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Aerodynamic centre of wing-fuselage combinations

Associated software: ESDUpac A1309
See ESDU 13009



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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes ESDU Aero A.08.01.01, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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AERODYNAMIC CENTRE OF WING-FUSELAGE COMBINATIONS

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AERODYNAMIC CENTRE OF WING-FUSELAGE COMBINATIONS

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
A	aspect ratio of equivalent wing planform, b^2/S		
a	lift-curve slope of equivalent wing planform	radian ⁻¹	radian ⁻¹
b	span of wing planform	m	ft
$\bar{c}$	standard (or geometric) mean chord of equivalent wing planform	m	ft
$\bar{\bar{c}}$	aerodynamic mean chord of equivalent wing planform	m	ft
c_f	root chord of true wing planform at side of projected fuselage planform (see Sketch 3.1)	m	ft
c_r	root chord of equivalent wing planform	m	ft
c_{ref}	general reference chord for stability calculations	m	ft
c_t	tip chord of equivalent wing planform	m	ft
c_0	centre-line chord of equivalent wing planform	m	ft
d	width of fuselage at leading edge of root chord of equivalent wing planform	m	ft
F	function used in estimating effect of fuselage on aerodynamic centre position (Equation (2.2))		
G	function used in estimating effect of fuselage on aerodynamic centre position (Equation (2.2))		
h	height of fuselage at leading edge of root chord of equivalent wing planform	m	ft
K_1, K_2	functions used in estimating effect of fuselage on aerodynamic centre position (Equation (2.2))		
l	overall fuselage length	m	ft
M	free-stream Mach number		
m	fuselage length forward of leading edge of root chord of equivalent wing planform (see Sketch 3.1)	m	ft
N	number of cranks in leading edge of true semi-wing planform		

n	fuselage length aft of trailing edge of root chord of equivalent wing planform (see Sketch 3.1)	m	ft
S	area of equivalent wing planform	m ²	ft ²
S_e	area of planform of true wing outside projected fuselage planform	m ²	ft ²
s	semi-span of wing planform, $b/2$	m	ft
$s_{l,0}$	spanwise distance to side of fuselage planform at point where leading edge of root chord of true wing planform meets side of projected fuselage planform (see Sketch 3.1)	m	ft
$s_{l,i}$	spanwise distance to crank i in leading edge of planform of true wing for $i = 1, 2, \dots, N$ (see Sketch 3.1)	m	ft
$\bar{x}$	chordwise location of aerodynamic centre of equivalent wing planform, measured positive aft from leading edge of aerodynamic mean chord of equivalent wing planform	m	ft
$\bar{\bar{x}}$	chordwise location of leading edge of aerodynamic mean chord of equivalent wing planform, measured positive aft from apex of equivalent wing planform	m	ft
x_f	chordwise location of leading edge of c_f measured positive aft from fuselage nose (see Sketch 3.1)	m	ft
x_h	chordwise location of aerodynamic centre of wing-fuselage combination, measured positive aft from leading edge of aerodynamic mean chord of equivalent wing planform	m	ft
Δx_h	forward shift in chordwise location of aerodynamic centre due to presence of fuselage, $\bar{x} - x_h$	m	ft
$x_{h\text{ ref}}$	chordwise location of aerodynamic centre of wing-fuselage combination, measured positive aft from zero-datum axis (see Sketch 4.1)	m	ft
x_{nose}	chordwise location of fuselage nose, measured positive aft from zero-datum axis (see Sketch 4.1)	m	ft
x_{ref}	chordwise location of general stability calculation reference point, measured positive aft from zero-datum axis (see Sketch 4.1)	m	ft
$\Delta x_{l,i}$	local increase at sawtooth in chordwise distance of wing leading-edge aft of fuselage nose	m	ft
β	compressibility factor, $(1 - M^2)^{1/2}$		
Λ_0	leading-edge sweepback angle of equivalent wing planform	degree	degree
$\Lambda_{1/2}$	half-chord sweepback angle of equivalent wing planform	degree	degree

$\Lambda_{l,i}$	leading-edge sweepback angle of true wing planform between spanwise positions $s_{l,i-1}$ and $s_{l,i}$ for $i = 1, 2, \dots, N$	degree	degree
$\Lambda_{l,N+1}$	leading-edge sweepback angle of true wing planform between spanwise positions $s_{l,N}$ and s	degree	degree
λ	taper ratio of equivalent wing planform, c_t/c_0		

Note: Amendment B of this Item in 1996 involved a reassessment of the rate at which the function F , see Section 2, varied with increase of forebody length. The rate apparent in the data of Derivation 2 was found to be too high in the light of additional data acquired since issue in 1976, Derivations 13 and 14, and from a re-analysis of the data in Derivations 5 to 12 made independently of the data of Derivation 2. The overall form of F in Figure 1 is similar to that of the original Figure but the variation with m/c_r is slower above $m/c_r = 1.5$.

