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Summary.—Previous measurements at high speeds made in the 12-in. Circular High Speed Tunnel of the lift, drag and pitching moment for an aerofoil with elevator have now been repeated for lift and moment with the gap between aerofoil and elevator sealed. It was found previously that there was no serious loss of control until a Mach number of $M = 0 \cdot 75$ to $0 \cdot 78$ was reached and this result has now been found to hold good for the "gap sealed" condition. Above $M = 0 \cdot 78$ the control, as measured by a_2 $(= \partial C_L / \partial \eta)$ falls rapidly, reaching one half its low-speed value at about $M = 0 \cdot 81$. This result holds good whether the gap is sealed or not. With the gap unsealed, a_2 was practically independent of Mach number at a value $3 \cdot 0$ from $M = 0 \cdot 45$ to $0 \cdot 73$; with the gap sealed the value of a_2 approximated to the value $3 \cdot 6/\sqrt{(1 - M^2)}$, following the Glauert formula, over the range $M = 0 \cdot 4$ to $0 \cdot 7$. The effect of sealing the gap is to increase a_2 by 40 per cent. at $M = 0 \cdot 4$ and 60 per cent. at $M = 0 \cdot 7$.

Introduction.—It had been suggested that compressibility effects on a tailplane elevator may be such as to cause serious loss of longitudinal control. In a report by Hilton, Pruden and Hyde[1] (1941) it was shown that at $M = 0 \cdot 8$ the lift of NACA 2417 was almost independent of the angle of incidence over a range of several degrees: it was thought possible therefore that a tailplane elevator might be insensitive to elevator angle.

Force measurements were therefore made on an EC 1240 symmetrical section aerofoil with a hinged flap, representing a tailplane and elevator. The elevator chord, measured to the hinge line, was $40 \cdot 5$ per cent. of the aerofoil chord. The tailplane incidence was varied by altering the incidence of the whole model, and the elevator incidence was set relative to the tailplane (Hilton and Knowler[2], 1941). There was a gap between aerofoil and elevator of $0 \cdot 01$ chords. Results have been published for this condition (Hilton and Knowler[3,4], 1943) but it has recently been found that the effectiveness of the elevator is increased by sealing the gap, especially at high speeds. Measurements were repeated therefore with the gap sealed, the results being given in this report. Moment results as well as lift results are quoted in full as such data are required for the study of the stresses produced by aileron operation at high speeds. The drag of a tailplane is of secondary importance, so no further measurements on drag have been made.

Experimental Details.—The shape of the aerofoil is given in Ref. 5 and details of the model are shown in Figs. 1A, 1B and 1C of this report. The elevator was attached by means of hinges which were sunk into the aerofoil and (except where they bridged the gap between elevator and aerofoil) were finished flush with the aerofoil surfaces.

The gap was sealed with plasticene which was blended to the adjoining surfaces. The elevator angle setting was altered by adjusting the grub screws A and B (Fig. 1B) which hold the elevator in position. The angle setting was deduced from measurements of the displacement of the trailing edge at right-angles to the chord. For this purpose, fine parallel scratches were ruled at the ends of the trailing edge and on to the end pieces in positions C and D (Fig. 1C). Measurements were made to the nearest $0 \cdot 001$ cm. with a travelling microscope at fixed distances along the end-pieces as defined by scratches (E, F and G) ruled at right angles to the trailing edge. The trailing edge by accident was slightly bowed in manufacture, the direction of the bow being such that the angle of setting, η, at the centre was about $\frac{1}{2}$ deg. less than at the ends.

* Includes A.R.C. 8041 and parts of A.R.C. 6532 and 7026.

The tests refer to an aerofoil of infinite aspect ratio, since the aerofoil spanned a closed tunnel. The end-pieces into which the aerofoil was built were nearly flush with the tunnel wall when the aerofoil was in position and the gear for changing the incidence and elevator setting and that for measuring the force on the aerofoil were outside the tunnel. Corrections were applied for the non-colinearity of the wind direction and the axis of the tunnel and for the constriction of the flow between the model and the tunnel walls. The constriction correction may possibly be in error when big shock waves are generated by the model at very high speeds and this error may affect the results. No correction was applied for the effect of humidity of the air, nor for end effects where the aerofoil passes through holes in the tunnel wall.

Measurements were made over a range of elevator settings approximately -6 to $+7$ deg. and for a range of angles of incidence -6 to $+6$ deg. To reduce the time involved in making the measurements, which was considerable, η settings between 0 and 3 deg. were omitted : this was justified by the smoothness of the results for the gap unsealed condition in this region. The absolute values of angles of incidence at which measurements were made were approximately 0, 2, 4, 5 and 6 deg. All the readings were repeated with the aerofoil reversed end for end, the difference between the results being employed as usual to deduce the correction for non-colinearity of wind direction and tunnel axis. After the application of this correction, the results for the aerofoil facing each way in turn were found to agree closely so it was considered unnecessary to give results for the two directions separately. If the aerofoil plus elevator were perfectly symmetrical, results for lift and moment for an elevator setting, η, would be the same as for a setting, $-\eta$, with the signs of C_L, C_m, α and η changed. The extent to which the asymmetry affects lift is illustrated at $M = 0 \cdot 5$ in Fig. 17 which is similar to Fig. 25 of Ref. 3. It refers to the gap-sealed condition.

The " aerodynamic " zero for lift was obtained by displacement of one set of curves laterally until the best agreement between the two was obtained ; it was found to be $0 \cdot 53$ deg. relative to the " geometrical " zero which was decided by the manufacture. The determination of the aerodynamic zero for moment results was made by displacing the C_m, η curves until C_m was zero for $\alpha = 0$ deg. and $\eta = 0$ deg. It was $0 \cdot 8$ deg. relative to the geometrical zero. The fact that it is greater than for lift is not surprising since moment is more sensitive than lift to camber near the trailing edge. Values of η given in this report are taken from the aerodynamic zero.

The final results in Figs. 2–12 are the mean of results for positive and negative elevator settings ; since the model is reversed end for end for both positive and negative settings, each curve is in effect the mean of four sets of observations.

The working section of the tunnel was modified between the taking of the results with the gap open and those with the gap closed; in the latter case the leakage round the ends of the aerofoil was greater. Repeat measurements, however, made with the gap open after the tunnel was modified showed that increased leakage has not affected the results to any appreciable extent.

Results for Lift.—The usual method of presenting lift results in the form of a " carpet " as a function of incidence and Mach number has been adopted. In the present report three variables are involved, *viz.* : incidence, α, Mach number and elevator setting η. As the most important factor in the working of an elevator or an aileron is the relation between lift and control setting the results are presented in the form of a " carpet " for two variables M and η, a separate " carpet " being given for each value of α.

The effect on the lift coefficient of sealing the gap is at once apparent. The elevator stall which began at $\alpha = \eta = 4$ deg. has been removed and at the same time the slope of the curves and hence the effectiveness of the elevator has increased noticeably.

When $\eta = 0$ deg. and the gap is sealed the results should be the same as those for an EC 1240 model with no elevator. It is therefore reasonable to make a comparison between these two sets of results ; this has been done for lift results in Fig. 12. The good agreement furnishes a check on the construction of the models and the consistency of the results.

Results for Moment.—The moment coefficients about the quarter-chord point are shown in " carpet " form in Figs. 7–11, a separate " carpet " being given for each angle of incidence.

Comparing Fig. 7 of the present report with Fig. 2 of Ref. 3 it will be seen that for the moments at $\alpha = 0$ deg. the C_m curves in the neighbourhood of $\eta = \pm 5$ deg. are not curved when the gap is sealed.

Results for Drag.—The C_D, η curves are given in Figs. 18–22, which are the same as Figs. 19–23 of Ref. 3. The exact form of the curves for $M = 0 \cdot 85$ is uncertain owing to the rapid variation of C_D with M at this speed ; the curves are therefore shown dotted.

Results for Lift Slope.—In Fig. 13 are graphs showing the relation between a_2 $(= \partial C_L/\partial \eta)$ and Mach number ; curves previously obtained for the gap unsealed condition are also given for comparison purposes on the same vertical scale. The increase due to sealing the gap is obvious. For speeds up to $M = 0 \cdot 75$ the value of a_2 is that found from the straight portion of the C_L, η curves. For higher speeds where the C_L, η curves are far from straight a mean slope has been taken. At the highest speeds the estimation of this mean is admittedly difficult but it can be seen that the value of a_2 can be altered considerably without appreciably affecting the form of the a_2, η curve. In Fig. 14 are given the a_1 $(= \partial C_L/\partial \alpha)$ curves in a form similar to that of the curves of a_2 against M. The remarks about the derivation of the values of a_2 apply *mutatis mutandis* to the derivation of the values of a_1.

The results in Fig. 13* shew that as the speed increases it becomes increasingly important to seal the gap if the highest elevator effectiveness is desired. The value of a_2 is approximately constant at $3 \cdot 0$ with the gap open, which suggests that the effect of the gap is to nullify the Glauert rise in lift. With the gap sealed the curve very approximately obeys the law $a_2 = 3 \cdot 6\ (1 - M^2)^{-1/2}$ over the whole range of the incidence tested. The loss of elevator effectiveness (as measured by a_2) was 40 per cent. at $M = 0 \cdot 4$ and 60 per cent. at $M = 0 \cdot 7$ respectively. The value of a_2 extrapolated to low speed is $3 \cdot 6$ with the gap sealed, representing a 25 per cent. increase over the extrapolated value $3 \cdot 0$ for the gap open and is closer to the theoretical value for a thin plate with flap given by Glauert in R. & M. 1095[6] (1927).

From Fig. 14 it can be seen that sealing the gap has very little effect on a_1 ; the curves gradually rise to a maximum between $M = 0 \cdot 7$ and $0 \cdot 75$ and rapidly fall as the speed is increased just as with the gap unsealed. The maximum of a_1 occurs at a slightly higher Mach number and the fall is considerably less violent than that of a_2. The unequal effects of sealing the gap on a_2 and a_1 is reflected in the a_2/a_1 against M curves given in Fig. 16. The low-speed value $0 \cdot 72$ can be compared with the theoretical value given by Glauert[6], (1927) $0 \cdot 75$, for the same hinge position, and with the low-speed results found from atmospheric tunnels $0 \cdot 68$ (Bryant[8], 1942, Fig. 2). The effect of sealing the gap has therefore been to improve the agreement betweeen theoretical and experimental values. This is to be expected as flow through a gap is not allowed for in Glauert's analysis.

The atmospheric tunnel result with a very small gap which was open lies midway between the $M = 0 \cdot 4$ high-speed tunnel results for gap open and gap sealed positions.

Results for Moment Slopes.—The variation of $\partial C_m/\partial \eta$ with Mach number at various angles of incidence is shown in Fig. 15. The effect of sealing the gap can be seen, in general, to result in an increase in the absolute value of $\partial C_m/\partial \eta$. Above $M = 0 \cdot 75$ the effect of sealing the gap does not appear to be consistent, as at 0 and $-$ 2 deg. the absolute value of $\partial C_m/\partial \eta$ is increased, while at $-$ 4 and $-$ 6 deg. it is decreased. The value of $\partial C_m/\partial \eta$ at these high speeds, however, is subject to considerable error due to the wide departure of the C_m, η curves from linearity.

