



ESDU 10023

Issued December 2011

With Amendment A

May 2012

Computer program for calculation of equivalent straight-tapered wing planform

Associated software: ESDUpac A1023



**ROYAL
AERONAUTICAL
SOCIETY**

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 The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants.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

Chairman	
Mr A.J. Wells	— Independent
Vice-Chairman	
Mr P.D. Chappell	— Independent
Members	
Mr K. Bradbrook	— BAE SYSTEMS, Preston
Mr P. Camacho*	— Boeing, Long Beach, CA, USA
Dr P.C. Dexter	— Independent
Mr J.R.J. Dovey	— Independent
Prof. K.P. Garry	— Cranfield University
Prof. J.M.R. Graham	— Imperial College, London
Mr M.J. Green	— Independent
Mr J.M. van den Heever*	— Denel Dynamics, South Africa
Dr G.A. Johnson	— BAE SYSTEMS, Advanced Technology Centre, Filton, Bristol
Dr E.H. Kitchen	— Rolls-Royce Commercial Aero Engines Ltd, Derby
Miss M. Maina	— Aircraft Research Association Ltd
Mr A. Miller	— Airbus UK, Filton, Bristol
Mr E. Totland*	— Saab AB, Linköping, Sweden
Mr J. Tweedie	— Short Brothers plc, Belfast

* Corresponding Member

The construction and subsequent development of the Data Item were undertaken by

Mr R.W. Gilbey — Group Head.

COMPUTER PROGRAM FOR CALCULATION OF EQUIVALENT STRAIGHT-TAPERED WING PLANFORM

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	3
3. PRINCIPLE OF THE EQUIVALENT WING	3
3.1 Practical Considerations for Cranked Wing Planform	5
4. PROGRAM	7
4.1 Input	7
4.2 Output	9
4.3 Running the Program	9
5. DERIVATION	10
6. EXAMPLES	10
6.1 Example 1	10
6.2 Example 2	16

COMPUTER PROGRAM FOR CALCULATION OF EQUIVALENT STRAIGHT-TAPERED WING PLANFORM

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
A	aspect ratio of equivalent straight-tapered wing, b^2 / S		
b	wing span (see Sketches 3.1, 3.2, 4.1)	m	ft
$\bar{c}$	geometric (or standard) mean chord of equivalent straight-tapered wing, S/b	m	ft
$\bar{\bar{c}}$	aerodynamic mean chord of equivalent straight-tapered wing (see ESDU 76003, Derivation 1)	m	ft
c_b	root chord of exposed half wing for wing-body (see Sketches 3.1, 3.3, 4.1), centre-line chord if body absent (see Sketch 3.2)	m	ft
c_r	root chord of exposed half wing for equivalent straight-tapered wing (see Sketches 3.1, 3.2), same as c_0 if body absent (see Sketch 3.2)	m	ft
c_t	wing tip chord (see Sketches 3.1, 4.1 and Section 3.1)	m	ft
c_0	gross wing centre-line chord for equivalent straight-tapered wing (see Sketches 3.1, 3.2, 4.1)	m	ft
$d_{0,i}$	sawtooth depth at leading edge of inboard chord of i 'th trapezoidal panel on each half wing, negative for forward shift of leading edge (see Sketches 3.2, 4.1)	m	ft
$d_{1,i}$	sawtooth depth at trailing edge of inboard chord of i 'th trapezoidal panel on each half wing, negative for forward shift of trailing edge (see Sketch 4.1)	m	ft
S	gross wing planform area of equivalent straight-tapered wing	m ²	ft ²
s	wing semi-span (see Sketches 3.1, 3.2, 4.1)	m	ft
s_i	spanwise distance from plane of symmetry of inboard chord of i 'th trapezoidal panel on each half wing (see Sketch 4.1); s_1 is distance to root chord of exposed half wing (see Sketches 3.1, 3.3, 4.1), $s_1 = 0$ if body absent (see Sketch 3.2)	m	ft

