



ESDU 75004

Issued May 1975

Supersedes ESDU W.S.02.03.01

Wave drag of wings at zero lift in inviscid airflow

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 The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants.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 which supersedes ESDU W.S.02.03.01, was monitored and guided by the Aerodynamics Committee. This Committee 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
Members	
Prof. L.F. Crabtree	— Bristol University
Mr R.L. Dommett	— Royal Aircraft Establishment
Mr H.C. Garner	— Royal Aircraft Establishment
Mr P.K. Jones	— Hawker Siddeley Aviation Ltd, Woodford
Mr J.R.C. Pedersen	— British Aircraft Corporation Ltd, Stevenage
Mr J.J. Perrin	— Aéropatiale, Châtillon
Mr M.R. Pike	— Rolls-Royce (1971) Ltd, Derby
Mr J.J. Spillman	— Cranfield Institute of Technology
Mr J.W.H. Thomas	— Hawker Siddeley Aviation Ltd, Hatfield
Mr H. Vogel	— British Aircraft Corporation Ltd, Weybridge
Mr J. Weir	— Salford University.

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

Mr P.D. Chappell	— Group Head
Mr P.F. Sheppard	— Engineer.

WAVE DRAG OF WINGS AT ZERO LIFT IN INVISCID AIRFLOW

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. GENERAL	1
3. FLOW REGIMES	2
4. INTERPOLATION IN λ AND m	2
5. BASIS AND APPLICABILITY OF DATA	3
6. DERIVATION	3
7. EXAMPLE	3
7.1 Example 1	3
7.2 Example 2	4
FIGURES 1 to 8	5 to 14

ESDU Copyright material. For current status contact ESDU.

WAVE DRAG OF WINGS AT ZERO LIFT IN INVISCID AIRFLOW

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
A	aspect ratio, b^2/S		
b	wing span	m	ft
C_{DW0}	wave drag coefficient at zero lift, $D_{W0}/\frac{1}{2}\rho V^2 S$		
c	chord	m	ft
c_r	wing centre-line chord	m	ft
c_t	wing tip chord	m	ft
D_{W0}	wave drag at zero lift	N	lbf
M	free-stream Mach number		
m	maximum thickness position of double-wedge section as fraction of chord		
n	fraction of chord		
S	planform area	m ²	ft ²
t	maximum thickness of wing section	m	ft
V	airspeed	m/s	ft/s
β	compressibility parameter, $(M^2 - 1)^{1/2}$		
$\Lambda_{1/2}$	sweepback of mid-chord line	degree	degree
λ	taper ratio, c_t/c_r		
ρ	air density	kg/m ³	slug/ft ³

2. GENERAL

Figures 1 to 8 present data for the wave drag at zero lift in inviscid airflow for wings with straight leading and trailing edges, streamwise tips and either symmetrical double-wedge or biconvex parabolic-arc sections of constant thickness/chord ratio across the span. Data are given for three values of taper ratio (0, 0.5 and 1.0) for wings with either rhombic ($m = 0.5$) or biconvex parabolic-arc sections. The effect of changing the maximum thickness position is illustrated by presenting data for the case of the double-wedge section (with $m = 0.3$) for taper ratios of 0 and 1.0. In each Figure $C_{DW0}/A(t/c)^2$ is plotted against βA and $A \tan \Lambda_{1/2}$ in carpet form and for all the cases of double-wedge section separate carpets are given for subsonic and supersonic ridge lines.

Issued May 1975 – 15 pages

The data in this Item are given in terms of the sweepback of the mid-chord line, $\Lambda_{1/2}$, which is related to the sweepback of the n -chord line, Λ_n , via the relation

$$A \tan \Lambda_{1/2} = A \tan \Lambda_n + 2(2n - 1) \left(\frac{1 - \lambda}{1 + \lambda} \right). \quad (2.1)$$

For design purposes it is useful to know the conditions giving sweptforward or sweptback trailing-edges. These are

$$A \tan \Lambda_{1/2} < 2 \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for sweptforward trailing edges,} \quad (2.2)$$

$$A \tan \Lambda_{1/2} > 2 \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for sweptback trailing edges.} \quad (2.3)$$

