



ESDU 87024

Issued November 1987
With Amendments A to D
August 2006

Low-speed drag coefficient increment at constant lift due to full-span plain flaps or controls

ESDU Copyright material. For current status contact ESDU.

Endorsed by
The Royal Aeronautical Society

AVA 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 The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants.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 was monitored and guided by the Aerodynamics Committee, which first met in 1942 and now has the following membership:

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

* Corresponding Member

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

Mr P.A. Carré — Engineer.

The person with overall responsibility for the work in this subject area is Mr P.D. Chappell, Head of the Aircraft Aerodynamics Group.

LOW-SPEED DRAG COEFFICIENT INCREMENT AT CONSTANT LIFT DUE TO
FULL-SPAN PLAIN FLAPS OR CONTROLS

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	2
2.1 Scope of the Item	2
2.2 General Considerations	2
3. DERIVATION OF METHOD	3
3.1 Unswept Wings	4
3.1.1 Positive flap deflections	4
3.1.2 Negative flap deflections	4
3.2 Swept Wings	4
4. APPLICABILITY AND ACCURACY	5
4.1 Applicability	5
4.2 Accuracy	6
5. DERIVATION AND REFERENCES	7
5.1 Derivation	7
5.2 References	8
6. EXAMPLES	8
6.1 Example 1	8
6.2 Example 2	9
6.3 Example 3	10
FIGURES 1 and 2	11 and 12
APPENDIX A PROGRAM FOR CALCULATING THE LOW-SPEED DRAG COEFFICIENT INCREMENT AT CONSTANT LIFT DUE TO FULL-SPAN PLAIN FLAPS OR CONTROLS	13
A1. INTRODUCTION	13
A2. INPUT	13
A3. INPUT AND OUTPUT CORRESPONDING TO EXAMPLES 1 AND 2	13
A3.1 Example 1	13
A3.2 Example 2	14

ESDU Copyright material. For current status contact ESDU.

LOW-SPEED DRAG COEFFICIENT INCREMENT AT CONSTANT LIFT DUE TO FULL-SPAN PLAIN FLAPS OR CONTROLS

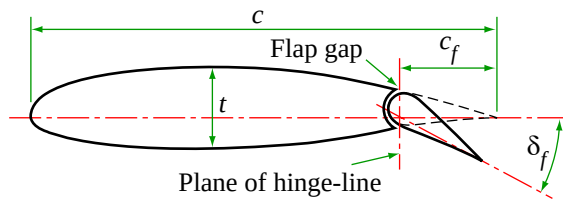
1. NOTATION AND UNITS

		SI	British
A	wing aspect ratio		
a_1	lift-curve slope of clean wing (<i>i.e.</i> $\delta_f = 0$)	rad^{-1}	rad^{-1}
C_D	wing drag coefficient (based on wing planform area)		
ΔC_D	increment in C_D at constant C_L due to deflection of full-span plain flap in simplified presentation, see Sketch 2.1		
ΔC_{Du}	value of ΔC_D for unswept wing		
C_L	wing lift coefficient (based on wing planform area)		
C_{LK}	upper limit of linearity of $C_D \sim C_L^2$ plot for clean wing (<i>i.e.</i> $\delta_f = 0$), see Sketch 2.1		
c	wing local chord	m	ft
c_f	flap local chord	m	ft
$F(\delta_f, \gamma; c_f/c)$	function in Figure 1, see Section 3.1.1		
$k(\gamma)$	factor in Figure 2, see Section 3.1.2		
R	Reynolds number (based on mean wing chord)		
t	maximum thickness of wing section	m	ft
α	angle of attack of wing root chord	rad	rad
α_K	α at C_{LK} , in general for cambered and twisted wing	rad	rad
α_0	α at $C_L = 0$ for clean wing (<i>i.e.</i> $\delta_f = 0$)	rad	rad
γ	angle between chord line of aerofoil section and line joining mid-thickness point at hinge location to trailing edge of undeflected flap, see Sketch 1.2	degree	degree
δ_f	flap deflection (positive trailing-edge down)	degree	degree
$\Lambda_{1/4}$	sweepback of wing 1/4-chord line	degree	degree
λ	wing taper ratio (wing tip chord/wing root chord)		
μ	part-span drag factor (see Item No. Aero F.02.01.07)		
μ_p	ratio of maximum local lift coefficient to C_L		

