



ESDU 89042

Issued November 1989

Supersedes ESDU A.08.01.07

With Amendment A

September 2012

Body effect on wing angle of attack and pitching moment at zero lift at low speeds

Associated software: ESDUpac A8942



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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes ESDU A.08.01.07, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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BODY EFFECT ON WING ANGLE OF ATTACK AND PITCHING MOMENT AT ZERO LIFT AT LOW SPEEDS

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BODY EFFECT ON WING ANGLE OF ATTACK AND PITCHING MOMENT AT ZERO LIFT AT LOW SPEEDS

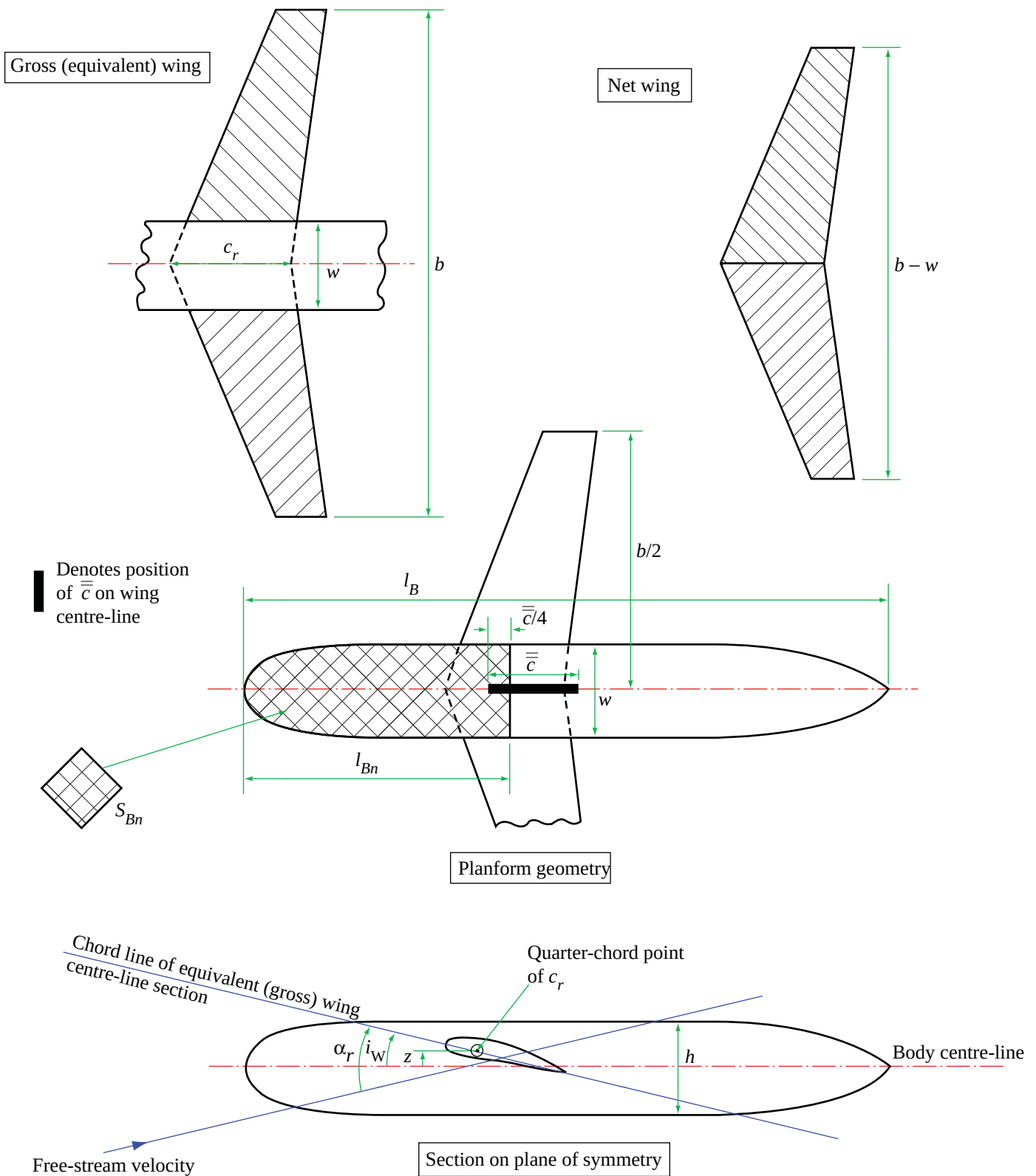
1. NOTATION AND UNITS (see Sketches 1.1, 3.1 and 4.1)