Conclusions.—The main conclusion to be drawn from previous results with the gap open was that the sensitivity of elevator and aileron controls should not be appreciably affected until a Mach number of $M = 0 \cdot 75$ to $0 \cdot 78$ is reached ; above this speed a_2 fell rapidly reaching one half of its low-speed value at about $M = 0 \cdot 81$. With the gap unsealed, a_2 was practically independent

*There is some difference between the present curve for $\partial C_L/\partial \eta$ at zero incidence and the corresponding curve in Ref. 4. This arises from the fact that in Ref. 4 measurements were made at zero incidence only ; in the present results measurements at other incidences were made and the results smoothed.

of Mach number at a value $3 \cdot 0$ from $M = 0 \cdot 45$ to $0 \cdot 73$; with the gap sealed the value of a_2 approximated to the value $3 \cdot 6/\sqrt{(1 - M^2)}$ thus following the Glauert formula over the range $M = 0 \cdot 4$ to $0 \cdot 7$. The effect of sealing the gap is to increase a_2 by 40 per cent. at $M = 0 \cdot 4$ and 60 per cent. at $M = 0 \cdot 7$.

Applicability of Results to Flight Conditions.—It should be noted that results obtained on the electrical balance in the 12-in. Circular High Speed Tunnel have not the same accuracy when applied to flight conditions as those obtained in the atmospheric or compressed-air tunnels. Among the errors which may arise are those due to (*a*) possible breakaway of the flow at the point where the aerofoil passes through the walls of the tunnels, (*b*) the presence of condensed moisture in the air which is not allowed for in the calculation of tunnel speed and (*c*) difference between test and flight Reynolds number. (The Reynolds number of the present tests in the High Speed Tunnel with 2-in. aerofoil varies from $0 \cdot 5$ to $0 \cdot 75$ millions.)

One of the effects of (*a*) is to increase the measured drag of the aerofoil over a range from about $M = 0 \cdot 55$ to the shock stall as shown by comparison with the results of pitot traverse; also the drag coefficient in general increases more rapidly with speed than does the corresponding curve obtained by pitot traverse methods. The effect of (*b*) is to cause an under-estimation of the speed by an amount which increases progressively with speed and for which an estimate is 2–4 per cent. at $M = 0 \cdot 8$. With regard to (*c*) there may be quite a marked scale effect on the breakaway. These results are put forward, however, with the knowledge that it will be some time before suitable tests can be carried out at full scale values of R_e and M on a tailplane elevator. It should be pointed out that the ordinary stall on plain aerofoils without elevators tested in the High Speed Tunnel occurs at an unusually low incidence. Thus NACA 0020 stalls at 10 deg. according to the High Speed Tunnel results published by Hilton[7] (1946), Fig. 10A. This may be an effect of compressibility or of the tunnel on the breakaway.

The observations and the laborious work of their reduction were carried out with the assistance of several members of the staff of the High Speed Tunnel.

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No.	*Author*	*Title, etc.*
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7	W. F. Hilton	An Experimental Analysis of the Forces of Eighteen Aerofoils at High Speeds. R. & M. 2058. May, 1946.
8	L. W. Bryant	A Summary of some Recent Model Researches on Control Characteristics. A.R.C. 6177. October, 1942. (Unpublished.)

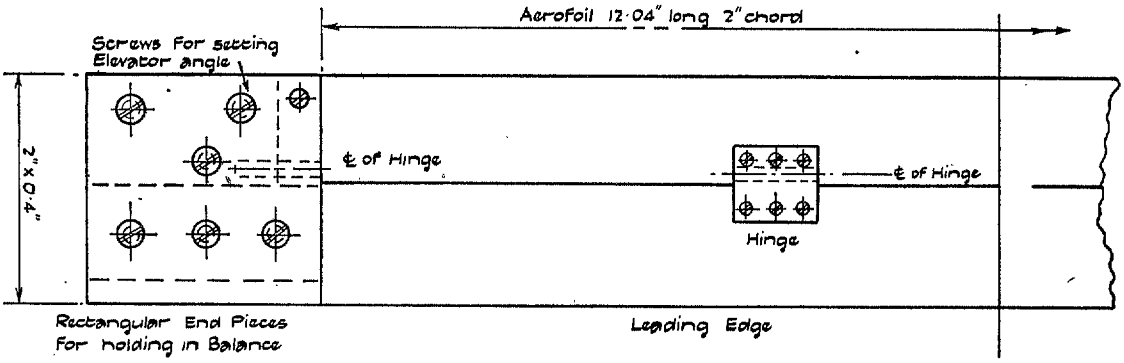


FIG. 1A.

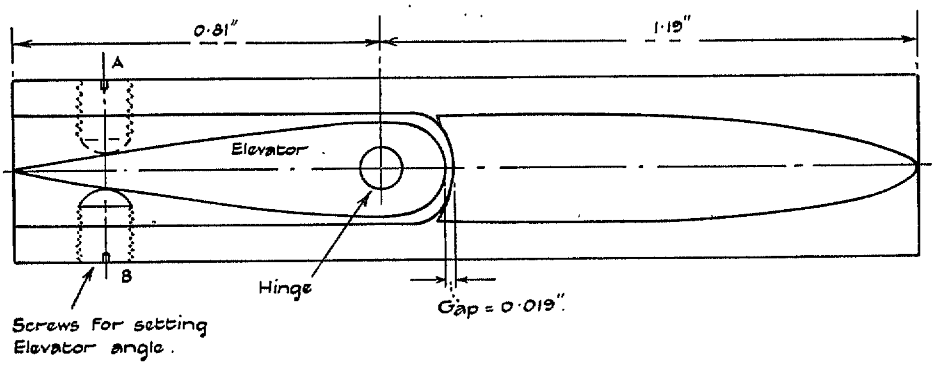


FIG. 1B. EC 1240 Aerofoil with Hinged Flap.

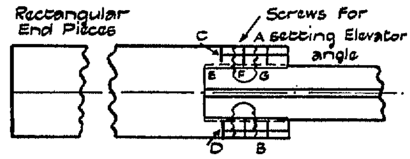


FIG. 1C. Detail of End Piece.

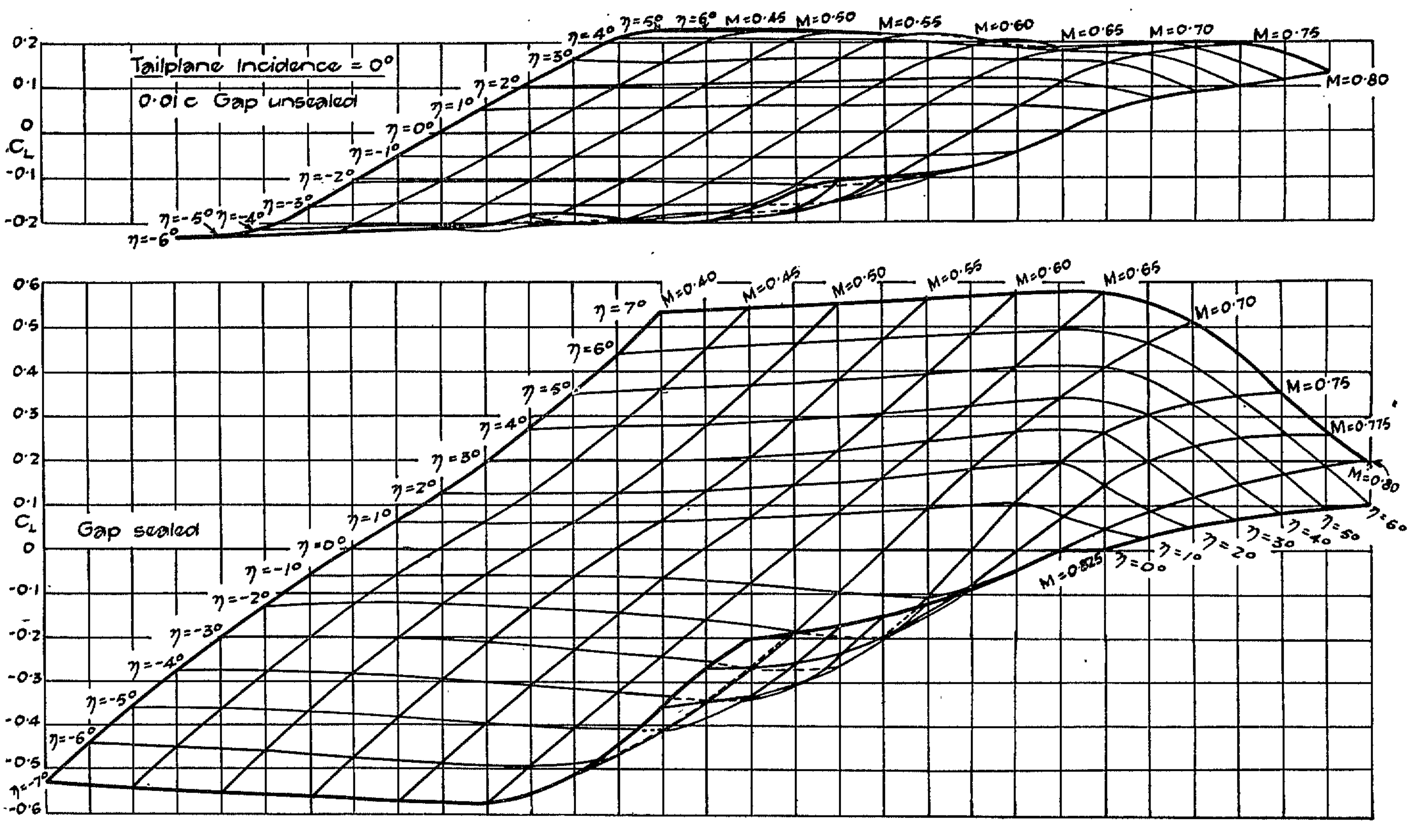


FIG. 2. EC 1240 Aerofoil with Elevator. Variation of Lift Coefficient (C_L) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 0$ deg.