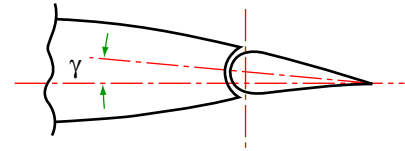
Issued December 1987

With Amendments A to D, August 2006 – 14 pages

This page Amendment D



Sketch 1.1



Sketch 1.2

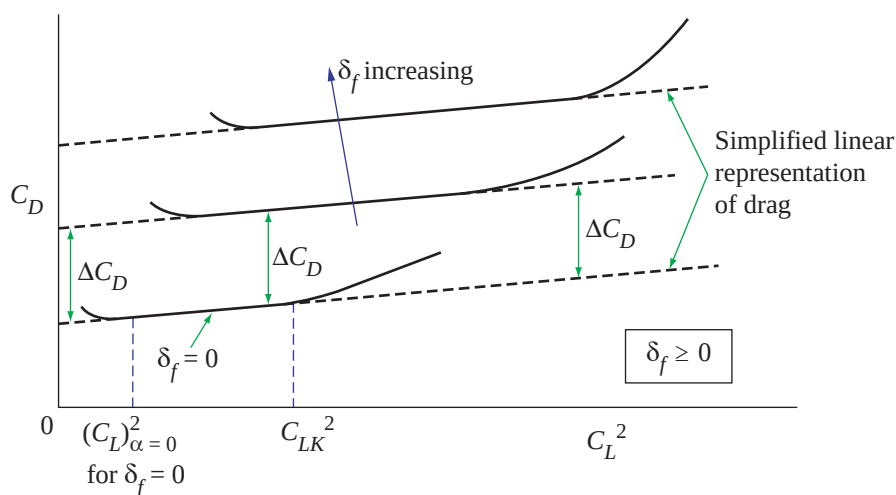
2. INTRODUCTION

2.1 Scope of the Item

This Item provides a method for estimating the increment in wing drag coefficient *at constant lift coefficient* due to the positive or negative deflection, $-20^\circ \leq \delta_f \leq 30^\circ$, of a full-span plain flap or control at low speeds. Such data provide a necessary step in determining, for example, the yawing moment due to aileron (see Item No. 88029, Reference 21).

2.2 General Considerations

The total drag coefficient of a wing with or without a deflected plain flap (or control) is often represented as a simple linear variation of C_D with C_L^2 as shown in Sketch 2.1. Over a C_L range of interest, for which the flow ahead of the flap is fully attached, this is a reasonably good representation of test data. Moreover, in the simplified representation the straight lines for $C_D \sim C_L^2$ are essentially parallel so that ΔC_D , the increment in drag coefficient due to flap deflection at constant lift coefficient, is independent of C_L to a good approximation. This Item presents an empirical method of determining ΔC_{Du} , the drag coefficient increment for a full-span plain flap on an isolated unswept wing at low speeds. A simple correction factor is applied to convert this to the corresponding increment for a swept wing. Part-span correction factors are provided in Item No. Aero. F.02.01.07 (Reference 17). An estimation of fuselage interference for flaps with inboard ends close to the fuselage may be made by the method of Item No. 97003 (Reference 23).



Sketch 2.1 Idealised drag characteristics for a wing with full-span plain flaps

This page Amendment D

Over a specified limited range of C_L the values of ΔC_D given by this Item are good approximations to the true increments in drag coefficient due to flap deflection at constant C_L . Item No. 06014 (Reference 24) describes the prediction of a zero-lift drag coefficient increment, derived from an empirical analysis *at constant incidence*, that may differ in value from ΔC_D but is better suited for use within the traditional method given in Section 5 of Item No. 97002, (Reference 22), where an assumed lift-dependent variation of C_D is added to a (possibly notional) zero-lift value to provide a simple parabolic model of the variation of C_D with C_L .

Section 3 outlines the analysis of the test data that led to the prediction method.

Section 4 provides a guide to the accuracy and limitations of the Item and discusses its extension to part-span flaps.

Section 6 illustrates the use of the method by means of two worked examples.

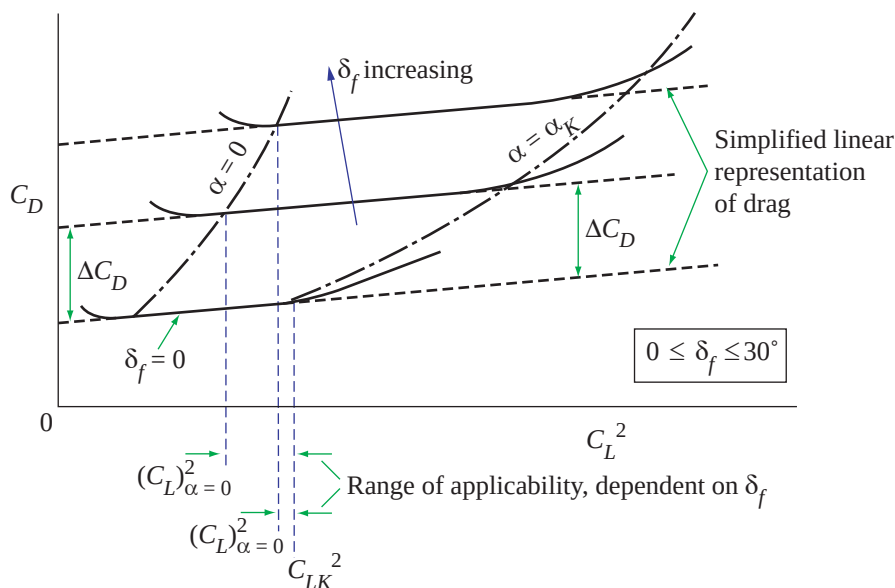
Appendix A provides details of a computer program.

3. DERIVATION OF METHOD

Experimental data (Derivations 1 to 15) for wings with full-span plain flaps were presented in terms of $C_D \sim C_L^2$ for various flap deflections, as illustrated in Sketch 2.1. From these presentations values of ΔC_D were obtained for empirical analysis.

It was found during the analysis that any camber in the region of the flap had an important effect on the increment in drag coefficient due to flap deflection, δ_f , produced by an aerofoil or wing. This aft camber is represented by the angle γ (see Sketch 1.2), so that a cambered section can be considered as equivalent to a symmetrical one having an effective flap deflection $(\delta_f + \gamma)$.

As shown in Sketch 3.1, for *positive* flap deflections, the values of ΔC_D represent true values over the limited C_L range from $(C_L)_{\alpha=0}$ to C_{LK} (see Section 4.1). The upper limit, C_{LK} , is set by the characteristics for $\delta_f = 0$ and a safe lower limit is $(C_L)_{\alpha=0}$, which increases as δ_f increases and thus constricts the range of applicability of the Item as shown.



Sketch 3.1 Limits of applicability for positive flap deflection

This page Amendment D