. & M. No. 651.\* The effect of varying the hinge position is shown in the four curves on Figure 6a. The values of hinge moment record the net differences on the four ailerons, in other words the net moment applied to the control stick.

Setting back the hinge by .41 of the chord provides a very uniform moment but, unfortunately, it will be noted that the controls are badly overbalanced above angles of 10 degrees. For this particular arrangement, setting the hinge back .3 of the chord would seem about right and the hinge moment, for an aileron angle of 12 degrees, is about one-quarter of that for an unbalanced surface.

A development of this method, which has received general application, is the Frise aileron. The moving surface is of airfoil form in cross section with a flat under surface. The aileron is mounted so that, when it is turned down, the nose remains screened behind the wing section, but when the aileron is turned

\*An Investigation of the Aerodynamic Properties of Wing Ailerons, Part II: The Balancing of Ailerons, by H. B. Irving and E. Ower. British Advisory Committee for Aeronautics Reports and Memoranda No. 651, 1919.

up, the nose portion projects below the wing section and thereby increases the drag on that side.

The horn type of balance is shown in Figure 6b and the hinge moment values for various aileron settings immediately reveals the disadvantages of this system. The balance, while satisfactory over a range of small angles, changes suddenly and imposes rapidly increasing loads on the control column. This system has further drawbacks in that the balance is concentrated on one side of the aileron and this introduces an offset load which necessitates a heavier structure than that used on other forms of balance. The chief advantage of this method lies in the ready way the balance area can be varied without alteration to the form or structure of the fixed portion of the wings. There is no hard and fast rule for determining the amount of balance area although it has been stated that the moment of area in front of the hinge to the moment of area behind the hinge should be approximately 1 : 6.

The only other balance system to which detailed reference will be made is the Avro type. In this arrangement the balance surface consists of a separate plane mounted above and forward of the hinge. From a mechanical point of view the balance effect is similar to those systems already described.

Wind tunnel experiments show that the Avro balance is distinctly superior to all other systems with the exception of the back-set hinge and Frise balance. The Avro system has some con-

structional advantage over the Frise method in the ready manner in which the balance can be removed and varied. The additional plane adds to the parasitic resistance and one authority states that the increase in resistance is of the order of 5 per cent of the total wing drag. This increased drag together with the uncleanliness that such a scheme presents are possibly the reasons why the system has not been extensively employed. Hinge moment curves for this system are shown in Figure 6c for 16 and 0 degrees incidence of the wings. The value of balanced area to actual aileron area shows wide variations, a mean ratio being of the order 1 : 10.

As so much depends on the nature of flow over the airfoil, balanced conditions are particularly liable to change with alterations in form and thickness of the airfoil used.

The forms of control discussed in this article do not cover the whole of the systems in use. Controllers of original type are used on the Hill Pterodactyl and the Glenny and Henderson Gadget. Floating ailerons, attached to the interplane struts of a biplane midway between top and bottom wings, have been used with some success. Definite figures of the performance and comparative merits of these systems are not available, and their application has been limited to a few experimental airplanes.

One of the difficulties associated with the development of full-scale control surfaces from wind tunnel tests lies in the

flexible structure of the wings. In some instances a wing and aileron which has proved stable in the wind tunnel has exhibited flutter tendencies when subject to full-scale tests. In view of these dangers it is not usual to provide the maximum balance indicated from the wind tunnel tests.