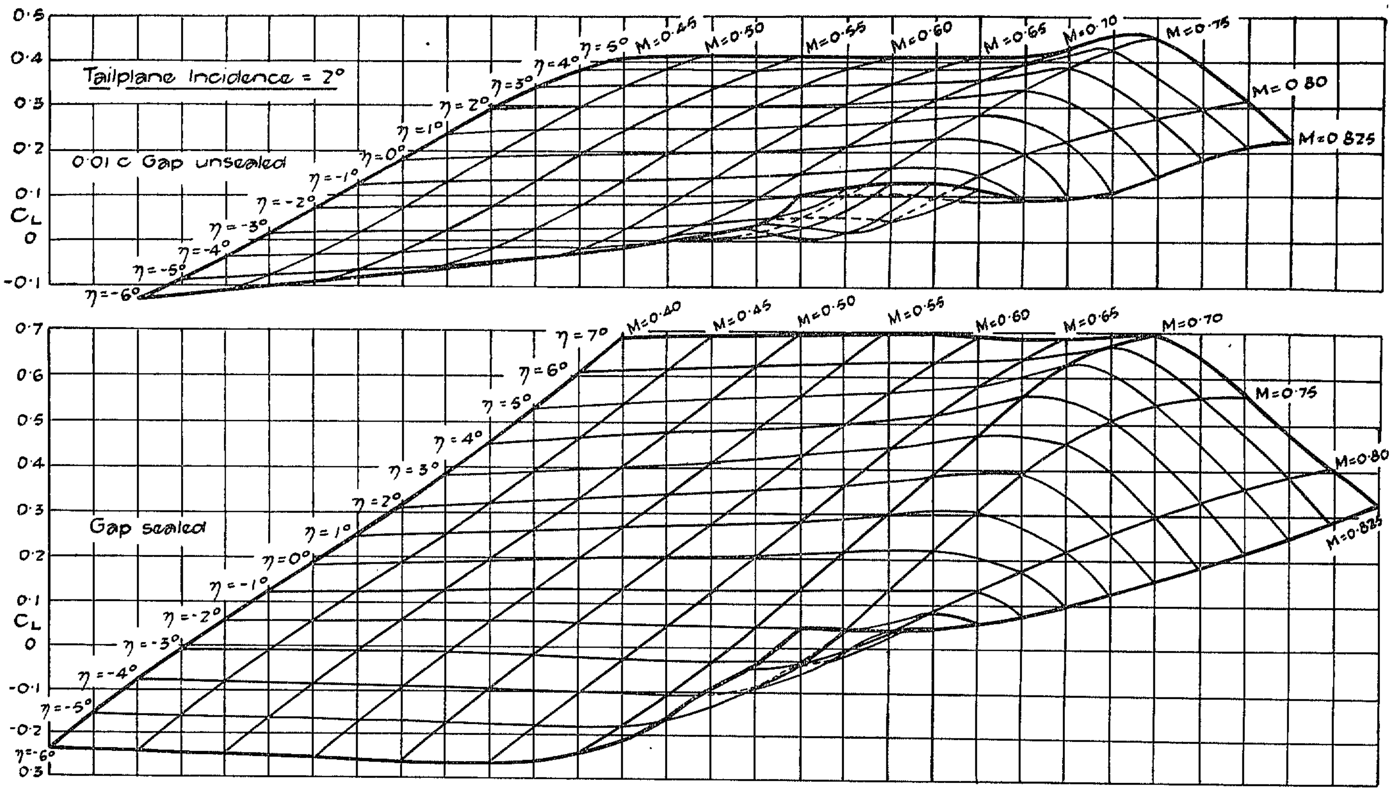


FIG. 3. EC 1240 Aerofoil with Elevator. Variation of Lift Coefficient (C_L) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 2$ deg.

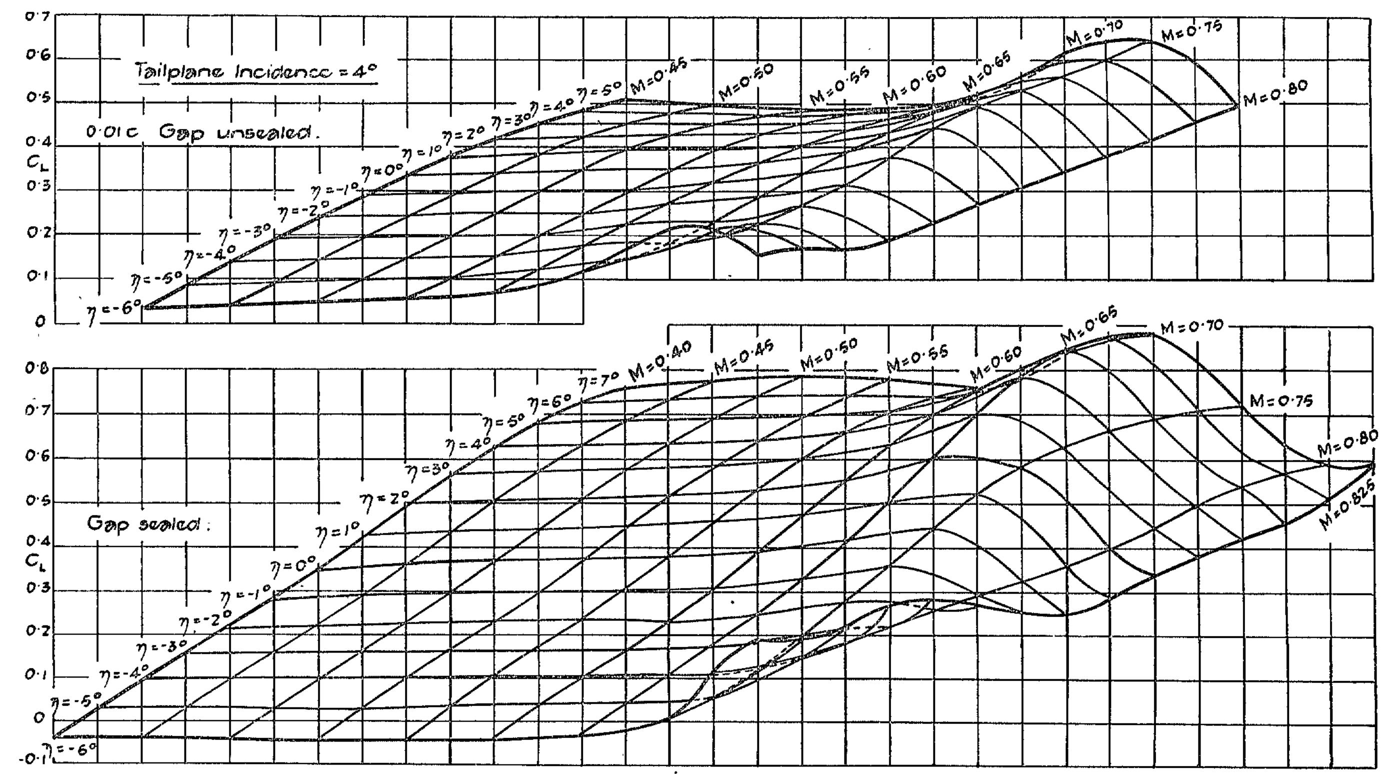


FIG. 4. EC 1240 Aerofoil with Elevator. Variation of Lift Coefficient (C_L) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 4$ deg.

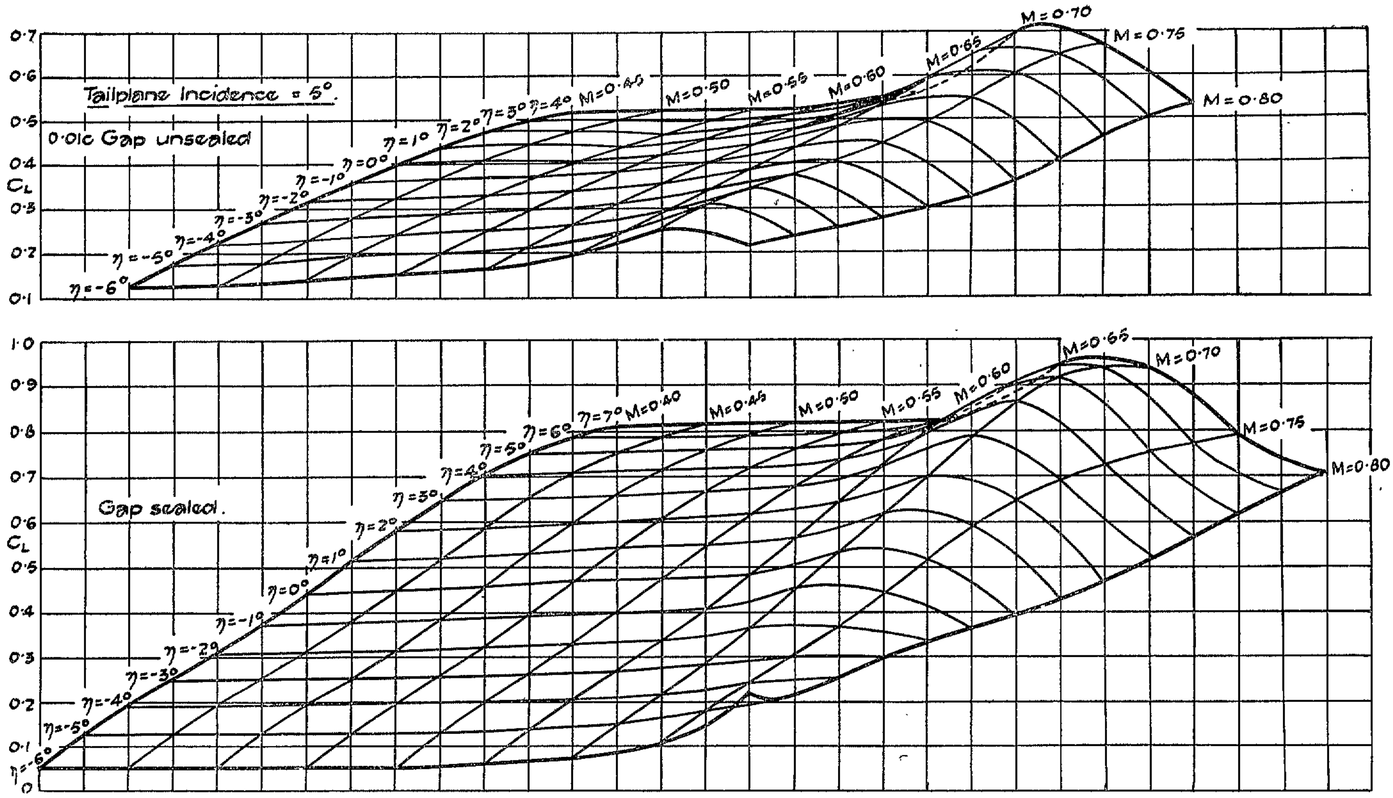


FIG. 5. EC 1240 Aerofoil with Elevator. Variation of Lift Coefficient (C_L) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence α = 5 deg.