		SI	British
A	aspect ratio of equivalent (gross) wing		
a_{1N}	lift-curve slope of net wing based on qS_N (from ESDU 70011, Derivation 15)	rad^{-1}	rad^{-1}
a_{1WB}	lift-curve slope of wing-body combination based on qS_W	rad^{-1}	rad^{-1}
b	span of equivalent (gross) wing	m	ft
C_{LW}	lift coefficient of equivalent (gross) wing based on qS_W		
C_{LWB}	lift coefficient of wing-body combination based on qS_W		
$\Delta_z C_{LWB}$	increment in C_{LWB} due to vertical displacement of wing from mid-body position		
C_{mW}	pitching moment coefficient of equivalent (gross) wing about quarter-chord point of $\bar{c}$ and based on $qS_W \bar{c}$		
C_{m0W}	pitching moment coefficient of equivalent (gross) wing at $C_{LW} = 0$ (from experiment or ESDU 87001, Derivation 20)		
$(C_{m0})_B$	increment in C_{m0W} due to body for unswept wing ($\Lambda_{1/4} = 0$) at mid-body height		
C_{m0WB}	pitching moment coefficient of wing-body combination at $C_{LWB} = 0$		
ΔC_{m0}	increment in C_{m0W} due to adding body, ($= C_{m0WB} - C_{m0W}$)		
$\Delta_s C_{m0}$	increment in $(C_{m0})_B$ due to sweepback of wing		
$\Delta_z C_{m0}$	increment in $(C_{m0})_B$ due to vertical displacement of wing from mid-body position		
$\bar{c}$	aerodynamic mean chord of equivalent (gross) wing	m	ft
c_r	centre-line chord of equivalent (gross) wing	m	ft
h	maximum height of body	m	ft
i_W	angle between chord line of equivalent (gross) wing centre-line section and centre-line of body, positive as shown in Sketch 1.1	rad or deg	rad or deg

K_1, K_2	slender-body theory factors in Equations (3.1) to (3.3)		
l_B	length of body	m	ft
l_{Bn}	distance between body nose and quarter-chord point of $\bar{c}$	m	ft
q	kinetic pressure	N/m ²	lbf/ft ²
S_B	planform area of body	m ²	ft ²
S_{Bn}	planform area of body forward of lateral line through quarter-chord point of $\bar{c}$	m ²	ft ²
S_N	planform area of net wing	m ²	ft ²
S_W	planform area of equivalent (gross) wing	m ²	ft ²
w	maximum width of body	m	ft
z	vertical displacement of quarter-chord point of c_r above mid-body position, positive for high wing	m	ft
α_r	angle of attack of chord line of equivalent (gross) wing centre-line section	rad or deg	rad or deg
α_{0rW}	value of α_r at $C_{LW} = 0$ (from experiment or ESDU 87031, Derivation 21)	rad or deg	rad or deg
$(\alpha_{0r})_1$	contribution to α_{0rW} due to camber alone (from ESDU 87031, Derivation 21)	rad or deg	rad or deg
α_{0rWB}	value of α_r for wing-body combination at $C_{LWB} = 0$	rad or deg	rad or deg
$\Delta\alpha_{0r}$	$\alpha_{0rWB} - \alpha_{0rW}$, see Sketch 3.1	rad or deg	rad or deg
δ_t	geometric twist of wing tip relative to centre-line chord of equivalent (gross) wing, positive leading-edge up	deg	deg
$\Lambda_{1/4}$	sweepback of wing quarter-chord line	deg	deg
λ	taper ratio of equivalent (gross) wing, tip chord/ c_r		
ϕ_a, ϕ_f	afterbody, forebody sweep angles as defined in Sketch 4.1	deg	deg
ψ	angle between zero-lift plane of wing and airflow direction for zero body-alone pitching moment	deg	deg