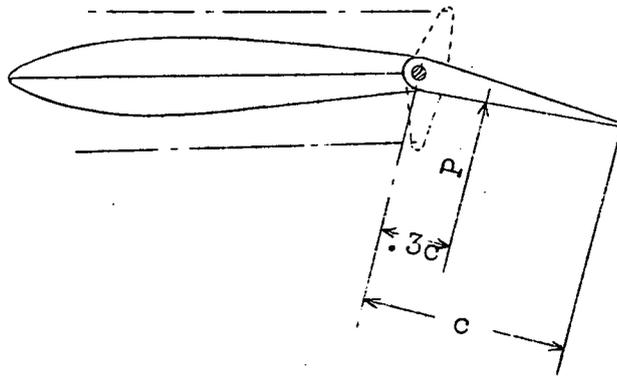


Fig.1

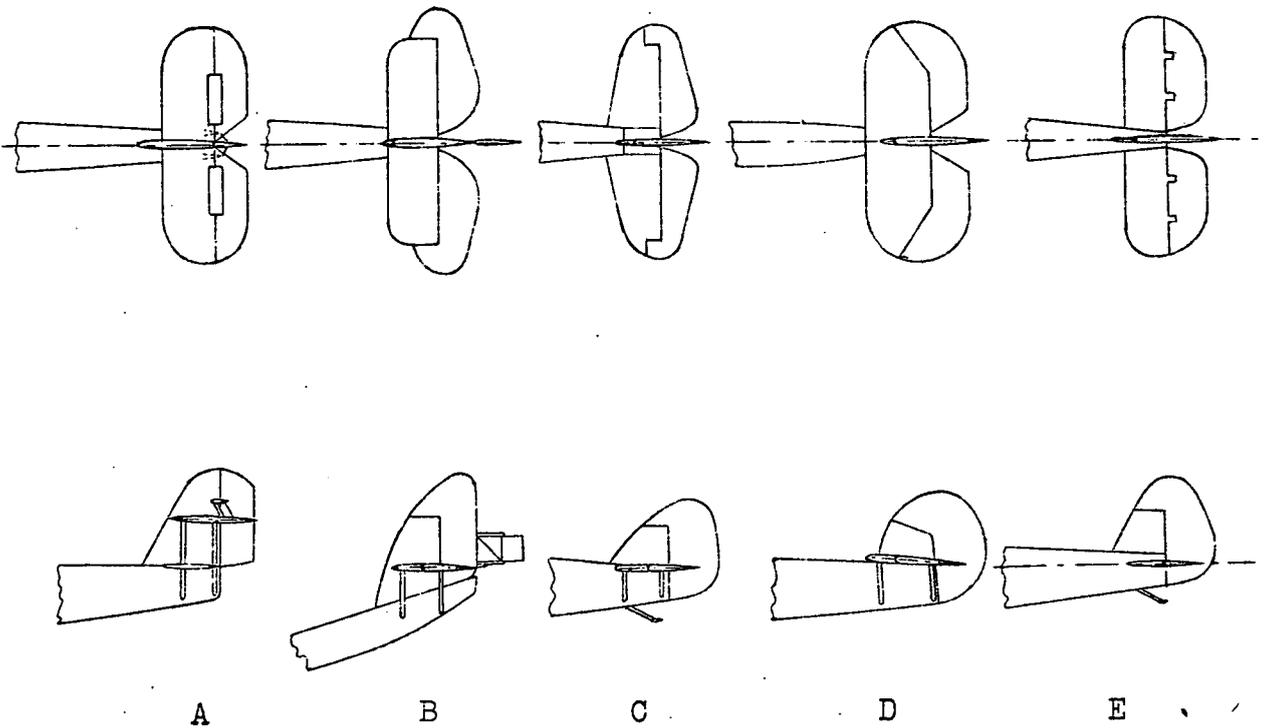


Fig.2 Five typical tail units showing different types of rudder and elevator balance.