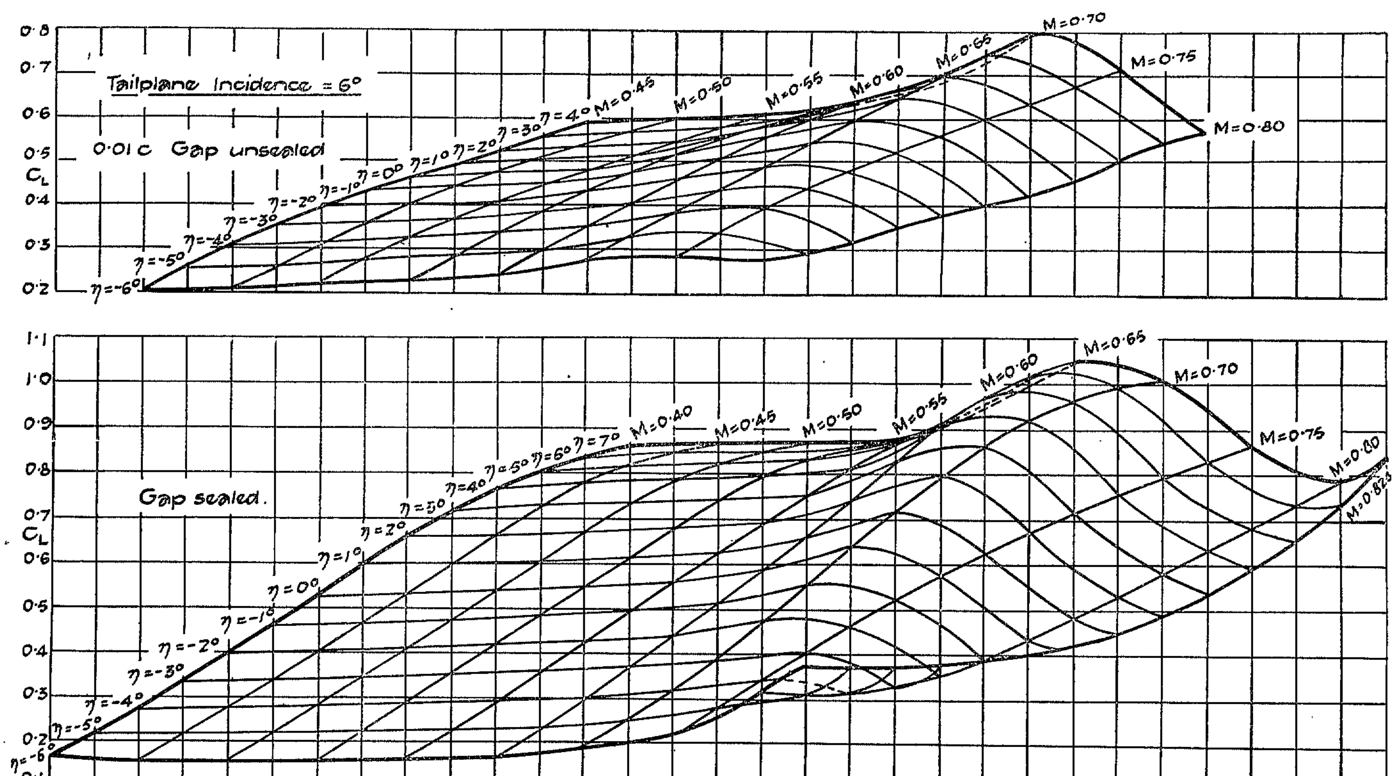


FIG. 6. EC 1240 Aerofoil with Elevator. Variation of Lift Coefficient (C_L) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence α = 6 deg.

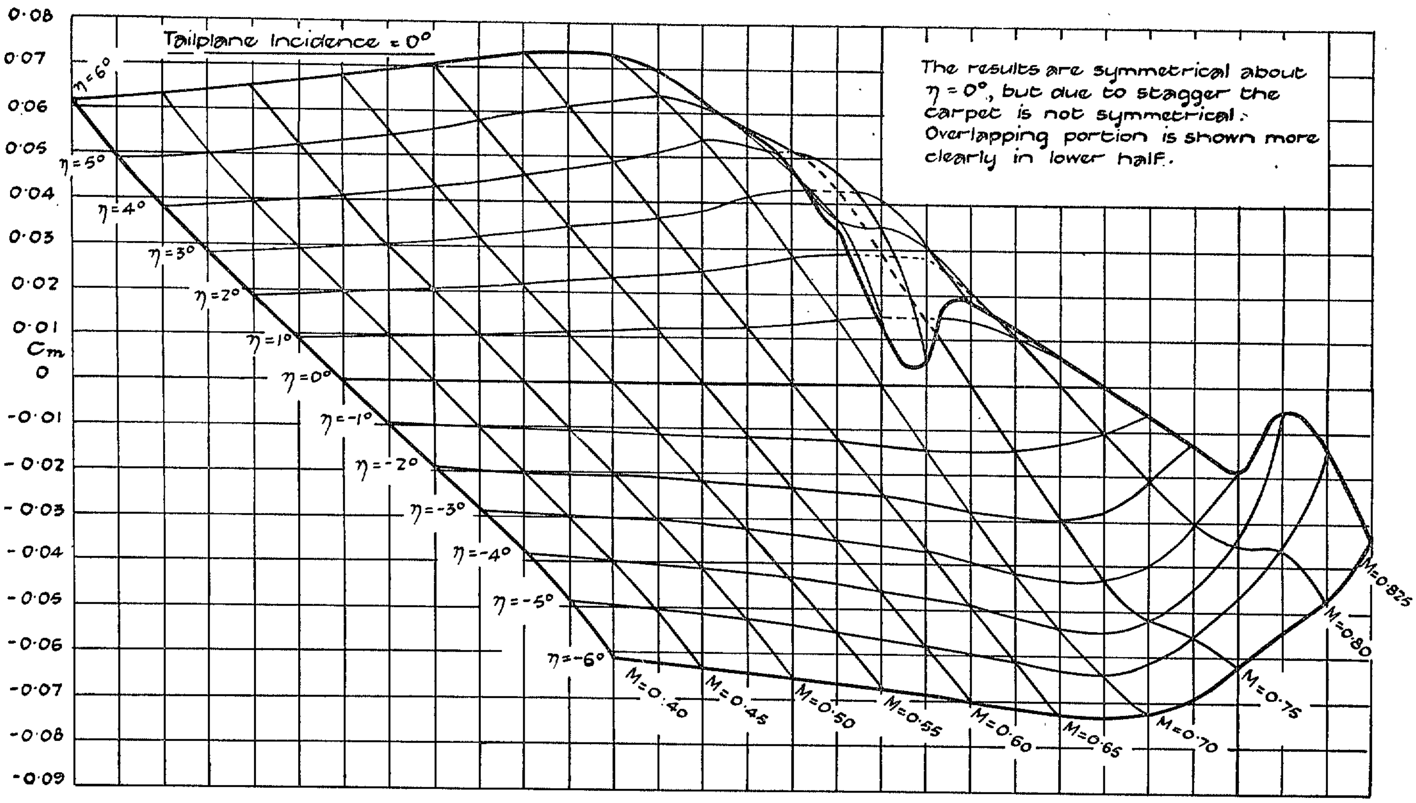


FIG. 7. EC 1240 Aerofoil with Elevator. Variation of Moment Coefficient (C_m) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 0$ deg.

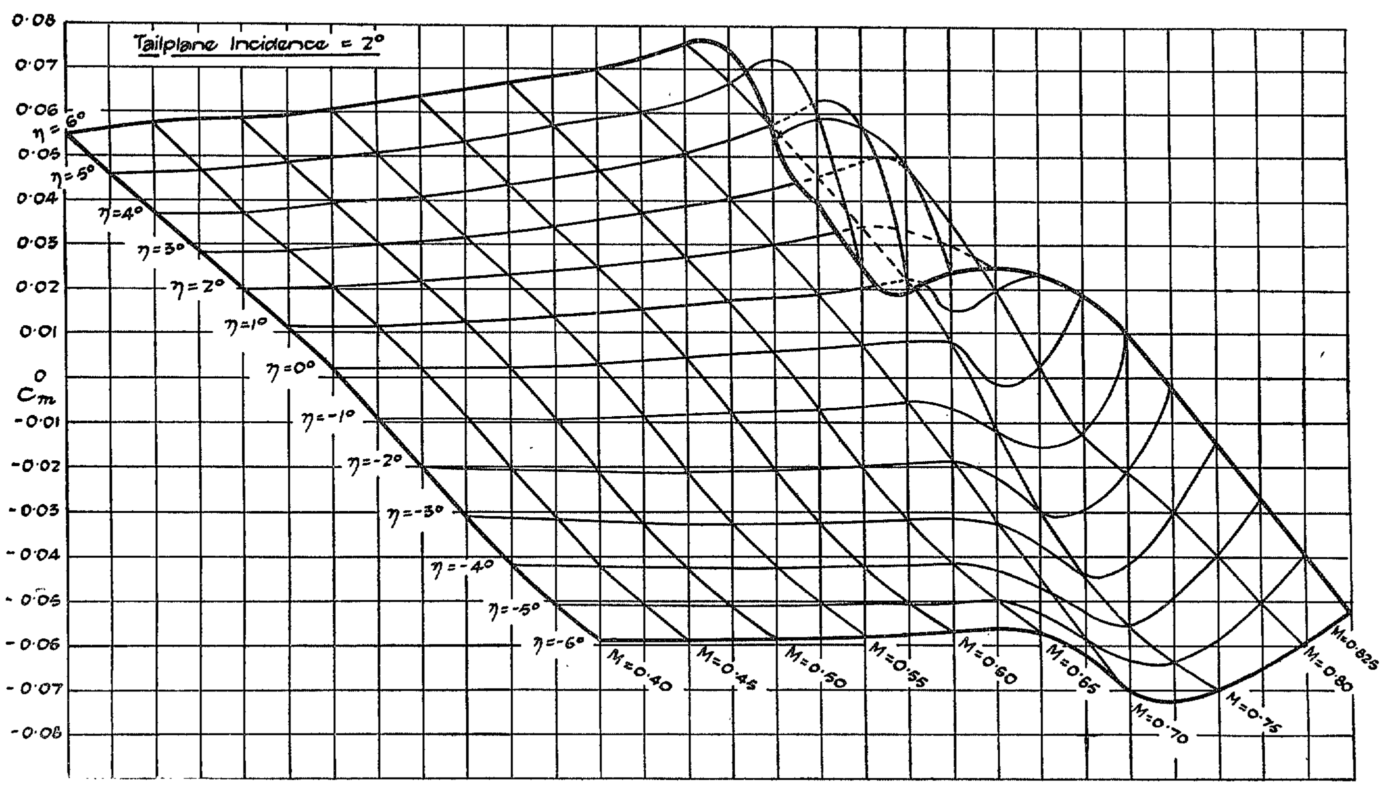


FIG. 8. EC 1240 Aerofoil with Elevator. Variation of Moment Coefficient (C_m) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 2$ deg.