2. OUTLINE OF METHOD

The chordwise position of the wing-fuselage aerodynamic centre, x_h , is calculated by finding the chordwise location of the aerodynamic centre, $\bar{x}$, of a straight-tapered wing planform equivalent to the true wing planform, and then incorporating a correction term Δx_h to allow for the effect of the fuselage. The equivalent wing planform is defined in Section 3. Measured positive aft from the leading edge of the aerodynamic mean chord of the equivalent wing planform, and expressed as a fraction of that chord, the position of the aerodynamic centre is given by the equation

$$\frac{x_h}{\bar{c}} = \frac{\bar{x}}{\bar{c}} - \frac{\Delta x_h}{\bar{c}}. \quad (2.1)$$

The value of $\bar{x} / \bar{c}$ is calculated from ESDU 70011 (Derivation 15), and the correction term $\Delta x_h / \bar{c}$ is given by the equation

$$\frac{\Delta x_h}{\bar{c}} = \frac{c_r d^2 F G}{\bar{c} a S} \left[1 + 0.15 \left(\frac{h}{d} - 1 \right) \right] - (K_1 + \lambda K_2), \quad (2.2)$$

where

F is a function of m/c_r and n/c_r and is plotted in carpet form in Figure 1, see note on page 3,

G is a function of $\beta d/c_r$ and is plotted in Figure 2,

K_1 is a function of d/b , $A \tan \Lambda_{1/2}$ and λ and is plotted in Figure 3 in carpets of $A \tan \Lambda_{1/2}$ and λ for $d/b = 0.08, 0.12$ and 0.16 (see Note below)

and K_2 is a function of βA and $A \tan \Lambda_{1/2}$ and is plotted in carpet form in Figure 4.

(Note: to determine K_1 at other values of d/b , the values of K_1 at the required $A \tan \Lambda_{1/2}$ and λ should be obtained from each of the carpets, and plotted against d/b . The value of K_1 at the required value of d/b is then read from this cross-plot.)

Equation (2.2) was developed from Derivations 1 to 4. Derivation 2 gives a method, based on a series of wind-tunnel tests, for predicting the effect of adding a fuselage to high aspect ratio, unswept wings. This provided the first term in Equation (2.2) which allows for the influence of fuselage length, width and width to height ratio. The function F allows for the effect of varying the fuselage forebody and afterbody lengths; the function G allows for the effect of varying the fuselage width. Derivation 1 suggests that the effect of wing sweepback on aerodynamic centre position can be treated by allowing for the change in spanwise load-grading over the gross wing caused by adding a fuselage. This approach has been adopted here and Derivation 4, which used the method of Derivation 3 to generate systematic theoretical data for the movement in aerodynamic centre position caused by this change in loading, was employed to establish the second term in Equation (2.2) by empirical means. The function K_1 represents the primary effect of wing sweepback and was constructed for $\beta A = 10$; the term λK_2 represents a correction to K_1 to allow for variations in βA . The geometric parameters needed to evaluate F , G , K_1 and K_2 are defined in Section 3.

Section 4 explains how the aerodynamic centre can be referred to reference positions and chords other than those assumed in Equation (2.1).

Note that the effect on aerodynamic centre due to wing-pylon mounted nacelles is obtained from ESDU 77012 (Reference 17) and the effect due to rear-fuselage pylon-mounted nacelles is obtained from ESDU 78013 (Reference 18).

The computer program ESDUpac A1309, associated with ESDU 13009, evaluates the chordwise position of the aerodynamic centre of wing-fuselage-nacelle combinations at subsonic speeds.

3. EQUIVALENT WING PLANFORM*

In calculating x_h for the wing-fuselage combination it is necessary to estimate the aerodynamic centre and lift-curve slope of the gross wing. This was done using ESDU 70011 which presents charts for determining these parameters in terms of aspect ratio, half-chord sweep angle and taper ratio, but only for straight-tapered wing planforms. An equivalent straight-tapered gross wing planform is therefore used to represent the true wing, see Sketch 3.1. When there are no cranks in the true wing planform the equivalent planform results simply from extrapolating to the centre-line the leading and trailing edges of the true wing planform. When there are cranks in the true wing a more complicated construction is needed and the equivalent wing planform is established by defining its tip and root chords in relation to the configuration planform as described here.

The geometric parameters needed to define and position the equivalent wing planform are calculated from the true wing-fuselage planform geometry. Both the fuselage and the wing are projected on to the same horizontal plane so that the vertical position of the wing on the fuselage is immaterial. In this way the intersections of the leading and trailing edges of the wing planform with the sides of the projected fuselage planform define a root chord for the true wing in terms of its length, c_f , and the position of its leading edge from the fuselage nose, x_f , see Sketch 3.1. Usually, the part of the projected fuselage intersected by the true wing planform has parallel sides and c_f is well defined by this procedure. In situations where this part of the fuselage is slightly curved, c_f should be taken as the chordwise distance from the point where the wing leading-edge intersects the fuselage planform to the wing trailing-edge, extended into the fuselage if necessary. This chord then defines a parallel-sided fuselage planform over the wing which is used in the construction of the equivalent gross wing planform.

If the true wing planform has a streamwise tip chord, this is taken, fixed relative to the fuselage planform, as the tip chord, c_t , of the equivalent wing planform. If the true wing has a non-streamwise tip chord or a small curved tip then the linear leading and trailing edges just inboard of the tip, at 0.9s say, are extrapolated outboard and their streamwise separation at maximum span is taken as c_t . The span of the equivalent wing planform is thus the span of the true wing planform.

The root chord of the equivalent wing planform is defined on the side of the fuselage planform. Its length, c_r , is determined such that the exposed planforms of the equivalent and true wings (*i.e.* the planforms outside the fuselage planform) have equal areas. Thus

$$c_r = \frac{S_e}{s - s_{l,0}} - c_t \quad (3.1)$$

where S_e is the area of the exposed panels of the true wing planform. Note that if the true wing does not have a streamwise tip chord, S_e is calculated to the constructed tip chord, c_t .

* Since the equivalent wing planform is a frequently used artifice a more detailed treatment is given in Addendum A to ESDU 76003 (Derivation 16).