RATE OF CHANGE OF LIFT COEFFICIENT WITH CONTROL DEFLECTION FOR FULL-SPAN PLAIN CONTROLS

This Item deals with plain-trailing-edge flaps when used as controls. For reference to Items that treat plain controls as part of a high-lift system, see the introductory information in Item No. 97002.

1. NOTATION AND UNITS

		SI	British
A	aspect ratio		
C_L	lift coefficient		
c	wing chord	m	ft
c_f	flap chord	m	ft
k_1	correction factor for wing thickness (see Equation (2.1))		
k_2	correction factor for Reynolds number (see Equation (2.1))		
M	free-stream Mach number		
R	Reynolds number based on aerodynamic mean chord of wing and free-stream velocity		
t	maximum thickness of wing section	m	ft
α	wing incidence	rad	rad
β	compressibility parameter, $(1-M^2)^{½}$		
δ	flap deflection angle in plane parallel to aircraft plane of symmetry*, positive downwards	rad	rad
$\Lambda_{½}$	sweepback of mid-chord line	degree	degree

Suffix

T	refers to theoretical value

* The flap deflection is usually specified in a plane normal to the hinge line. It follows that

$$\delta = \tan^{-1}(\tan\delta_H \cos\Lambda_h),$$

where δ_H is the deflection in the plane normal to the hinge line and Λ_h is the sweepback of the hinge line.

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2. NOTES

Throughout this Item the control is referred to as a wing trailing-edge flap although the Item is also applicable to a tailplane/elevator combination.

The flap effectiveness $\partial C_L/\partial\delta$ is presented in terms of the wing lift-curve slope $[\partial C_L/\partial\alpha]_T$, the wing and flap geometry, Reynolds number and free-stream Mach number for full-span plain flaps on straight-tapered wings having a constant flap chord/wing chord ratio along the span and no gap between wing and flap. The presentation is based on lifting-surface theory calculations, Derivation 11, with corrections for wing thickness and Reynolds number. It is applicable to subcritical wing flow and only to the linear part of the flap characteristic.

The rate of change of lift coefficient with flap deflection is expressed by

$$\frac{\partial C_L}{\partial\delta} = \left[\frac{\partial C_L}{\partial\delta}\bigg/\frac{\partial C_L}{\partial\alpha}\right]_T \left[\frac{\partial C_L}{\partial\alpha}\right]_T [1 - k_1 k_2]\,, \tag{2.1}$$

where $\left[\frac{\partial C_L}{\partial\delta}\bigg/\frac{\partial C_L}{\partial\alpha}\right]_T$ is given in Figure 1 in terms of $1/\beta A$ and c_f/c and is relatively independent of wing taper and sweepback; k_1, which relates to $R = 10^6$, corrects for thickness and is given by Figure 2 in terms of $(t/c)\sec\Lambda_{1/2}$ and c_f/c; k_2 corrects for Reynolds number and is given by Figure 3 in terms of $\log_{10} R$ and c_f/c. Item No. 70011 should be used to obtain $\left[\partial C_L/\partial\alpha\right]_T$.

The corrections for wing thickness and Reynolds number are derived from Item Nos Aero W.01.01.05 and Aero C.01.01.03. It is assumed that the aerofoil trailing-edge is wedge-shaped of angle equal to 100 t/c degrees. The dependence of k_1 on R and the dependence of k_2 on t/c are relatively small and have been neglected. Comparison with experiment shows that these assumptions are satisfactory, although for a section well away from the above conditions*, for example, one with a cusped trailing-edge, a significant error may be introduced.

For flaps of constant chord on tapered wings experimental evidence on split flaps (see Item No. 74009) suggests the use of a value of c_f/c appropriate to mid semi-span. The effect of a small gap between wing and flap is covered by Item No. Aero C.01.01.04.

Supporting experimental data for finite aspect ratio are contained in Derivations 1 to 10. The ranges of these data are shown on Figures 1 to 3. Although they represent only small proportions of the areas of the carpets, each of these carpets has been derived from wider variations of the parameters. Moreover, consistent agreement with experiment indicates that $\partial C_L/\partial\delta$ from this method is accurate to within ±0.2 rad^{-1}.