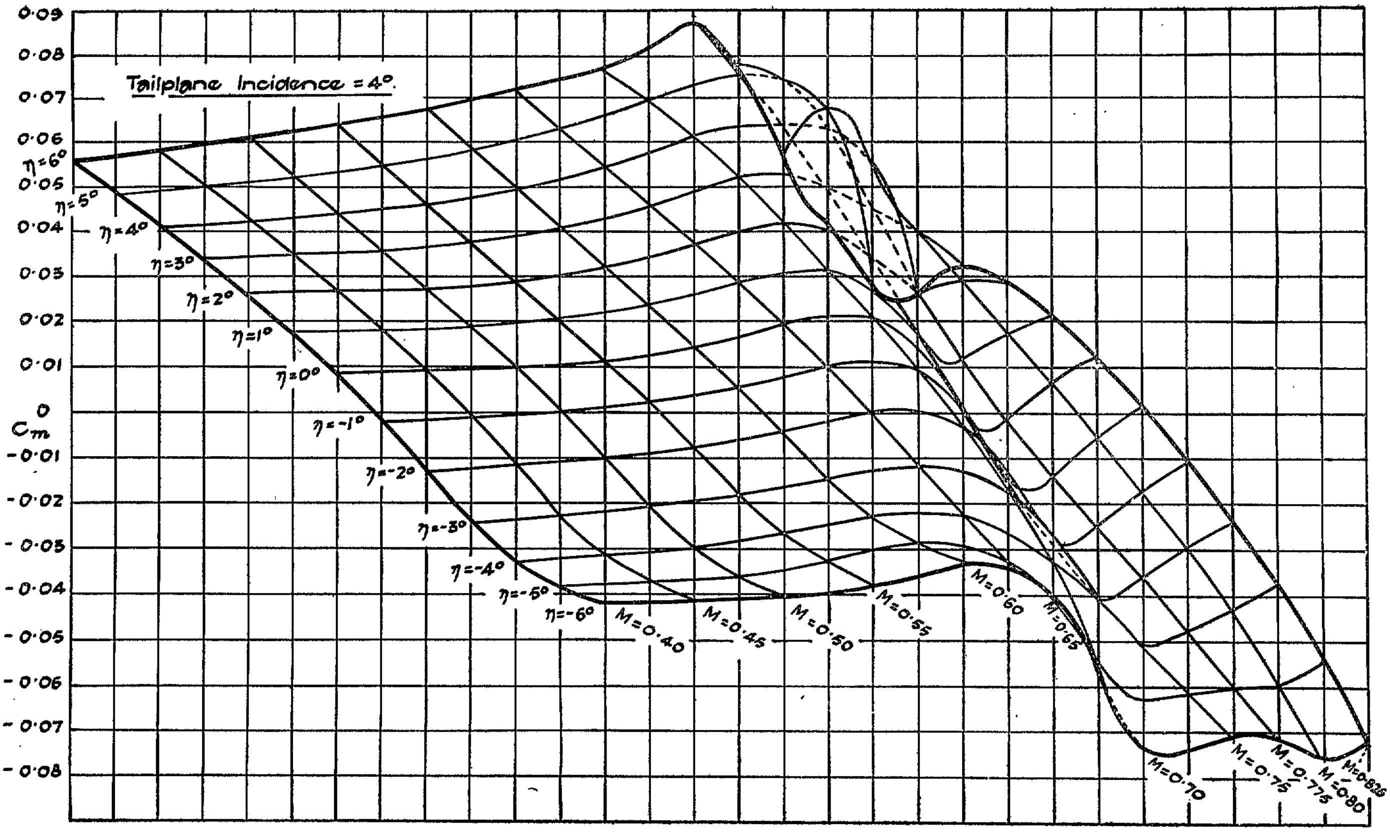


FIG. 9. EC 1240 Aerofoil with Elevator. Variation of Moment Coefficient (C_m) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 4$ deg.

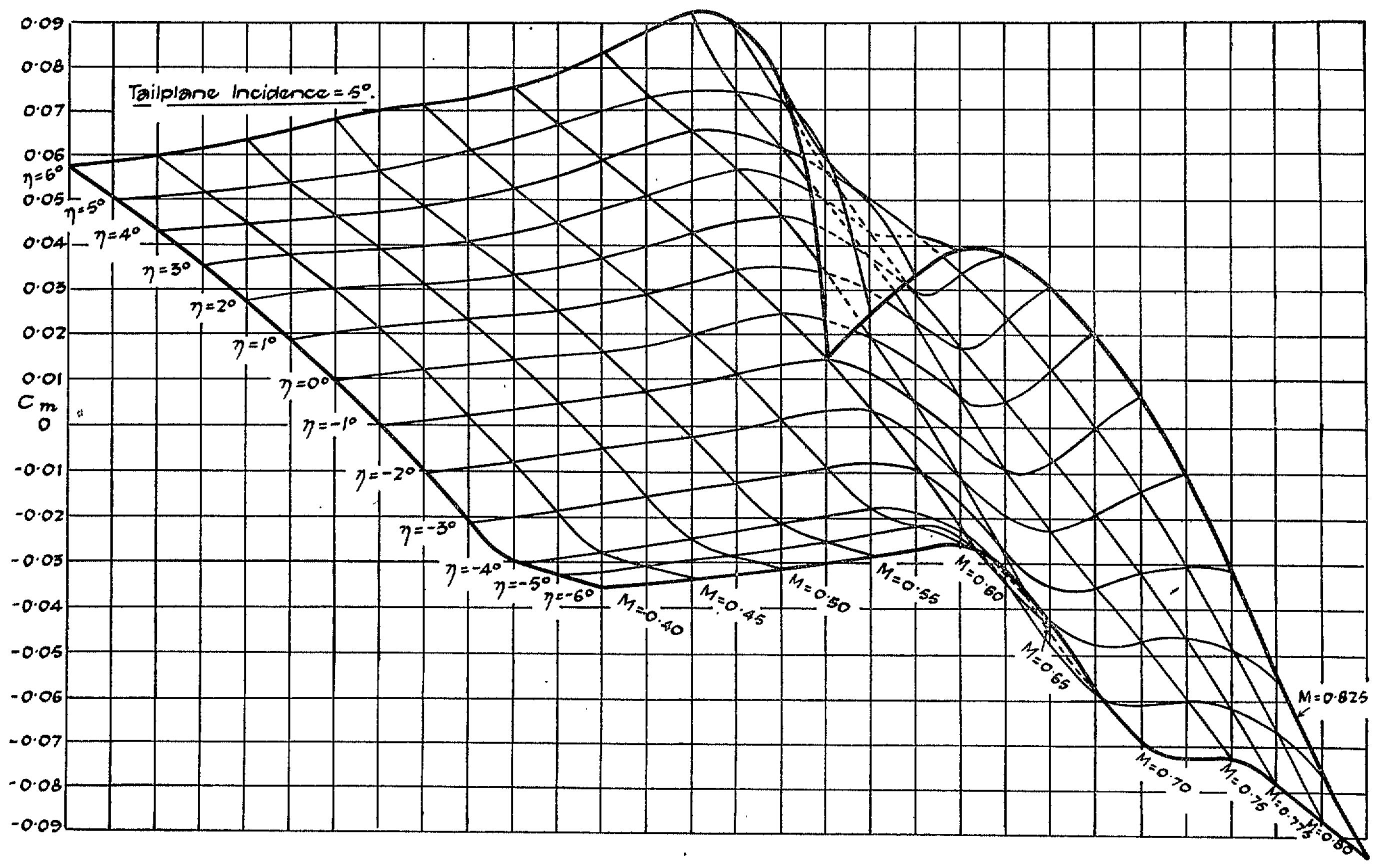


FIG. 10. EC 1240 Aerofoil with Elevator. Variation of Moment Coefficient (C_m) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 5$ deg.

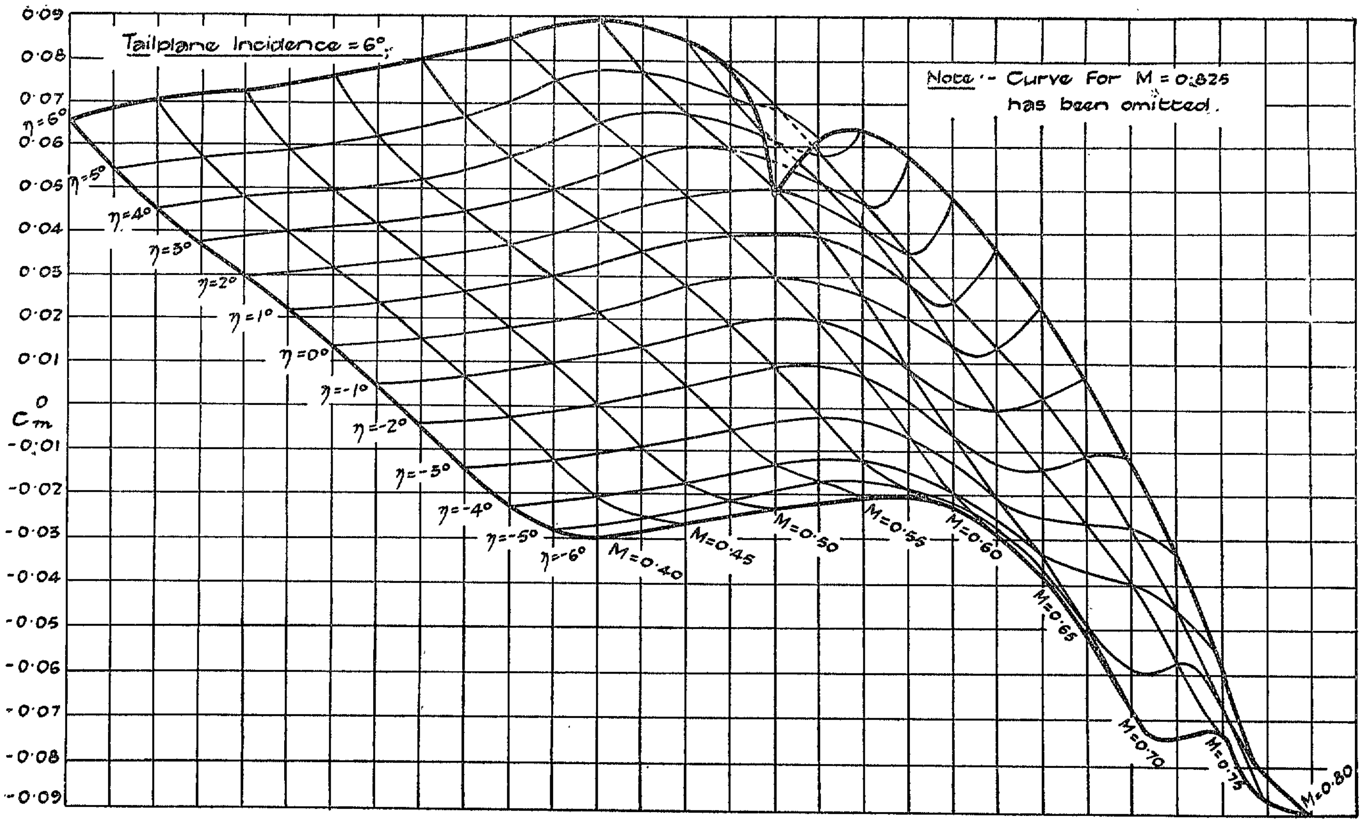


FIG. 11. EC 1240 Aerofoil with Elevator. Variation of Moment Coefficient (C_m) with Elevator Angle (η) and Mach Number (M), for Tailplane Incidence $\alpha = 6$ deg.