3. FLOW REGIMES

There are four main flow regimes covered by the data presented in the Figures. These flow regimes are defined by the following expressions:

$$\beta A - A \tan \Lambda_{1/2} < -2 \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for subsonic trailing edges,} \quad (3.1)$$

$$-2 \left(\frac{1 - \lambda}{1 + \lambda} \right) < \beta A - A \tan \Lambda_{1/2} < 2(1 - 2m) \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for supersonic} \quad (3.2)$$

trailing edges and subsonic ridge lines,

$$2(1 - 2m) \left(\frac{1 - \lambda}{1 + \lambda} \right) < \beta A - A \tan \Lambda_{1/2} < 2 \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for supersonic} \quad (3.3)$$

ridge lines and subsonic leading edges,

and
$$\beta A - A \tan \Lambda_{1/2} > 2 \left(\frac{1 - \lambda}{1 + \lambda} \right) \text{ for supersonic leading edges.} \quad (3.4)$$

4. INTERPOLATION IN λ AND m

If, for wings with rhombic or biconvex parabolic-arc sections, it is necessary to interpolate for values of taper ratio between the three given in the Figures, the use of a cross-plot is strongly advised, provided that no change in flow regime is involved. For all other cases in which an interpolation in λ is required and for all cases in which an interpolation in m is required the following procedures will be found useful. From an analysis of the data given in the Figures, together with additional data from Derivation 1, it has been found that for subsonic trailing edges (Expression (3.1)) the variation of $C_{DW0}/A(t/c)^2$ with $(1 - \lambda^{1/2})/(1 + \lambda^{1/2})$ is essentially linear (to within about ± 10 per cent) for fixed values of βA and $A \tan \Lambda_{1/2}$. For supersonic leading edges (Expression (3.4)), on the other hand, the variation of $C_{DW0}/A(t/c)^2$ with λ is essentially linear (to within about ± 5 per cent). For the "mixed flow" regimes defined by Expressions (3.2) and (3.3) linear interpolation for $C_{DW0}/A(t/c)^2$ in λ is adequate (to within about ± 10 per cent in the worst cases).

Similar analyses with regard to m (from the only available data¹, for $\lambda_c = 0$) have shown that for subsonic and supersonic ridge lines linear interpolation in, respectively, $(1 + m^2)/(1 - m^2)$ and $1/m^2$ is satisfactory, to well within ± 10 per cent over the range $0.2 \leq m \leq 0.6$.

5. BASIS AND APPLICABILITY OF DATA

The theory from which the data¹ presented in the Figures were derived is that of linearised supersonic flow, which limits their application to wings with small t/c (< 0.1 , say). It is in addition a theory for inviscid flow in which no flow separation occurs over the wing surface.

The kinks which the curves exhibit on the boundaries of the various flow regimes correspond to conditions for which linear theory is invalid; moreover, they do not occur as sharp peaks in practice.

The portions of the curves for constant $Atan\Lambda_{1/2}$ shown dotted instead of full (generally near $\beta A = 0$) are interpolations which have not been verified by calculation.

To apply the data of this Item to the wave drag estimation of wing-body combinations, see Item No. Aero A.S.02.03.01.

6. DERIVATION

1. BISHOP, R.A. Charts of the theoretical wave drag of wings at zero lift. ARC CP 313,
CANE, E.G. 1957.

7. EXAMPLE

7.1 Example 1

Find the theoretical wave drag coefficient at zero lift at a Mach number of 3 for a wing of rhombic ($m = 0.5$) section with $t/c = 0.04$ and a trapezoidal planform, with $A = 2$ and $\lambda = 0.25$, having unswept trailing-edges.

For unswept trailing-edges, $Atan\Lambda_{1/2} = 2 \left(\frac{1-\lambda}{1+\lambda} \right)$ which, for $\lambda = 0.25$, gives $Atan\Lambda_{1/2} = 1.2$.

The reduced aspect ratio, $\beta A = (3^2 - 1)^{1/2} \times 2 = 5.66$.

From Figures, 2b, 3b and 5b for $m = 0.5$, with $\beta A = 5.66$ and $Atan\Lambda_{1/2} = 1.2$, the following cross-plot is obtained:

