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REPORTS AND MEMORANDA, No. 575.

THE EFFECT OF ASPECT RATIO AND SHAPE OF WING TIP ON AEROFOIL CHARACTERISTICS.—By H. GLAUERT, of the Royal Aircraft Establishment. Presented by the CONTROLLER, Technical Department, Department of Aircraft Production.



JANUARY, 1919.



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# THE EFFECT OF ASPECT RATIO AND SHAPE OF WING TIP ON AEROFOIL CHARACTERISTICS.

By H. GLAUERT, of the R.A.E.

Presented by the CONTROLLER, Technical Department, Aircraft Production.

*Reports and Memoranda, No.* 575. *January,* 1919.

SUMMARY.—(*a*) *Introductory.*—From experiments on the distribution of pressure over a wing (R. & M. 73 and 353) a mean loading curve has been deduced which is independent of the shape of the wing tip, and this has been standardised by the Technical Department, as the basis for strength calculations. Reports R. & M. 550 and 557 also give experimental data as to the effect of shape of wing tip on the characteristics of an aerofoil.

(*b*) *Range of the investigation.*—The mean curves deduced from the pressure plotting experiments have been used to calculate the effect of aspect ratio and shape of wing tip on the lift coefficient and position of the centre of pressure. Three forms of wing tips—" square," " S.E.5," and " B.E.2c "—have been considered. The shape of wing tip called " S.E.5 " is the original type fitted to the aeroplane, and was only used on the earliest aeroplanes of this type. An attempt has also been made to calculate the best span of aileron for these different wings.

(*c*) *Conclusions.*—The calculated corrections to the lift coefficient and centre of pressure coefficient due to change of aspect ratio and change of tip shape were found to be in good agreement with experimental data, and the method of calculating by means of the loading curve referred to above, and given at the end of this report, has been fully justified. The best span of aileron was found to be two-thirds of the semi-wing span for all wing tips. There is no experimental data to confirm this figure, but the result is consistent with the experimental data of report R. & M. 550.

(*d*) *Applications.*—The report shows that the correction for change of shape of wing tip from the results of tests on square-ended tips can be calculated by the method suggested in the report.

1. Two reports, R. & M. 550 and 557, have been issued recently dealing with the effect of different shaped wing tips on the aerodynamical qualities of a biplane wing arrangement of aspect ratio 6, unit gap-chord ratio and zero stagger. These tests were

(B3546) Wt. 868—104. 1625. 7/19. Gp. 82.

TABLE 1.

LIFT COEFFICIENTS (CALCULATED).

| | —— | Square. | S.E.5. | B.E.2c. |
|---|---|---|---|---|
| Area lost at tip. | $s_e$. | 0. | 0·282. | 0·274. |
| Aspect ratio (2*s*) | 5 | 0·985 | 1·044 | 1·031 |
| | 6 | 1·000 | 1·049 | 1·039 |
| | 7 | 1·011 | 1·054 | 1·044 |
| | 8 | 1·019 | 1·057 | 1·048 |

These values can be used to calculate the effect of wing tips on the lift coefficient at any angle of incidence. The results of R. & M. 557 are compared in this way in Table 2 for three angles of incidence.

TABLE 2.

EFFECT OF SHAPE OF WING TIP ON LIFT COEFFICIENT.

| Angle of incidence. | Report R. & M. 557. | | | Calculated. | |
|---|---|---|---|---|---|
| | Square. | S.E.5. | B.E.2c. | S.E.5. | B.E.2c. |
| 2 | 0·138 | 0·148 | 0·142 | 0·145 | 0·143 |
| 4 | 0·258 | 0·270 | 0·258 | 0·270 | 0·268 |
| 6 | 0·378 | 0·388 | 0·385 | 0·396 | 0·393 |

The agreement obtained by this method of calculation is remarkably good considering the nature of the results, upon which it is based, and it appears that the correction for shape of tip can be deduced with sufficient accuracy in this way. Also the model S.E.5 wing had rather increased incidence towards the tip, which might be expected to increase the lift. The "wash-in" was, however, neutralised by the bad form of the wing section near the tip.

The calculated corrections for aspect ratio are also of the same magnitude as shown by model tests. No great reliance can, however, be placed on the values obtained, as they depend on the assumption that the central portions of the wing give the same lift whatever the aspect ratio, and this assumption has not yet been checked by model experiments.

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|---|---|---|---|---|
| Area lost at tip. | $s_0$. | 0. | 0·282. | 0·2[illegible]4. |
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4. The mean curve of loading and the law for the position of the centre of pressure have also been used to calculate the effect of the shape of wing tip on the centre of pressure of the whole wing.