Subscripts

<i>expt</i>	denotes experimental value
<i>pred</i>	denotes predicted value

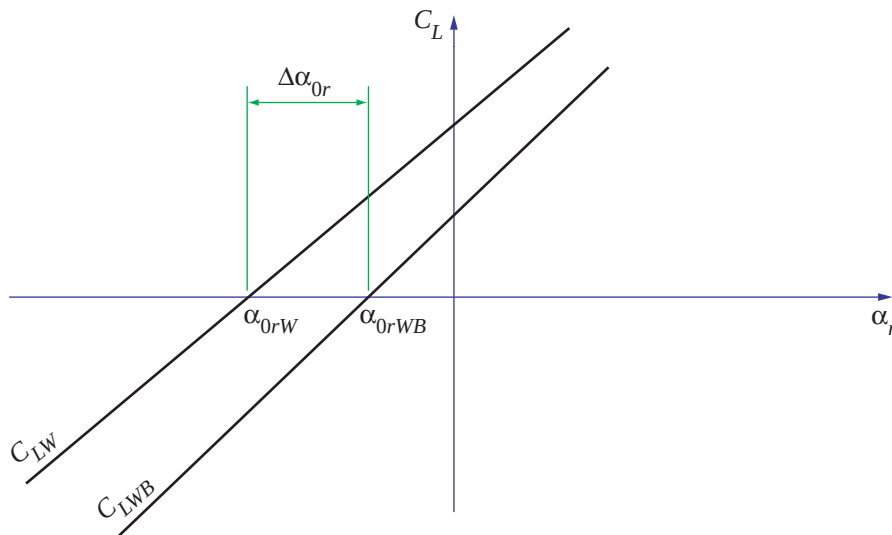


Sketch 1.1 Definition of geometry

2. INTRODUCTION

This Item provides simple, mostly empirical, methods for estimating the change of zero-lift angle of attack and pitching-moment coefficient for a wing due to adding a fuselage of circular or approximately circular cross-section. The method for zero-lift angle of attack is presented in Section 3, and is an adaptation of a formula from Derivation 17. The method for zero-lift pitching-moment coefficient is presented in Section 4, and is based on the predictions of Derivation 2 for unswept wings on axisymmetric bodies, with additional empirical allowance for wing sweep and body asymmetry. The effects of Mach number and Reynolds number are discussed in Section 5. The applicability and accuracy of the methods are given in Section 6. The Derivation is listed in Section 7, and Section 8 provides a worked example. Details of a computer program for the method, ESDUpac A8942, are given in Appendix A.

3. ZERO-LIFT ANGLE OF ATTACK



Sketch 3.1 Lift coefficient curves

In inviscid flow the force on a closed body at any angle of attack is zero. However, in viscous flow the force is found to be finite, due largely to the boundary layer on the afterbody. This, combined with aerodynamic interference of the wing and body, gives rise to a change of lift and zero-lift angle of attack when a body is attached to a wing. An axisymmetric body attached to an uncambered, untwisted wing with zero setting angle, and with the wing on the centre-line of the body, should preserve symmetry so that $\alpha_{0rW} = \alpha_{0rWB} = 0$.

The lift on the body is affected by the upwash and downwash due to the wing and vice versa. The crossflow around the body induces a change in the angles of attack of the wing sections, particularly near the wing-body junction. In addition, vertical displacement of the wing further complicates the flow pattern.

Because these effects are greatly influenced by viscosity they are difficult to predict. However, Derivation 17 gives the following expression to estimate the total lift of a wing-body combination for circular section bodies, with wing-body interference effects for mid-wings estimated via slender-body theory as set out in Derivation 13, and with an empirical allowance for wing height from Derivation 14:

$$C_{LWB} = K_1 a_{1N} \left\{ [\alpha_r - i_W - \alpha_{0rW} + (\alpha_{0r})_1] + \frac{K_2}{K_1} [i_W - (\alpha_{0r})_1] \right\} + \Delta_z C_{LWB}, \quad (3.1)$$

where $K_1 = \frac{a_{1WB}}{a_{1N}}$ and $K_2 = \frac{1}{a_{1N}} \left(\frac{\partial C_{LWB}}{\partial i_W} \right)$ for constant body angle of attack.

Derivation 17 gives the following numerical approximations to the slender-body values of K_1 and K_2 for $w/b \leq 0.2$,

$$K_1 = \left(1 + 2.15 \frac{w}{b} \right) \frac{S_N}{S_W} + \frac{\pi}{2a_{1N}} \frac{w^2 S_N}{S_W}, \quad (3.2)$$

and
$$K_2 = \left(1 + 0.7 \frac{w}{b} \right) \frac{S_N}{S_W}. \quad (3.3)$$

From Derivation 14 there is the empirical approximation, for $w/b \approx 0.1$,

$$\Delta_z C_{LWB} = -0.2 c_r w(z/h)/S_W, \quad (3.4)$$

where a linear variation with z/h has been assumed between values of $\pm 0.1 c_r w/S_W$ quoted for “low” or “high” wings, respectively.