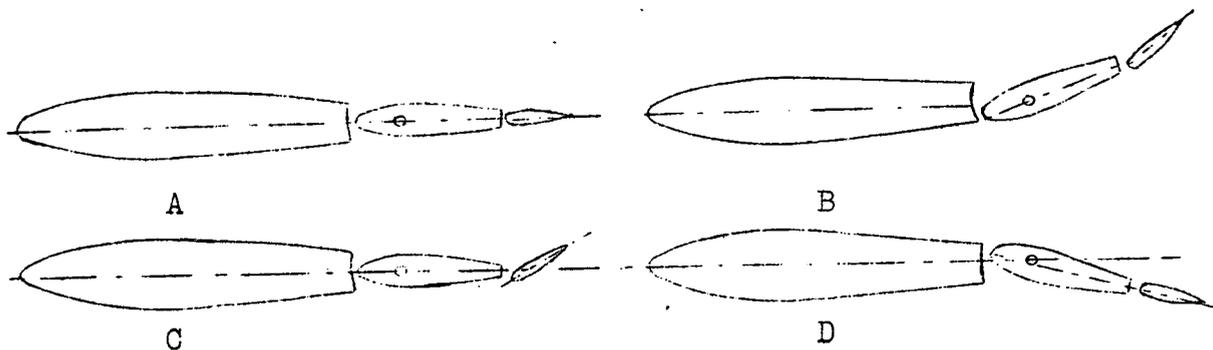
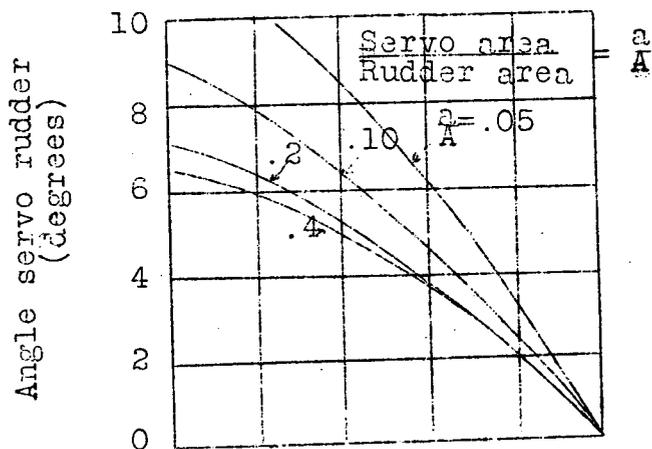


Fig. 3 The principle of operation of a Flettner type servo rudder.

Servo angle required to hold Main rudder over 10°



Servo angle required to hold Main rudder over 20°

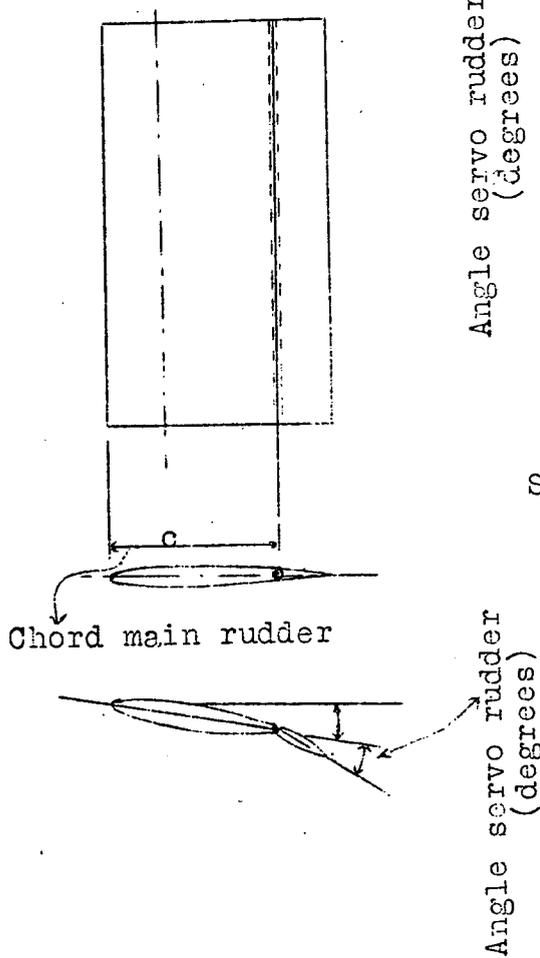
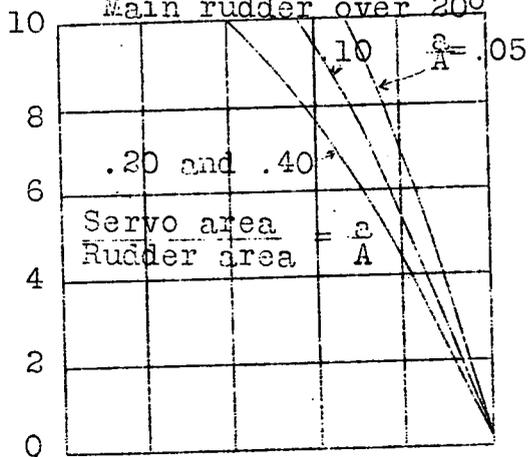


Fig. 4 Position main rudder hinge.