x	distance from longitudinal datum* (positive aft)		
x_{cb}	distance aft from longitudinal datum* to leading edge of c_b (see Sketches 3.1, 3.2, 4.1)	m	ft
x_{c0}	distance aft from longitudinal datum* to apex of equivalent straight-tapered wing (i.e. leading edge of c_0) (see Sketches 3.1, 3.2, 4.1)	m	ft
x_t	distance aft from longitudinal datum* to leading edge of tip chord, (see Sketches 3.1, 3.2)	m	ft
$\bar{x}_0$	distance aft of apex of equivalent straight-tapered wing to leading-edge of $\bar{c}$ (see ESDU 76003, Derivation 1)	m	ft
$\bar{x}_{1/4}$	distance aft of apex of equivalent straight-tapered wing to quarter-chord of $\bar{c}$	m	ft
$\Lambda_{0,i}$	leading-edge sweep of i 'th trapezoidal panel on each half of cranked wing (see Sketch 4.1)	deg	deg
$\Lambda_{1,i}$	trailing-edge sweep of i 'th trapezoidal panel on each half of cranked wing (see Sketch 4.1)	deg	deg
Λ_0	leading-edge sweep of equivalent straight-tapered wing (see Sketch 4.1)	deg	deg
$\Lambda_{1/4}$	quarter-chord sweep of equivalent straight-tapered wing	deg	deg
$\Lambda_{1/2}$	half-chord sweep of equivalent straight-tapered wing	deg	deg
Λ_1	trailing-edge sweep of equivalent straight-tapered wing (see Sketch 4.1)	deg	deg
λ	wing taper ratio (c_t/c_0) for equivalent straight-tapered wing		

* The longitudinal datum is any convenient point on the centreline.

2. INTRODUCTION

The methods of many Data Items that predict the aerodynamics of wings and wing-body combinations assume a straight-tapered wing for the presentation of correlations in terms of the planform parameters, aspect ratio, sweep and taper ratio. This reflects their predominance in the database. However, the methods are often also applicable to wings with modest cranks and sawteeth, but implementation requires a suitable representation as an equivalent straight-tapered planform. A 'crank' is defined as a distinct spanwise station at which there is a change in sweepback in either leading-edge or trailing-edge or both. A 'sawtooth' is defined as a distinct spanwise station where the chord changes discontinuously. In practice, the wing chord increases for sections outboard of the spanwise position by moving the leading-edge forward of the original planform.

Addendum A of ESDU 76003 (Derivation 1) describes a geometric construction of such an equivalent wing. The concept has been employed as a standard procedure in numerous applications within the ESDU Aerodynamics Series and has proved satisfactory. Its employment is subject to the proviso that although the geometric construction can be applied to any multi-cranked wing, with or without sawteeth, it would be expected to be a reasonable representation aerodynamically only for wings where the leading-edge sweep is constant, or has only minor changes, over the greater part of the span and for conditions where the flow over the wing is fully attached.

Note that, in this Item, a 'wing' is taken to be the usual pair of symmetrically disposed identical half-wings, such as in Sketches 3.1 or 3.2.