Let $\lambda$ be the distance of the leading edge of any section behind that of the whole wing, $c$ the length of the chord, $\theta_o$ the centre of pressure coefficient of any section, and $\theta$ that of the whole wing. It can easily be seen that

$$\theta \int_o^s \phi \, dx = \int_o^s \phi \, (\lambda + \theta_o c) \, dx,$$

and this equation reduces to

$$\frac{\theta - \theta_o}{\theta_o} = \frac{\int_o^a \phi \left( \frac{\lambda}{\theta_o} + c - 1 \right) dx}{s - 0{\cdot}21}$$

where $a$ is the value of $x$ at which the wing reaches its full chord, *i.e.*, where $\lambda = 0$ and $c = 1$. This equation has been used to calculate the correction to the centre of pressure coefficient for the shape of the wing tip. There is, of course, no correction for the square ended wing.

TABLE 3.

CORRECTION TO C.P. COEFFICIENT.

| Aspect ratio. | S.E.5 | | | B.E.2c. | | |
|---|---|---|---|---|---|---|
| | $\theta_o = 0{\cdot}3$. | 0·4. | 0·5. | $\theta_o = 0{\cdot}3$. | 0·4. | 0·5. |
| 5 | 0·022 | 0·018 | 0·015 | 0·004 | 0·001 | – 0·001 |
| 6 | 0·018 | 0·015 | 0·013 | 0·004 | 0·001 | – 0·001 |
| 7 | 0·015 | 0·013 | 0·011 | 0·003 | 0·001 | – 0·001 |
| 8 | 0·013 | 0·011 | 0·009 | 0·003 | 0·001 | – 0·001 |

These results have also been compared with the experimental data of report R. & M. 557, and were found to be in good agreement.

### TABLE 4.

### EFFECT OF WING TIPS ON C.P. COEFFICIENT.

| Angle of incidence. | Report R. & M. 557. | | | Calculated. | |
|---|---|---|---|---|---|
| | Square. | S.E.5. | B.E.2c. | S.E.5. | B.E.2c. |
| 0 | 0·441 | 0·458 | 0·445 | 0·455 | 0·441. |
| 2 | 0·349 | 0·364 | 0·356 | 0·366 | 0·352 |
| 6 | 0·282 | 0·302 | 0·286 | 0·301 | 0·287 |
| 10 | 0·266 | 0·281 | 0·265 | 0·285 | 0·271 |

5. Calculations have also been made to estimate the best span of ailerons for lateral control, but the crude nature of the assumptions only allows a general idea of the result to be obtained. The method of analysis adopted was to assume that the rolling and hinge moments were both proportional to the aileron angle, an assumption which is justified for small angles by the results of report R. & M. 550. For ailerons of different shape or span the rolling moment L and the hinge moment H were also assumed to be proportional to the corresponding moments due to the load on one aileron when the aileron angle was zero. The distribution of the load along the chord of the aileron was assumed to be triangular, so that the centre of pressure was at one third of the chord. Finally, the efficiency of the aileron was taken to be proportional to $L^3/H$ to take account of the lower gearing, which can be used with the ailerons which give the greater rolling moment.

Write $c_1$ for the chord and $s_1$ for the span of the flap. Then for a square ended wing we have the equations

$$L = \int_0^{s_1} \phi\, c_1^2 (s - x)\, dx.$$

$$H = \int_0^{s_1} \frac{1}{3} \phi\, c_1^3\, dx$$

and so

$$L = c_1^2 (s\, s_1 - \tfrac{1}{2} s_1^2 - 0{\cdot}21\, s + 0{\cdot}06)$$

$$H = \frac{1}{3} c_1^3 (s_1 - 0{\cdot}21)$$

so long as $s_1 > 1{\cdot}2$ as is generally the case. From these equations the values of $L^2/H$ were calculated, and the best value of $s_1$ was derived. It was found that $s_1/s$ varied from 0·70 at aspect ratio 5 to 0·62 at aspect ratio 7, but as the determination depends on fixing the maximum of the curves, no great importance can be attached to the variation of $s_1/s$. If the variation of load at the tip were ignored, the expressions derived would be

$$L = \tfrac{1}{2} c_1^2 s_1 (2s - s_1).$$

$$H = \frac{1}{3} c_1^3 s_1,$$

and the best aileron span would be $\frac{s_1}{s} = \frac{2}{3}$, *i.e.*, each aileron should be one-third of the total span. Calculations were also made for the S.E.5 and B.E.2c types of wing tip. The expressions for L and H become very complicated, and the graphical solution is somewhat laborious. The final values deduced for $s_1/s$ showed no systematic differences from those for the square ended wing. For the S.E.5 tips the values varied from 0·65 to 0·62, and for the B.E.2c tips from 0·65 to 0·72 for aspect ratios 5 to 7. The general conclusion reached for the square ended wing appears, therefore, to be applicable to any ordinary form of wing tip. This result is in agreement with the conclusions of report R. & M. 550 where ailerons of different span were tested on wings with B.E.2c type of tips. It was found in that case that the efficiency increased with the span for values of $\frac{s_1}{s}$ from $\frac{1}{3}$ to $\frac{2}{3}$. It is to be regretted that the experiments were not continued until the efficiency began to fall off, as it is impossible to say how far the assumptions made above give a result which would apply in practice.

