



ESDU 89009

Issued July 1989

Supersedes ESDU Aero C.04.01.05
and in part ESDU Aero C.04.01.00

Hinge moment coefficient derivatives for trailing-edge controls on wings at subsonic speeds

ESDU Copyright material. For current status contact ESDU.



Documents

Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes ESDU Aero C.04.01.05 and in part ESDU Aero C.04.01.00 was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

Chairman	
Mr H.C. Garner	— Independent
Vice-Chairman	
Mr P.K. Jones	— British Aerospace (Commercial Aircraft) Ltd, Woodford
Members	
Mr G.E. Bean*	— Boeing Aerospace Company, Seattle, Wash., USA
Dr N.T. Birch	— Rolls-Royce plc, Derby
Mr E.A. Boyd	— Cranfield Institute of Technology
Mr K. Burgin	— Southampton University
Dr T.J. Cummings	— Short Brothers plc
Mr J.R.J. Dovey	— Independent
Mr L. Elmeland*	— Saab-Scania, Linköping, Sweden
Dr J.W. Flower	— Independent
Mr P.G.C. Herring	— Sowerby Research Centre, Bristol
Mr R. Jordan	— Aircraft Research Association
Mr J.H. Kraus*	— Northrop Corporation, Hawthorne, Calif., USA
Mr J.R.C. Pedersen	— Independent
Mr R. Sanderson	— Messerschmitt-Bölkow-Blohm GmbH, Bremen, W. Germany
Mr A.E. Sewell*	— McDonnell Douglas, Long Beach, Calif., USA
Mr M.R. Smith	— British Aerospace (Commercial Aircraft) Ltd, Bristol
Miss J. Willaume	— Aérospatiale, Toulouse, France.

* Corresponding Member

The technical work in the assessment of the available information and the construction and subsequent development of the Data Item was carried out by

Mr R.W. Gilbey — Senior Engineer.

HINGE MOMENT COEFFICIENT DERIVATIVES FOR TRAILING-EDGE CONTROLS ON WINGS AT SUBSONIC SPEEDS

CONTENTS

	Page
1. NOTATION AND UNITS (SEE SKETCH 1.1)	1
2. INTRODUCTION	4
3. METHOD	4
3.1 Basic Equations	4
3.2 Derivative b_1	5
3.3 Derivative b_2	5
3.4 Rectangular Wing	6
3.5 Sectional Properties	6
4. ACCURACY AND APPLICABILITY	7
4.1 Accuracy	7
4.2 Applicability	7
5. DERIVATION	9
6. EXAMPLE	12

HINGE MOMENT COEFFICIENT DERIVATIVES FOR TRAILING-EDGE CONTROLS ON WINGS AT SUBSONIC SPEEDS

1. NOTATION AND UNITS (see Sketch 1.1)

		SI	British
A	aspect ratio		
$(a_1)_0$	lift-curve slope with angle of attack for two-dimensional section in incompressible flow	rad^{-1}	rad^{-1}
$(a_2)_0$	lift-curve slope with control deflection for two-dimensional section in incompressible flow	rad^{-1}	rad^{-1}
b_1	hinge moment coefficient derivative $\partial C_H / \partial \alpha$	rad^{-1}	rad^{-1}
$(b_1)_0$	value of b_1 for two-dimensional section in incompressible flow	rad^{-1}	rad^{-1}
Δb_1	contribution from induced camber to b_1	rad^{-1}	rad^{-1}
b_2	hinge moment coefficient derivative $\partial C_H / \partial \delta$	rad^{-1}	rad^{-1}
b'_2	hinge moment coefficient derivative $\partial C_H / \partial \delta'$	rad^{-1}	rad^{-1}
$(b_2)_0$	value of b_2 for two-dimensional section in incompressible flow	rad^{-1}	rad^{-1}
Δb_2	contribution from induced camber to b_2	rad^{-1}	rad^{-1}
C_H	hinge moment coefficient for control, $H / \frac{1}{2} \rho V^2 \bar{c}_f s_f$		
C_L	lift coefficient for wing, $L / \frac{1}{2} \rho V^2 S$		
c	wing chord	m	ft
c'	wing chord measured normal to wing quarter-chord line	m	ft
c'_b	control balance chord forward of hinge line measured normal to wing quarter-chord line	m	ft
c_f	control chord aft of hinge line	m	ft
c'_f	control chord aft of hinge line measured normal to wing quarter-chord line	m	ft
$\bar{c}_f$	geometric mean control chord aft of hinge line, $\int_{\eta_i}^{\eta_o} c_f d\eta$	m	ft