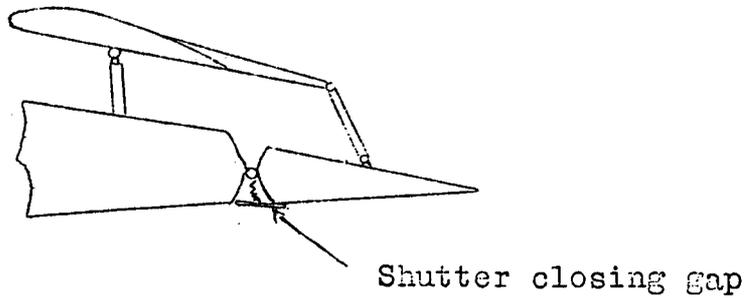


Fig. 5 Dornier DoX balance.

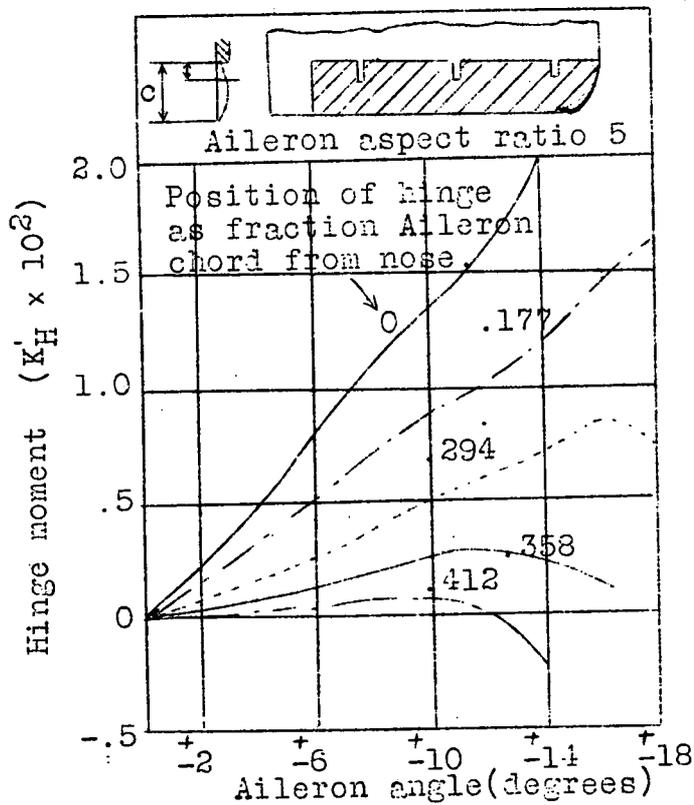


Fig. 6a