* For such cases it is advisable to use the full procedure of Item Nos Aero W.01.01.05 and Aero C.01.01.03 in replacing $[1–k_1k_2]$ by $[(a_2)_0/(a_2)_{0T\,t=0}]/[(a_1)_0/2\pi]$ in the notation of those Items where suffix $t = 0$ refers to an aerofoil of zero thickness.

3. DERIVATION

1.	AMES, M.B	Wind-tunnel investigation of two airfoils with 25-percent-chord Gwinn and plain flaps. NACA tech. Note 763, 1940.
2.	HOGGARD, H.P McKINNEY, E.G.	Wind-tunnel investigation of control-surface characteristics of plain and balanced flaps with several trailing-edge angles on an NACA 0009 tapered semispan wing. NACA tech. Note 1248, 1946.
3.	SCHNEITER, L.E NAESETH, R.L	Wind-tunnel investigation at low speed of the lateral control characteristics of ailerons having three spans and three trailing-edge angles on a semispan wing model. NACA tech. Note 1738, 1948.
4.	GURYANSKY, E.R. LIPSON, S.	Effect of high-lift devices on the longitudinal and lateral characteristics of a 45° sweptback wing with symmetrical circular-arc sections. NACA RM L8D06 (TIL 1923), 1948.
5.	JOHNSON, H.S. HAGERMAN, J.R.	Wind-tunnel investigation at low speed of an unswept untapered semispan wing of aspect ratio 3.13 equipped with various 25-percent-chord plain flaps. NACA tech. Note 2080, 1950.
6.	JOHNSON, H.S. HAGERMAN, J.R.	Wind-tunnel investigation at low speed of a 45° sweptback untapered semi-span wing of aspect ratio 1.59 equipped with various 25-percent-chord plain flaps. NACA tech. Note 2169, 1950.
7.	PASAMANICK, J. SELLERS, T.B.	Low-speed investigation of leading-edge and trailing-edge flaps on a 47.5° sweptback wing of aspect ratio 3.4 at a Reynolds number of 4.4×10^6. NACA RM L50E02 (TIL 2404), 1950.
8.	DODS, J.B. TINLING, B.E.	Summary of results of a wind-tunnel investigation of nine related horizontal tails. NACA tech. Note 3497, 1951.
9.	SMITH, D.W. REED, V.D.	Subsonic static longitudinal stability and control characteristics of a wing-body combination having a pointed wing of aspect ratio 2 with constant-percent-chord trailing-edge elevons. NACA RM A53C20 (TIL 3739), 1953.
10.	–	Unpublished wind-tunnel work at Aérospatiale, 1971.
11.	GARNER, H.C.	Unpublished theoretical work at the National Physical Laboratory, 1971.

4. EXAMPLE

Find the linear rate of change of lift coefficient with flap deflection at a Mach number of 0.4 for a wing with full-span sealed plain flaps for which $c_f/c = 0.25$. The straight-tapered wing has $A = 6$, $\Lambda_{½} = 32°$, λ (taper ratio) = 0.5, $t/c = 0.085$ and $R = 7 \times 10^6$.

From Item No. 70011, with $\lambda = 0.5$, $\beta A = (1 - 0.4^2)^{½} \times 6 = 5.50$ and $A \tan\Lambda_{½} = 6 \times \tan 32° = 3.75$,

$$\frac{1}{A}\left[\frac{\partial C_L}{\partial \alpha}\right]_T = 0.685$$

and, thus,

$$\left[\frac{\partial C_L}{\partial \alpha}\right]_T = 6 \times 0.685 = 4.11 \text{ rad}^{-1}.$$

From Figure 1, with $1/\beta A = 1/5.50 = 0.182$ and $c_f/c = 0.25$,

$$\left[\frac{\partial C_L}{\partial \delta}\Big/\frac{\partial C_L}{\partial \alpha}\right]_T = 0.636.$$