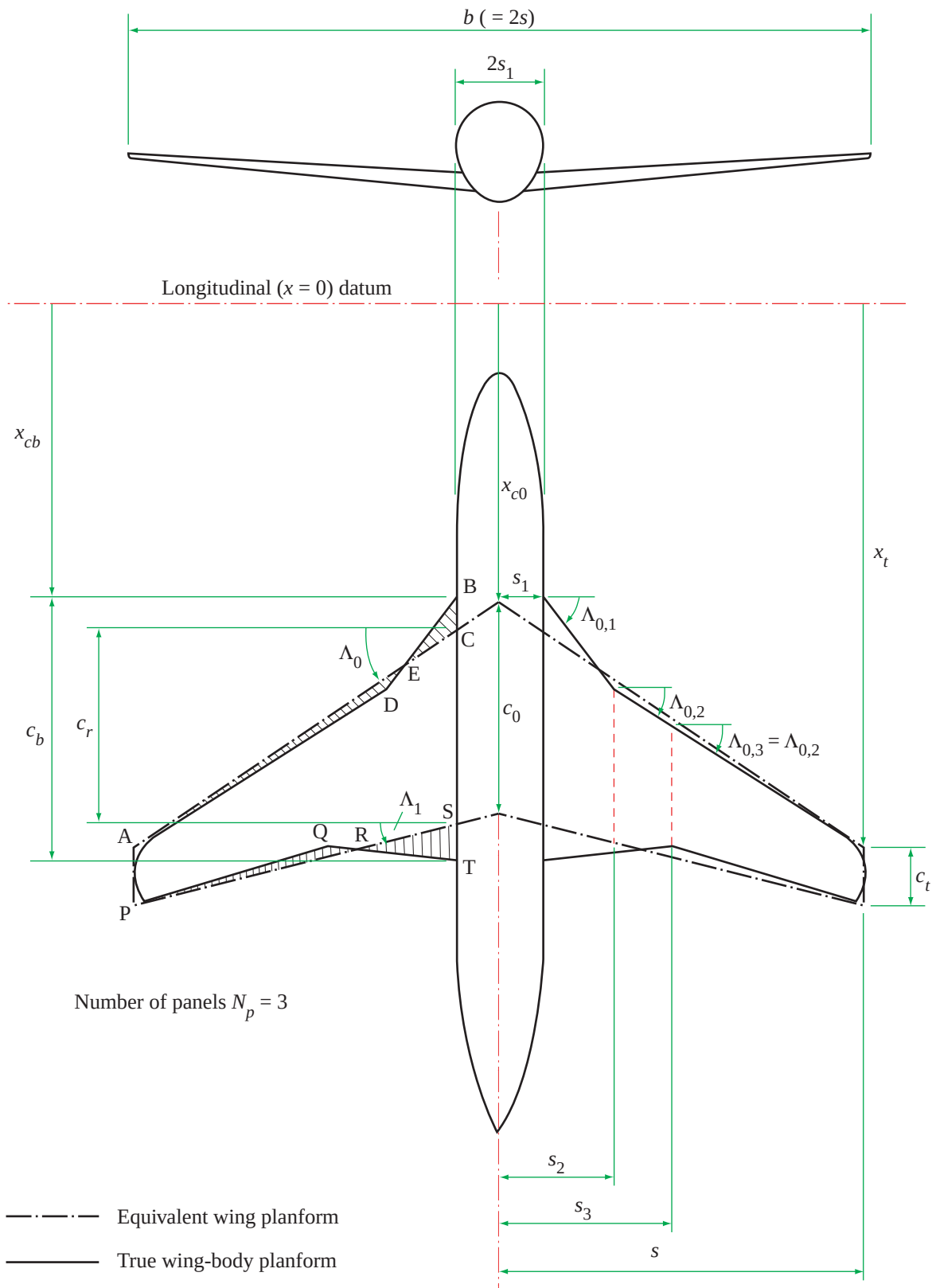
This Data Item provides a computer program, ESDUpac A1023, that calculates the geometry of the equivalent wing.