$\bar{c}_f$	aerodynamic mean control chord aft of hinge line, $\int_{\eta_i}^{\eta_o} c_f^2 d\eta / \bar{c}_f$	m	ft
F_B	factor on induced camber contributions to allow for control balance		
G_1, G_2, G_3	functions used in calculation of induced camber contribution, see Equations (3.5) and (3.6)	rad ⁻¹	rad ⁻¹
H	hinge moment	N m	lbf ft
K	correction factor for rectangular wing, see Section 3.4		
L	lift	N	lbf
M	Mach number		
R	Reynolds number based on wing mean chord		
S	wing area	m ²	ft ²
s	wing semispan	m	ft
s_f	control span, $s_f = s(\eta_o - \eta_i)$	m	ft
t	maximum thickness of wing section	m	ft
t_h	thickness of control at hinge line	m	ft
V	free-stream velocity	m/s	ft/s
α	angle of attack	rad	rad
α_i	mean induced angle of attack	rad	rad
β	compressibility parameter, $(1 - M^2)^{1/2}$		
δ	control deflection angle measured in plane parallel to plane of symmetry	rad	rad
δ'	control deflection angle measured in plane normal to hinge line	rad	rad
$\Lambda_{1/4}$	sweep angle of wing quarter-chord line	deg	deg
$\Lambda_{1/2}$	sweep angle of wing half-chord line	deg	deg
Λ_h	sweep angle of control hinge-line	deg	deg
η	spanwise distance from wing centre-line as fraction of semispan		

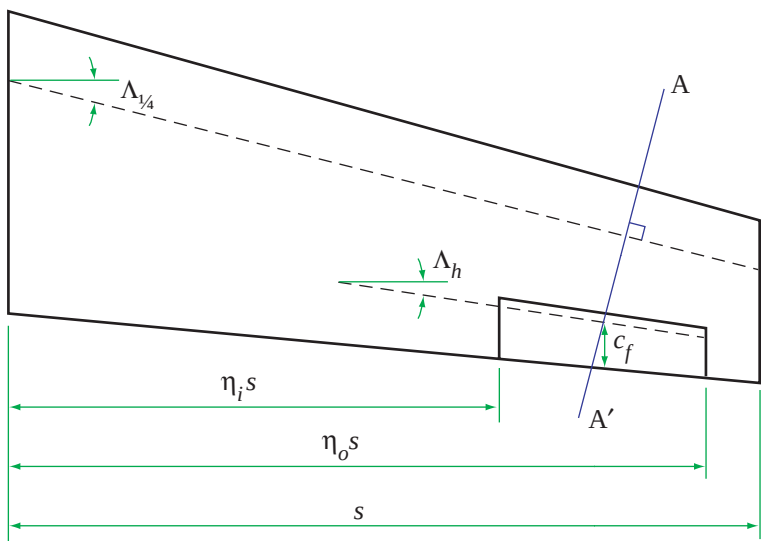
η_i, η_o	values of η at inboard and outboard limits of aileron at hinge line		
λ	ratio of wing tip chord to wing centre-line chord		
ρ	density of air	kg/m ³	slug/ft ³
τ'	section trailing-edge angle in plane normal to quarter-chord line	deg	deg

Superscript

* as in $(a_1)_0^*$ denotes properties for a ‘standard’ section for which $\tau' = 2 \tan^{-1}(t/c')$

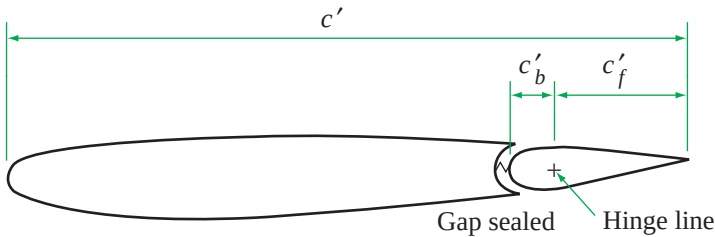
Subscript

T as in $(a_1)_{0T}$ denotes theoretical value



Planform geometry

AA' normal to quarter-chord line and passing through mid-span of control



Section AA'

Sketch 1.1 Planform and section geometry

2. INTRODUCTION

This Item provides a method for estimating the hinge moment coefficient derivatives b_1 and b_2 for full-span and part-span sealed controls on swept and unswept wings at speeds where the flow over the wing is wholly subsonic and fully attached. It may also be used for controls on tailplanes or fins. The method follows the traditional approach for a wing of finite aspect ratio, whereby the two-dimensional sectional values are corrected for the effects of induced angle of attack and induced camber, see Derivations 1, 2, 11, 12 and 18 for example. The basic equations for the derivatives are essentially in the form of lifting-line theory, but with lifting-surface theories used to give a better evaluation of the induced angle of attack and to provide the important additional contribution due to induced camber. The equations permit ready substitution of known two-dimensional characteristics.

None of the various published versions of the above technique is sufficiently comprehensive in its theoretical calculations to cover in a satisfactory manner all configurations of interest. The method in this Item follows Derivation 18 in its treatment of wing sweep, which was based on a successful modification to the earlier work of Derivation 11. The presence of control balance is allowed for by adapting the theoretical calculations made in Derivation 2 for unswept wings. Empirical corrections are presented for part-span effects for controls that extend from a general inboard station η_i to near the wing tip, $\eta_o \geq 0.9$. The two-dimensional properties of the wing and control are assumed to be effectively constant over the span of the control. Prandtl-Glauert similarity parameters are employed to model the first order effects of compressibility at low to moderate subsonic speeds.