From Figure 2, with $c_f/c = 0.25$ and $(t/c) \sec \Lambda_{½} = 0.085 \times 1.179 = 0.100$,

$$k_1 = 0.16$$

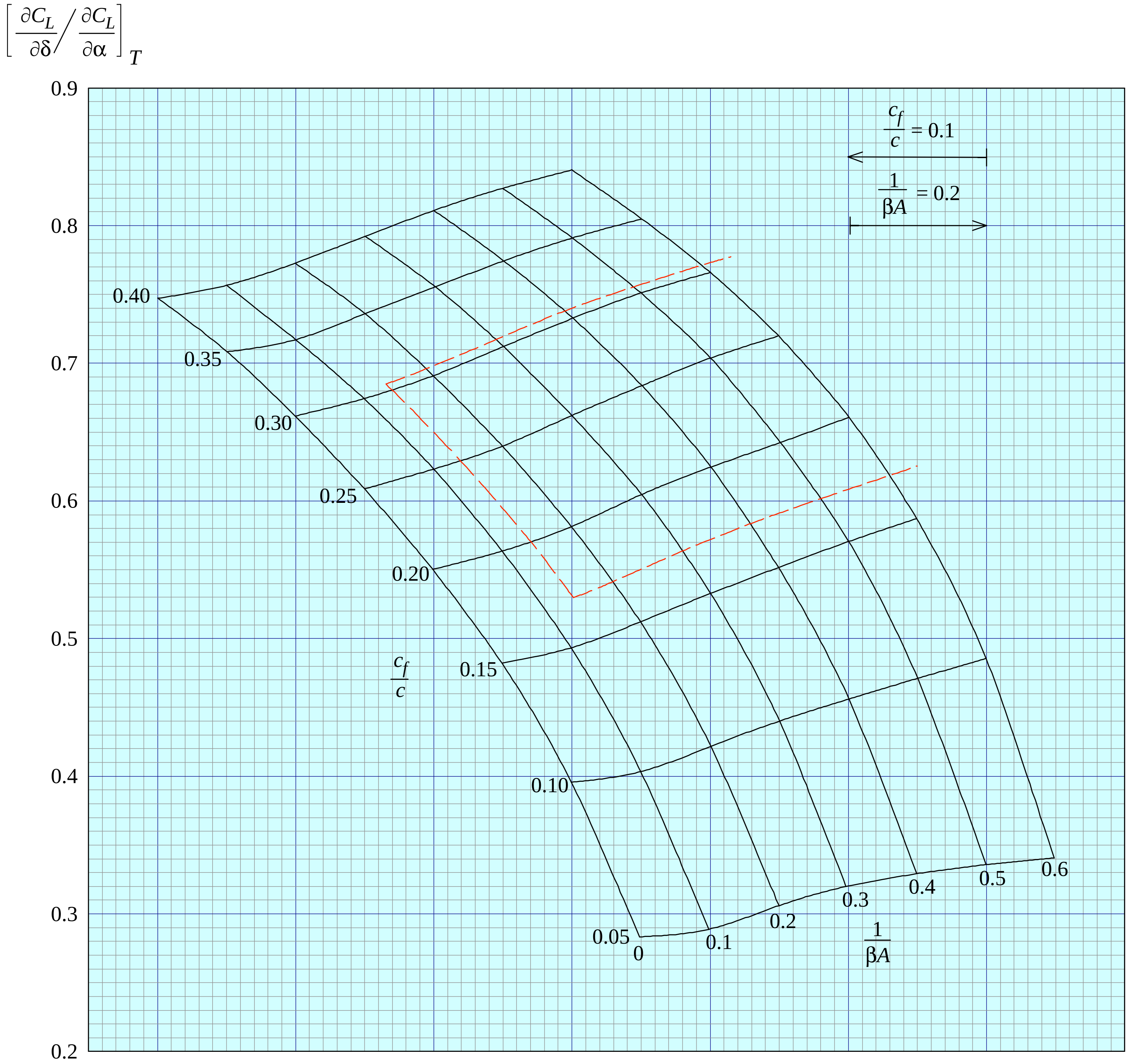
and from Figure 3, with $c_f/c = 0.25$ and $\log_{10} R = 6.845$,