Rearrangement of Equation (3.1) with $C_{LWB} = 0$ allows formulae for α_{0rWB} and $\Delta\alpha_{0r}$ to be developed. However, comparisons with experimental data have established that wing height has only a minor influence on those parameters and that a simpler prediction method of comparable accuracy can be produced if the small contribution $\Delta_z C_{LWB}$ is omitted from Equation (3.1) before rearrangement.

With $C_{LWB} = \Delta_z C_{LWB} = 0$, Equation (3.1) can be rewritten to give

$$\alpha_r = \alpha_{0rWB} = \alpha_{0rW} + \left[1 - \frac{K_2}{K_1} \right] [i_W - (\alpha_{0r})_1], \quad (3.5)$$

and hence
$$\Delta\alpha_{0r} = \alpha_{0rWB} - \alpha_{0rW} = \left[1 - \frac{K_2}{K_1} \right] [i_W - (\alpha_{0r})_1]. \quad (3.6)$$

Values of α_{0rW} and $(\alpha_{0r})_1$ may be calculated by the method of ESDU 87031 (Derivation 21), see Section 8 for example. If experimental values of α_{0rW} are available then they may be substituted instead.

With the term due to $\Delta_z C_{LWB}$ already neglected, the necessity to calculate a_{1N} is completely avoided, without unacceptable loss of accuracy, by taking a typical value of $\pi w^2/(2a_{1N} S_N) = 0.03$ and so writing

$$K_1 = \left(1.03 + 2.15 \frac{w}{b} \right) \frac{S_N}{S_W} \quad (3.7)$$

so that

$$\frac{K_2}{K_1} = \frac{(1 + 0.7w/b)}{(1.03 + 2.15w/b)}. \quad (3.8)$$

Figure 1 gives K_2/K_1 as a function of w/b .

4. ZERO-LIFT PITCHING-MOMENT COEFFICIENT

The change in zero-lift pitching-moment coefficient ΔC_{m0} due to adding a body to a wing is, for similar reasons to those discussed earlier for angle of attack, difficult to predict with precision. Although the pitching moments for the body and wing can be estimated separately, the complex flow around a wing-body combination precludes a simple addition.

Derivation 2 gives an empirical method for estimating the change in zero-lift pitching-moment coefficient due to adding an axisymmetric body to an unswept wing. The contribution $(C_{m0})_B$ for a wing mounted at mid-body height is obtained from Figure 2, (from Derivation 2). A further term $\Delta_z C_{m0}$ accounts for wing height on the body, and the result in Derivation 2 has been generalised herein by the assumption of a linear variation with z/h . Accounting for wing sweep is theoretically difficult but a simple increment $\Delta_s C_{m0}$ calculated from the twist, aspect ratio and sweep of the quarter-chord line is proposed.

Thus

$$\begin{aligned} C_{m0WB} &= C_{m0W} + \Delta C_{m0} \\ &= C_{m0W} + (C_{m0})_B + \Delta_z C_{m0} + \Delta_s C_{m0} \end{aligned} \quad (4.1)$$

where the wing-alone value C_{m0W} may be found by the method of ESDU 87001 (Derivation 20), see Section 8 for example. If experimental values of C_{m0W} are available then they may be substituted instead.

With $(C_{m0})_B$ obtained from Figure 2, the remaining components of ΔC_{m0} are

$$\Delta_z C_{m0} = 0.01(z/h), \quad (4.2)$$

and

$$\Delta_s C_{m0} = -0.053[(C_{m0})_B \delta_t (w/b) A \tan \Lambda_{1/4}]^{0.3}, \text{ where } \delta_t \text{ is in degrees.} \quad (4.3)$$

Note that in Equation (4.2), the sign of component $\Delta_z C_{m0}$ is dependent on the sign of z and is positive for a high wing.

Note also that Equation (4.3) has been developed for configurations with $\delta_t \leq 0$ and $\Lambda_{1/4} \geq 0$, and should not be employed otherwise.

To evaluate $(C_{m0})_B$ from Figure 2, the angle between the zero-lift plane of the wing and the airflow direction for zero body-alone pitching moment ψ (in degrees) is required. For axisymmetric bodies, with i_W and α_{0rW} in degrees, this is obtained as

$$\psi = i_W - \alpha_{0rW}. \quad (4.4)$$

However, for downswept forebodies or upswept afterbodies or any other asymmetries, it is more difficult to define ψ unless experimental data are known for the body alone. In the absence of body-alone data, analysis of the few data available from compatible wing-body and wing-alone tests suggests that the