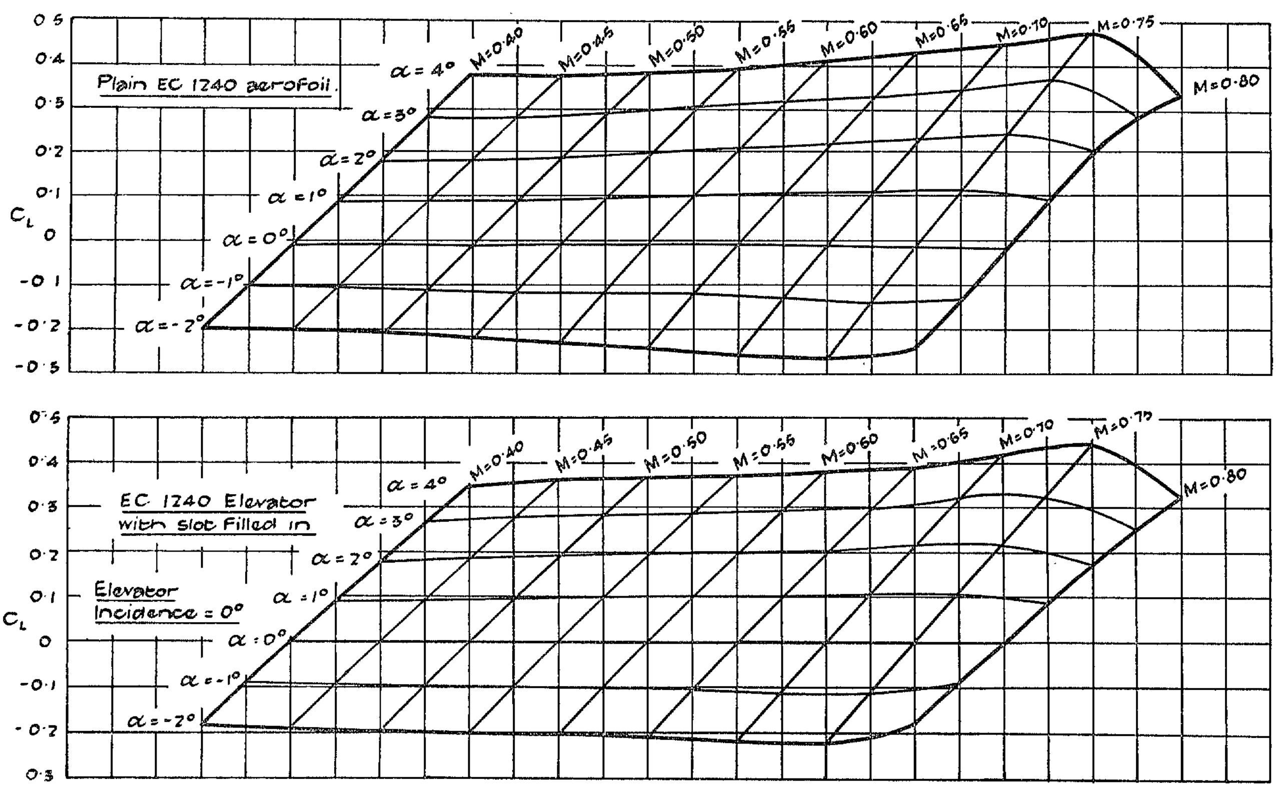
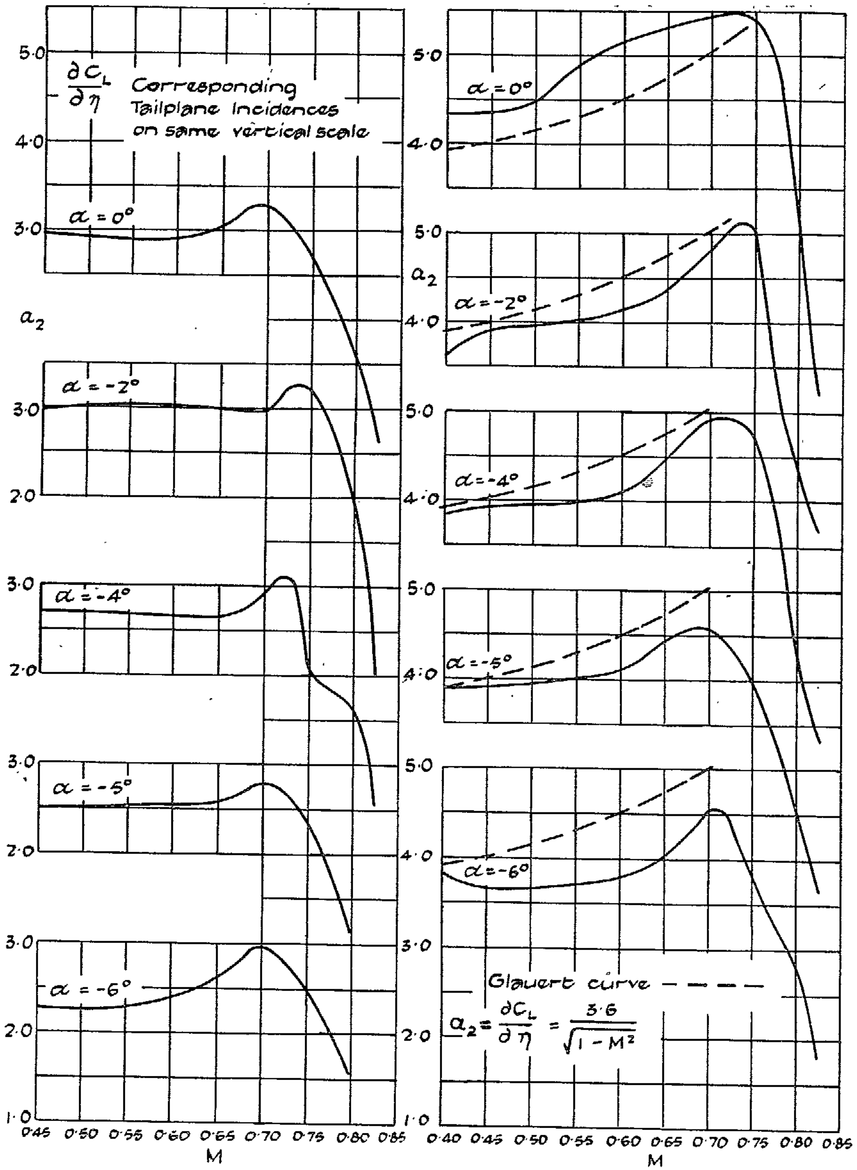
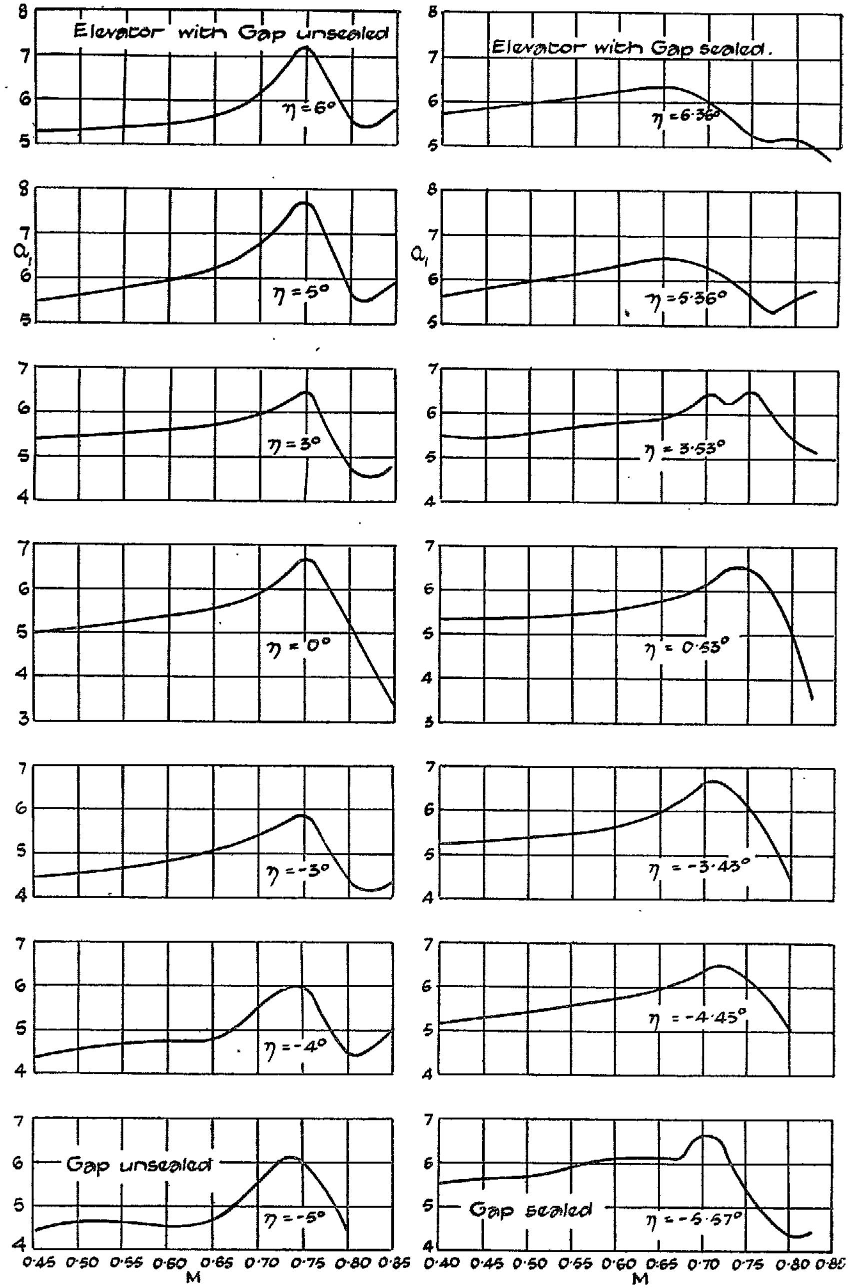


FIG. 12. Comparison of Lift Carpet for EC 1240 Aerofoil with Lift Carpet for EC 1240, Elevator at 0 deg.



Elevator with gap unsealed. Elevator with gap sealed.

FIG. 13. EC 1240 Elevator.
Variation of $a_2 = \partial C_L/\partial\eta$ (η in radians) with M for Various Values of α.



Elevator with gap unsealed. Elevator with gap sealed.

FIG. 14. EC 1240 Elevator.
Variation of $a_1 = \partial C_L/\partial\alpha$ (α in radians) with M for Various Values of η.

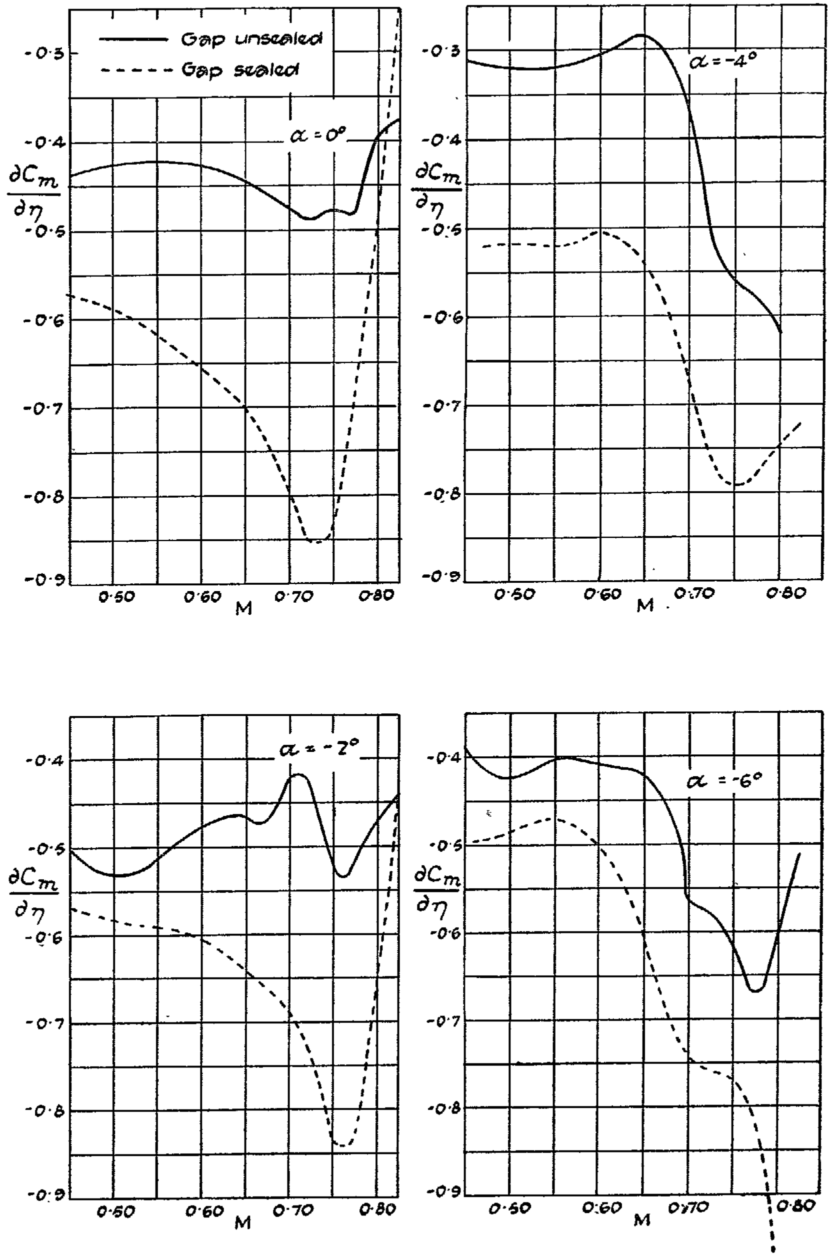


FIG. 15. Variation of $\partial C_m/\partial \eta$ (η in radians) with M for Various Values of α.