$$k_2 = 0.56.$$

Hence, by Equation (2.1),

$$\frac{\partial C_L}{\partial \delta} = 0.636 \times 4.11 \times [1 - (0.16 \times 0.56)]$$

$$= 2.38 \text{ rad}^{-1}.$$



$\left[\frac{\partial C_L}{\partial \delta} \middle/ \frac{\partial C_L}{\partial \alpha}\right]_T$
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
$\frac{c_f}{c} = 0.1$
$\frac{1}{\beta A} = 0.2$
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
$\frac{c_f}{c}$
0
0.1
0.2
0.3
0.4
0.5
0.6
$\frac{1}{\beta A}$

FIGURE 1

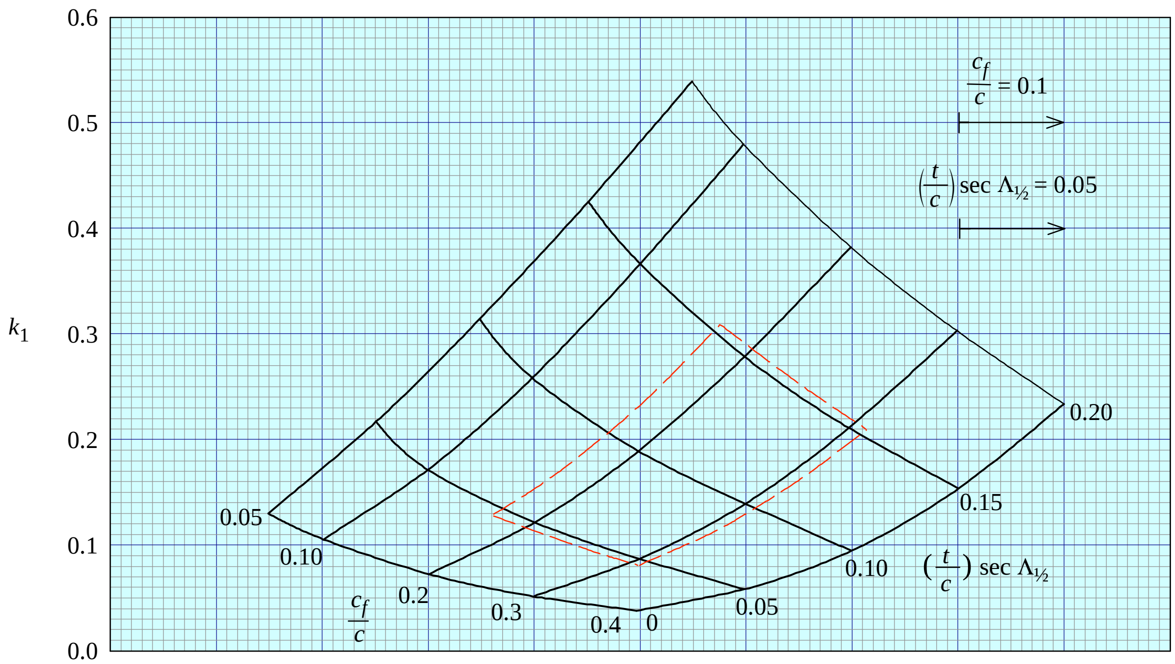


FIGURE 2

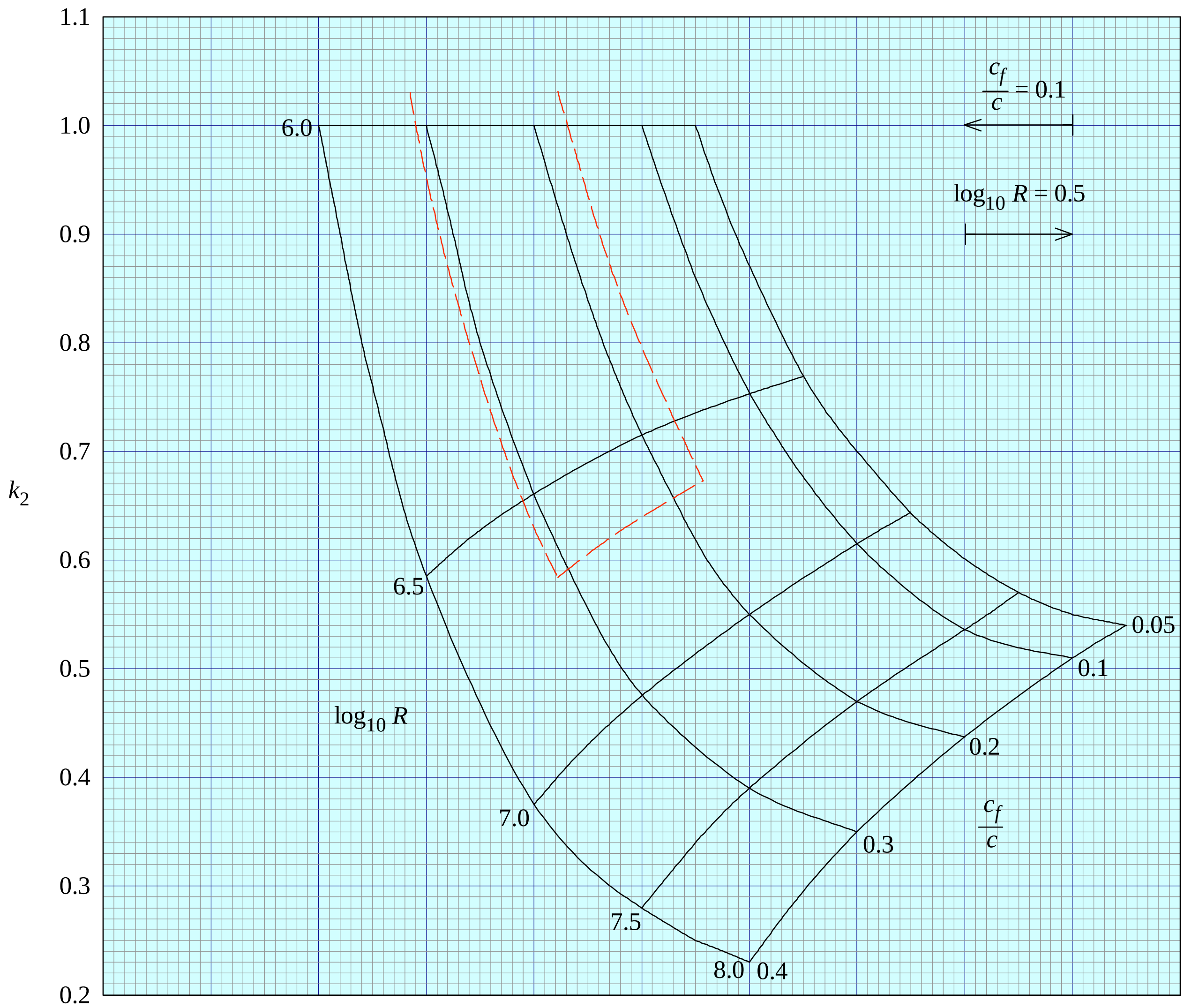


FIGURE 3

THE PREPARATION OF THIS DATA ITEM

The work on this particular Item which supersedes Item No. Aero C.01.01.06 was monitored and guided by the Aerodynamics Committee which first met in 1942 and now has the following membership.

Chairman
Mr E.C.Carter – Aircraft Research Association

Vice-Chairman
Prof. G.M. Lilley – Southampton University

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Prof. L.F. Crabtree – Bristol University
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Mr. J. Taylor – Hawker Siddeley Aviation Ltd, Woodford
Mr J.W.H. Thomas – Hawker Siddeley Aviation Ltd, Hatfield
Mr. J. Weir – Salford University.

The member of staff who undertook the technical work involved in the initial assessment of the available information and the construction and subsequent development of the Item was

Mr J.W. Allan – Senior Engineer.