Item No. Aero C.04.01.00 (Derivation 29) provides a general introduction to the treatment of control hinge moment coefficient derivatives within the Aerodynamics Sub-series. It should be consulted for a brief description of the individual Items that are available and their inter-relationship. In addition, it gives qualitative guidance on the effects of control geometry and flow conditions on the range of linearity of hinge moment characteristics.

3. METHOD

3.1 Basic Equations

In incompressible flow the derivatives for a finite wing are related to the section values normal to the wing quarter-chord line by the equations*

$$b_1 = (b_1)_0 \left(1 - \frac{\alpha_i}{\alpha}\right) \cos \Lambda_{1/4} \cos \Lambda_h + \Delta b_1 \quad (3.1)$$

$$\text{and} \quad b_2 = \left((b_2)_0 - \frac{\alpha_i}{\delta} (b_1)_0\right) \cos \Lambda_{1/4} \cos \Lambda_h + \Delta b_2, \quad (3.2)$$

where α_i is the mean induced angle of attack and Δb_1 and Δb_2 are induced camber contributions. These equations make the assumption that the angle α_i is constant across the span, which is a reasonable assumption for wings that are approximately elliptically loaded. For loadings that depart significantly from the elliptical a spanwise integration with α_i as a function of η is necessary, as described in Derivation 2 or Item No. Aero C.04.01.06 (Derivation 28). However, a relatively simple correction is possible for a rectangular wing that has constant two-dimensional properties, see Section 3.4.

* The equations assume $\bar{c}_f = \bar{c}_f^*$, having been derived originally for data with $\lambda \geq 0.5$.

3.2 Derivative b_1

The assumptions made in Derivation 18 lead to the substitution

$$\frac{\alpha_i}{\alpha} = 1 - \frac{dC_L/d\alpha}{(a_1)_0 \cos \Lambda_{1/4}}, \quad (3.3)$$

where $(a_1)_0$ is the two-dimensional lift-curve slope for the section normal to the wing quarter-chord line and $dC_L/d\alpha$ is the wing lift-curve slope estimated by lifting-surface theory. Values of $dC_L/d\alpha$ can be obtained from Item No. 70011 (Derivation 34). As in Derivation 20, for example, Prandtl-Glauert similarity parameters are incorporated to allow for first-order compressibility effects. With $dC_L/d\alpha$ calculated at the Mach number of interest, the general form for b_1 becomes

$$b_1 = \frac{(b_1)_0}{(a_1)_0} \left(\frac{dC_L}{d\alpha} \right) \cos \Lambda_h + \Delta b_1. \quad (3.4)$$

In this Item the correction Δb_1 is evaluated as

$$\Delta b_1 = G_1 + G_2, \quad (3.5)$$

where G_1 is the theoretically based contribution for a full-span control and G_2 is a purely empirical correction for part-span effects.

Lifting-surface values of G_1 for a plain control in incompressible flow were calculated in Derivation 18 for $2 \leq A \leq 6$ and $0 \leq \Lambda_{1/4} \leq 45^\circ$. These are reproduced in Figure 1 where $2\pi\beta G_1/F_B(a_1)_0 \cos \Lambda_h$ is given in three carpets as a function of $(1/\beta)\tan \Lambda_{1/4}$ and βA for values of the control chord ratio measured normal to the quarter-chord line, $c_f'/c' = 0.2, 0.3$ and 0.4 . The data for unswept wings have been slightly adjusted to be compatible with the data for unswept wings given in Derivation 2 as these covered higher aspect ratios. For swept wings, extrapolations above $\beta A = 6$ have been made by taking the form of the variation for the unswept wing as a guide and noting that, for all sweep angles, G_1 must tend to zero as βA becomes very large. The factor F_B allows for control balance and has been deduced from the data given in Derivation 2 for nose-balanced and internally-balanced controls on unswept wings. For those two types of control F_B is given in Figure 2 as a function of c_f'/c' and balance c_b'/c_f' . For a plain control F_B is unity.

The empirical part-span correction G_2 is obtained from Figure 3 where $2\pi\beta G_2/F_B(a_1)_0 \cos \Lambda_h$ is given in a carpet as a function of η_i and $A \tan \Lambda_{1/2}$. It is assumed that $\eta_o \geq 0.9$.

3.3 Derivative b_2

In the evaluation of b_2 given in Derivation 18 for full-span controls, some necessary simplifications were made to facilitate the lifting-surface calculations of the control-deflected loadings and only a partial evaluation of the induced effects was performed. Comparisons with experimental data showed that the overall contribution of the neglected components was acceptably small. However, although the resulting equation for b_2 resembles Equation (3.2) the approximation is such that the separate effects of induced angle of attack and induced camber cannot be identified. The equation for b_2 is

$$b_2 = \left((b_2)_0 - \frac{(a_2)_0}{(a_1)_0} (b_1)_0 \right) \frac{\cos \Lambda_h}{(\beta^2 + \tan^2 \Lambda_{1/4})^{1/2}} + \frac{(a_2)_0}{(a_1)_0} (b_1 + G_3), \quad (3.6)$$