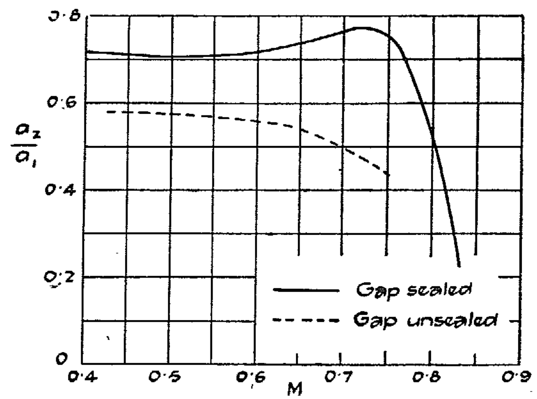


FIG. 16. Variation of a_2/a_1 with Mach Number.

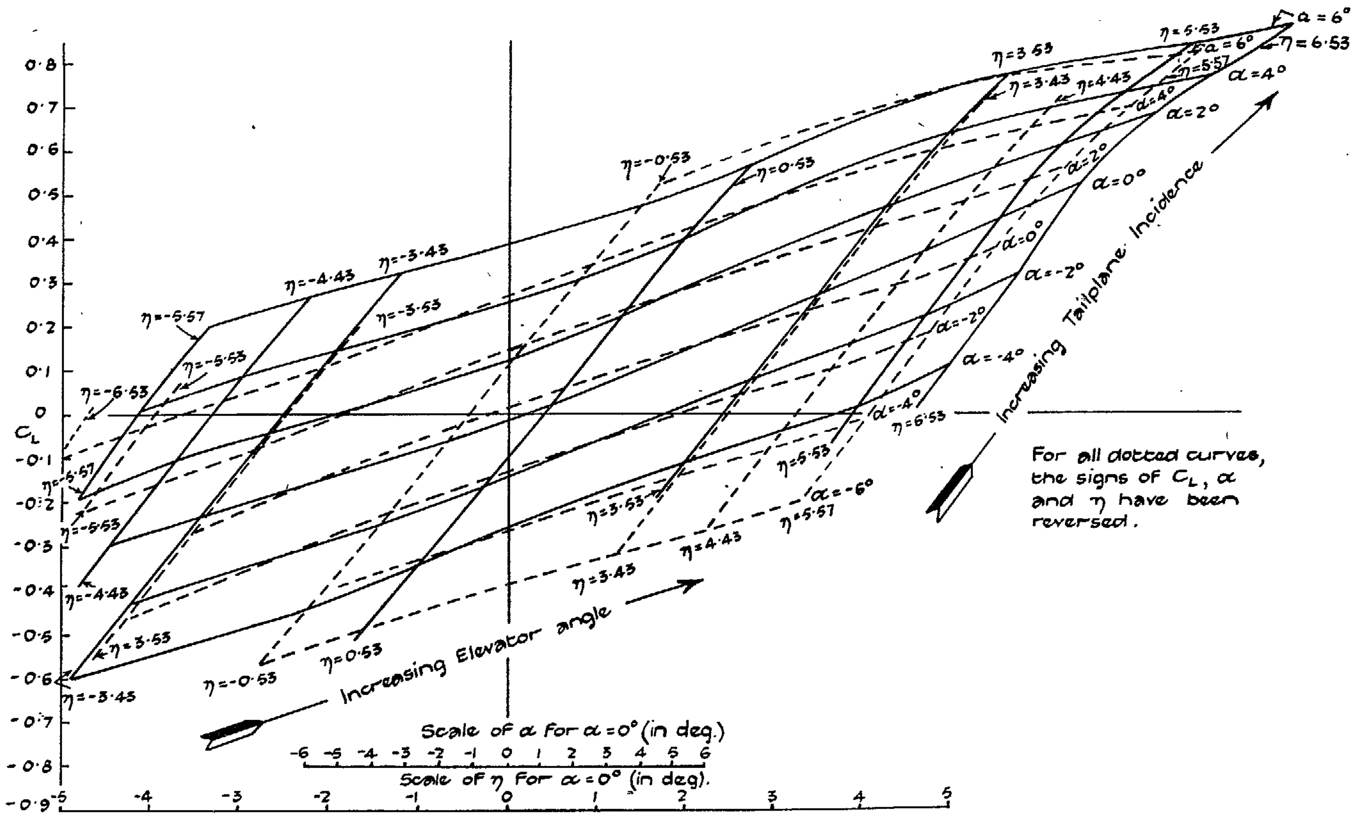


FIG. 17. Lift Curve for EC 1240 Tailplane—Elevator with Gap Sealed showing Variation of Lift Coefficient with Elevator Angle (η) and Incidence (α) $M = 0{\cdot}5$.

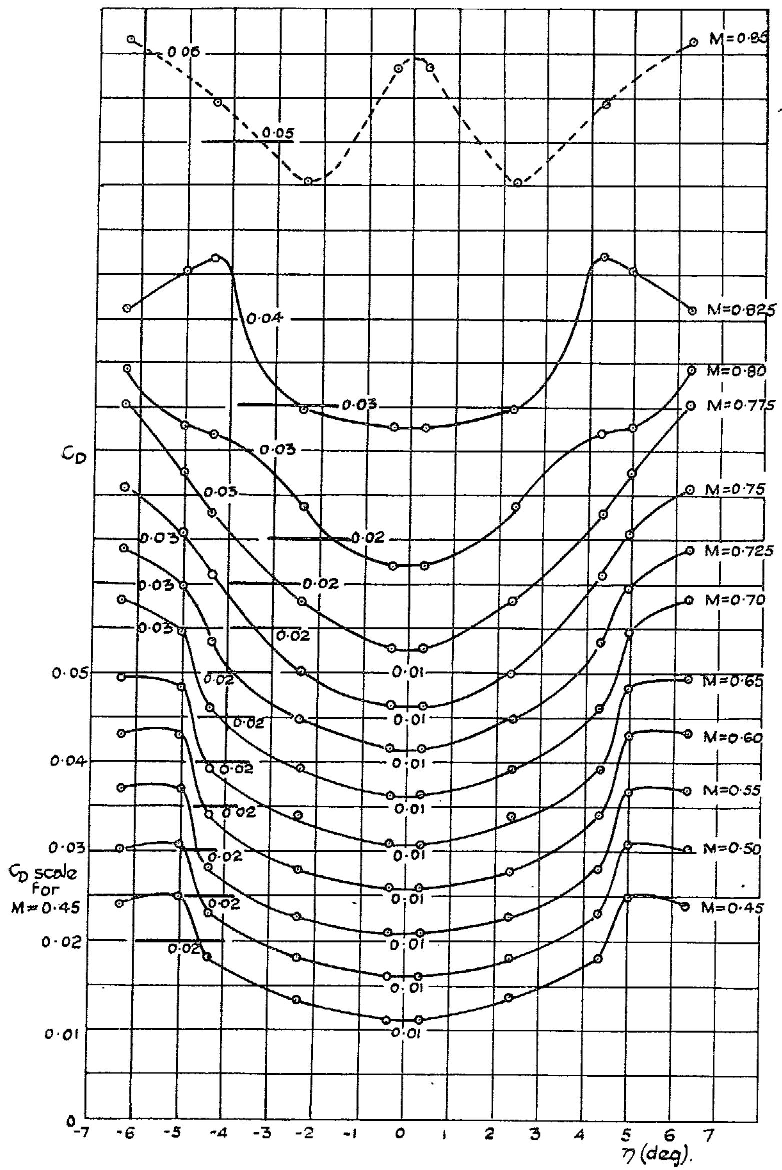


FIG. 18. Variation of Drag Coefficient with Elevator Angle for Tailplane Incidence 0 deg.

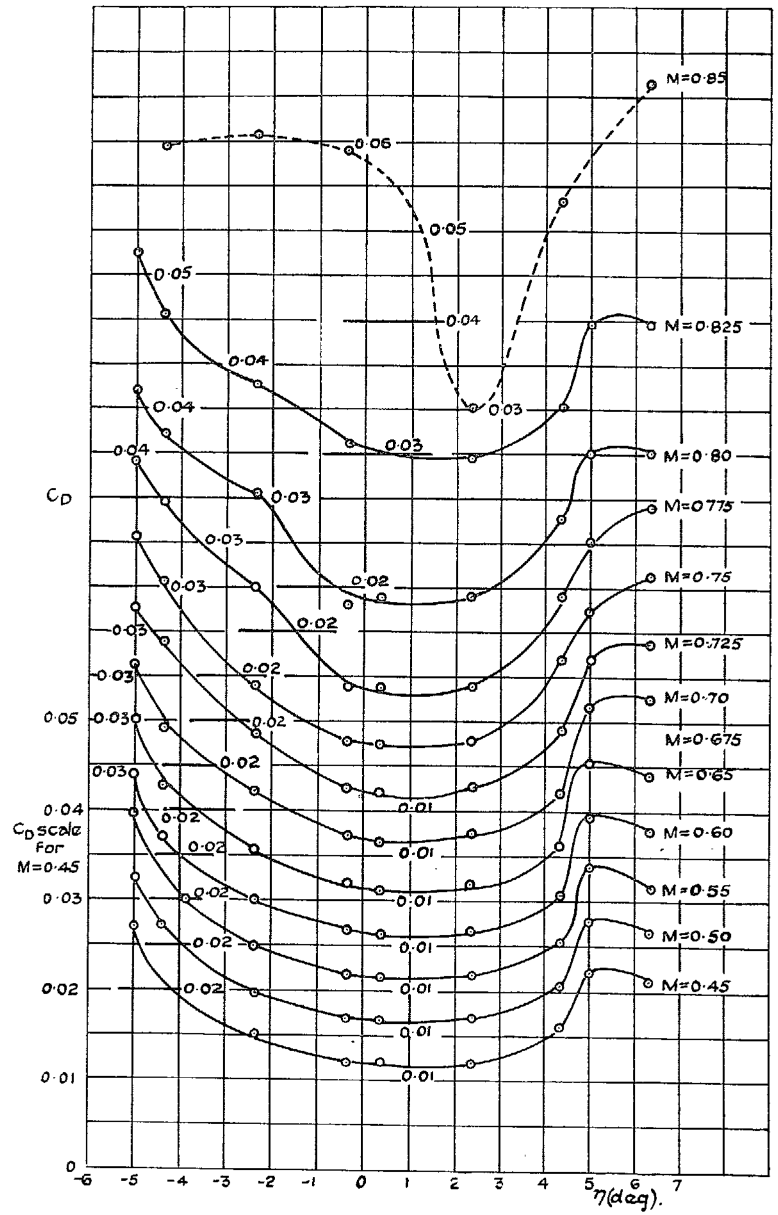


FIG. 19. Variation of Drag Coefficient with Elevator Angle for Tailplane Incidence — 1 deg.