3. PRINCIPLE OF THE EQUIVALENT WING

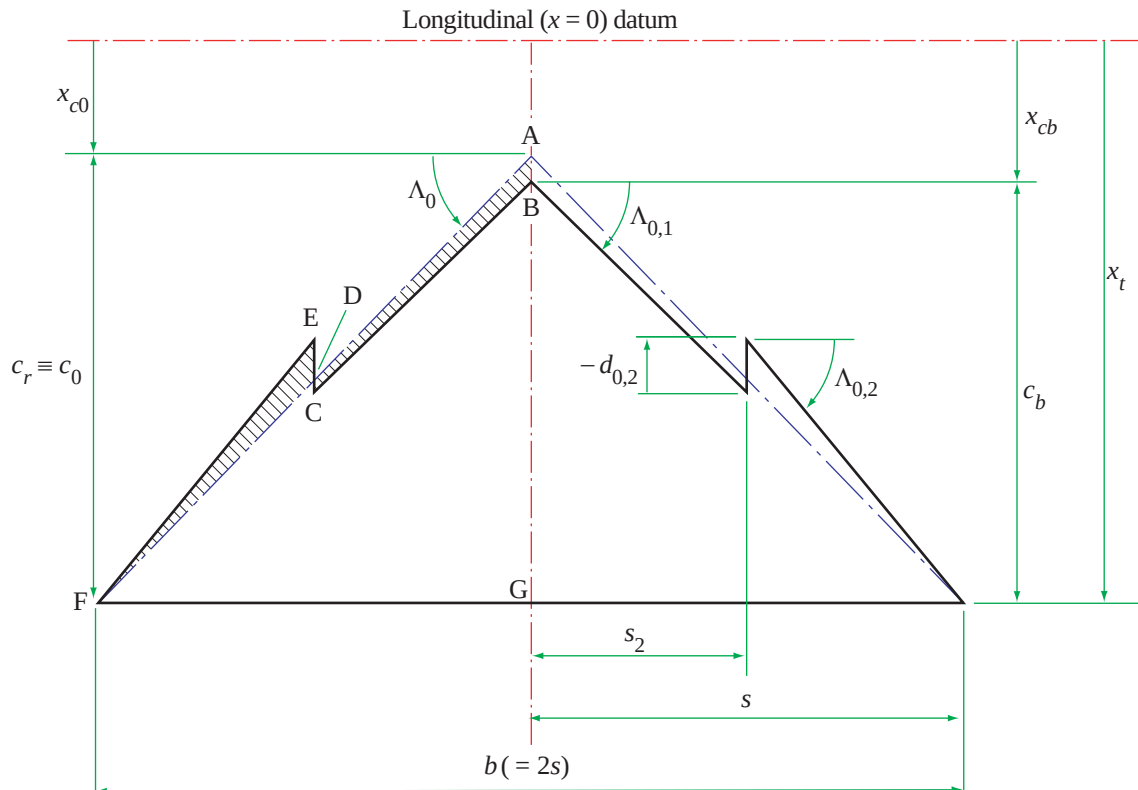
The basis underlying the method is that the gross span, exposed wing area and tip chord of the cranked wing are maintained and that the distance, x_t , of the leading edge of the tip chord aft of the longitudinal datum is unaltered. The leading-edge and trailing-edge of the equivalent wing are constructed as 'mean' lines so that there is a balance of included and excluded areas, which is illustrated in Sketches 3.1 and 3.2 for simple cases.

For the cranked wing in Sketch 3.1, the leading-edge of the equivalent wing is constructed so that the excluded area within BEC is equal to the included area within AED. Similarly, for the trailing-edge the area within PQR is equal to the area within TSR. The total exposed wing areas BDAPQT and CAPS are thus equal. As stated in Section 2, the equivalent wing will only be a satisfactory representation aerodynamically if the leading edge sweep is largely unaltered.

In Sketch 3.2 for the wing with a sawtooth, the area within ABCD equals the area within DEF, and thus the areas BCEFG and AFG are equal.



Sketch 3.1 Cranked-wing-body combination, front view and planform



There is no body in this example so $s_1 = 0$

- · — · — Equivalent wing planform
- True wing planform

Sketch 3.2 Wing with sawtooth

3.1 Practical Considerations for Cranked Wing Planform

For a wing-body combination, before the equivalent wing can be constructed it is necessary to establish a root chord at the body side for the cranked planform. The first step is to project both the body and wing onto the same horizontal plane so that the vertical position of the wing is immaterial. The intersections of the wing leading edge and the wing trailing edge with the side of the projected body planform immediately define a root chord, c_b , at a distance, s_1 from the plane of symmetry, provided that between the points of intersection the body side is at a uniform distance from the plane of symmetry. In situations where this part of the body is slightly curved, the root chord should be taken as the chordwise distance drawn aft from the body/leading-edge intersection until it cuts the trailing edge, extended into the body if necessary, see Sketches 3.3a and 3.3b which show how s_1 and c_b are defined for a body bowing out and bowing in.

The tip chord is not an input to the program, but is defined perforce by the other geometric input parameters. The construction of the equivalent straight-tapered wing assumes that the leading-edge and trailing-edge of the cranked wing extend to maximum span and that their separation there defines the tip chord. This follows the recommendation of the hand calculation method given in ESDU 76003. Sketch 3.1 shows how for a curved tip the leading-edge and trailing-edge slopes just inboard of the tip are extended to form c_t at maximum span.