6. The general conclusions to be derived from the calculations described in this report are that the mean loading curve (Fig. 2) and the assumption that the centre of pressure is at the same fraction of the chord along the whole span lead to results which are in excellent agreement with experimental data. It is possible by means of these data to calculate with sufficient accuracy the lift coefficient and centre of pressure of a wing with shaped tips from the test of a square ended wing of different aspect ratio. The errors due to calculating the corrections in this way appear to be less than 0·005 in the lift coefficient and less than 0·003 in the centre of pressure coefficient.

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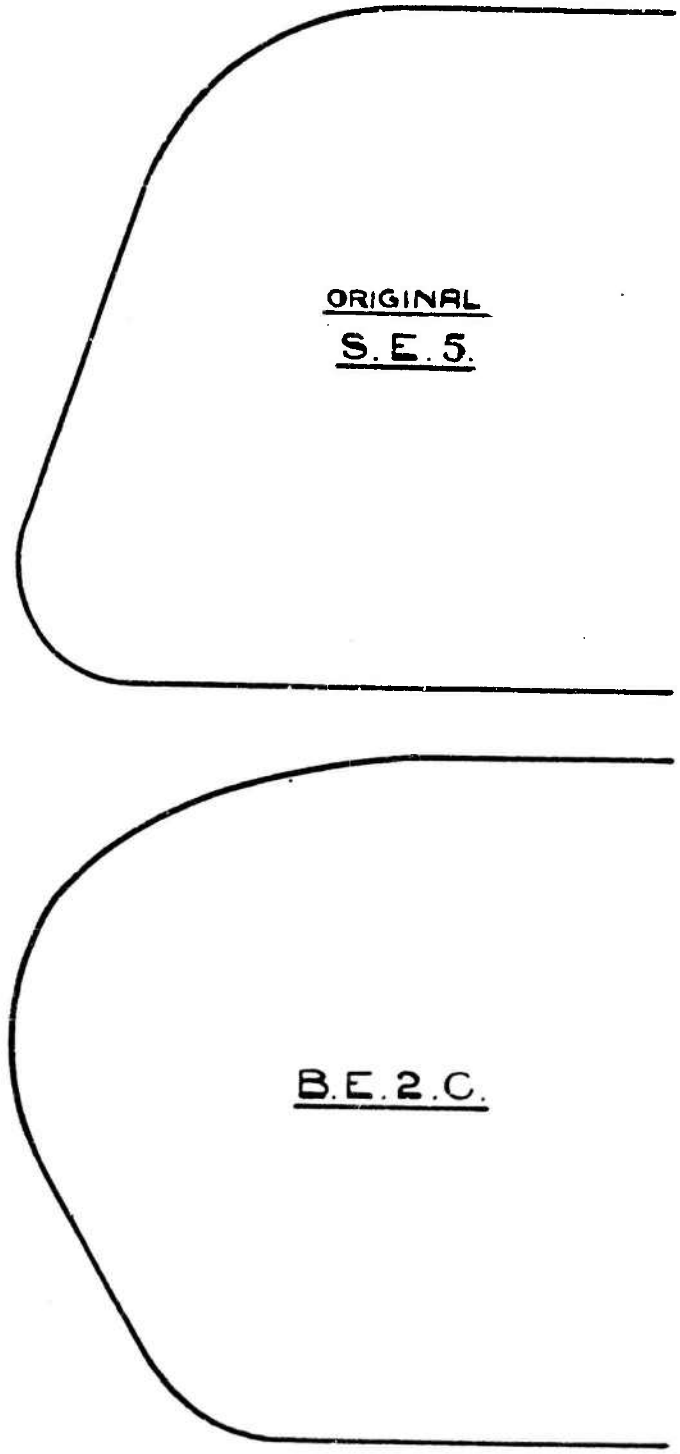
REPORT No 575. FIG: I.

# FORM OF WING TIPS



STANDARD DISTRIBUTION OF LOAD OVER A WING TIP