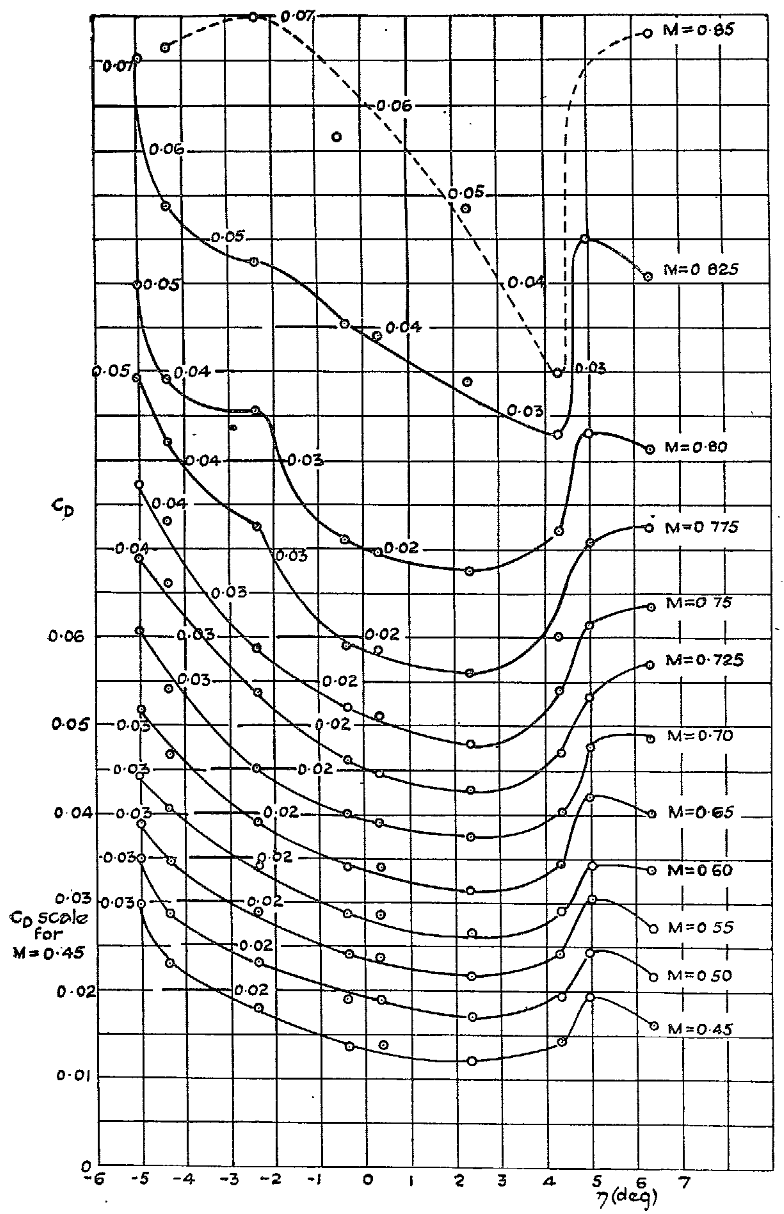


FIG. 20. Variation of Drag Coefficient with Elevator Angle for Tailplane Incidence — 2 deg.

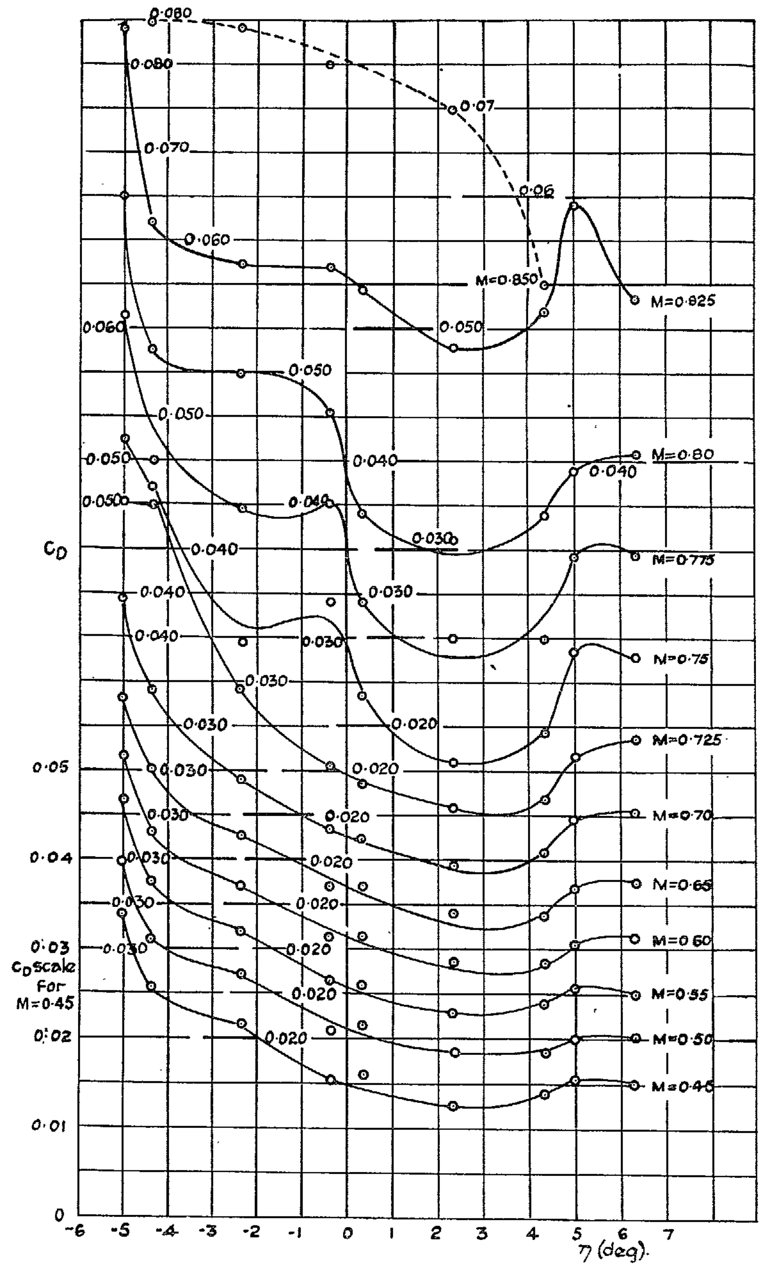


FIG. 21. Variation of Drag Coefficient with Elevator Angle for Tailplane Incidence — 3 deg.

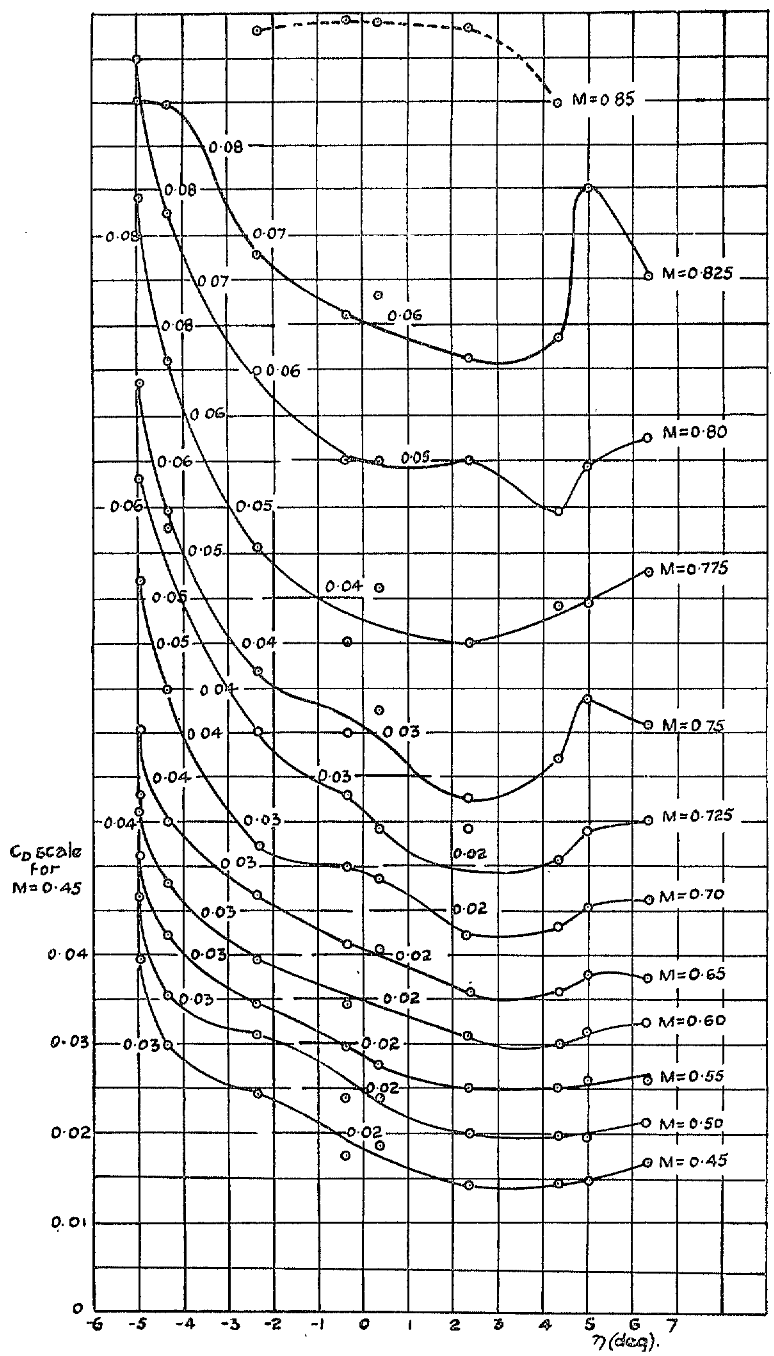


Fig. 22. Variation of Drag Coefficient with Elevator Angle for Tailplane Incidence — 4 deg.

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