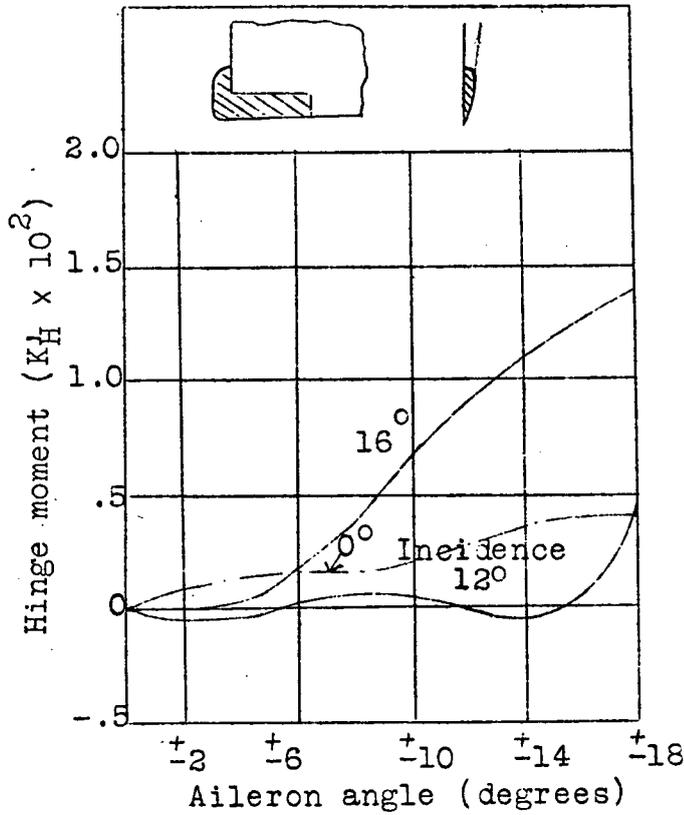


Fig.6b

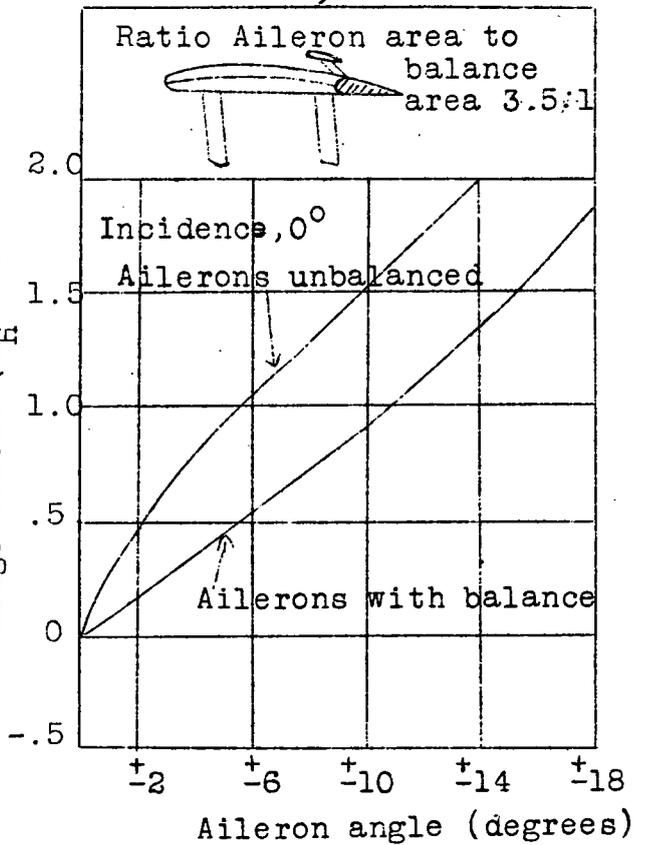
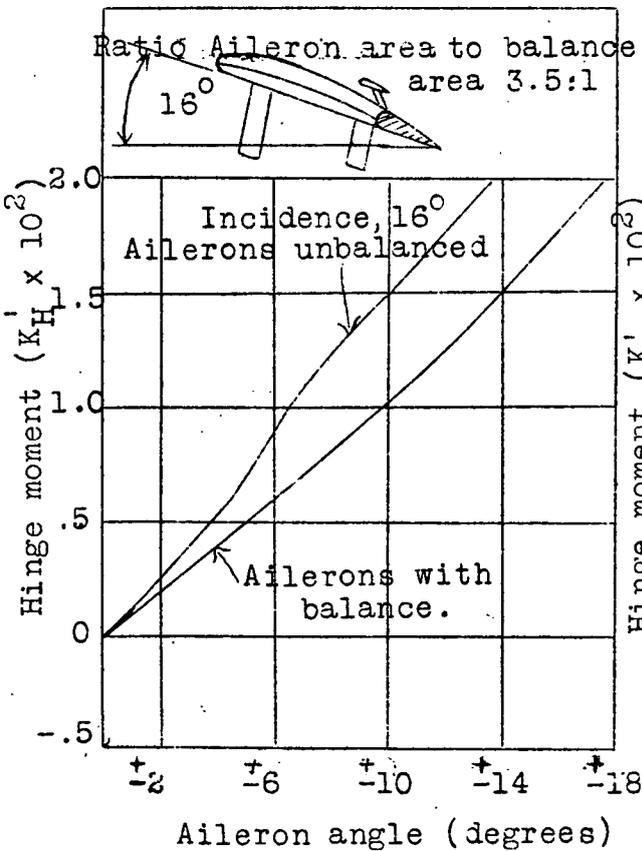


Fig.6c