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Aerodynamic centre of wing-body combinations

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AERODYNAMIC CENTRE OF WING-BODY COMBINATIONS

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AERODYNAMIC CENTRE OF WING-BODY COMBINATIONS

1. NOTATION AND UNITS (see Sketch 1.1)

		<i>SI</i>	<i>British</i>
A	net wing aspect ratio, $4(s - r)^2/S$		
C_L	lift-coefficient based on net wing area		
C_N	normal force coefficient based on body maximum cross-sectional area		
C_m	pitching moment coefficient about wing-root leading edge based on body maximum cross-sectional area and diameter, positive nose up		
c_r	wing-root chord at wing-body junction, see Sketch 1.1	m	ft
c_t	wing-tip chord, see Sketch 1.1	m	ft
D	body maximum diameter, see Sketch 1.1	m	ft
F	function in Equation (3.3), see Figure 1		
$K_{B(W)}$	ratio of change in body lift due to presence of wing to lift of net wing		
$K_{W(B)}$	ratio of wing lift in presence of body to lift of net wing		
L	overall body length, see Sketch 1.1	m	ft
l_A	afterbody length, see Sketch 1.1	m	ft
l_f	forebody length, see Sketch 1.1	m	ft
M	free-stream Mach number		
R_L	Reynolds number based on overall body length		
r	body maximum radius, see Sketch 1.1	m	ft
S	net wing area, $(s - r)(c_r + c_t)$	m ²	ft ²
s	gross wing semi-span, see Sketch 1.1	m	ft
x_{ac}	distance of aerodynamic centre aft of body nose tip	m	ft
x'_{ac}	distance of aerodynamic centre aft of wing-root leading edge	m	ft

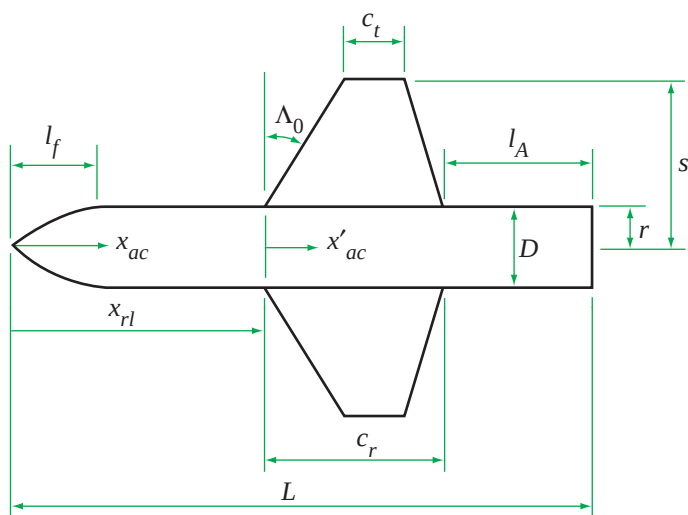
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$(x'_{ac})_{B(W)}$	distance of aerodynamic centre aft of wing-root leading edge of carry-over load on body due to presence of wing	m	ft
$(x'_{ac})_{W(B)}$	distance of aerodynamic centre aft of wing-root leading edge of interference load on wing due to presence of body	m	ft
x_{rl}	distance of wing-root leading edge aft of body nose tip	m	ft
α	angle of attack	radian	radian
β	compressibility parameter, $ M^2 - 1 ^{\frac{1}{2}}$		
Λ_0	sweepback of wing leading-edge	degree	degree
$\Lambda_{1/4}$	sweepback of wing quarter-chord line	degree	degree
$\Lambda_{1/2}$	sweepback of wing mid-chord line	degree	degree
λ	taper ratio, c_t/c_r		

Subscripts

B	denotes body alone
C	denotes combination
W	denotes net wing alone



Sketch 1.1

2. INTRODUCTION

This Item presents a means of estimating the aerodynamic centre at zero angle of attack for configurations comprising an axisymmetric body with a wing mounted at mid-height. The aerodynamic centre is that point about which there is no change of pitching moment due to change of lift. The Item must be used in conjunction with Item No. 91007 (Reference 8), which provides data relating to lift-curve slopes of such configurations. Data are also required for both body and wing in isolation which may be obtained from Item No. 89008 (Reference 6) or 90034 (Reference 7) and Item No. 70011 (Reference 3) or 70012 (Reference 4), respectively. The method is based on Derivation 1, which is further developed in Derivation 2, and is applicable to both subsonic and supersonic speeds.

Within the limits of accuracy of this Item the lift-curve slope may be taken as equal to the normal-force-curve slope. The data are presented graphically, but a complete set of the equations used is given in Appendix A. The use of the method is illustrated by means of a worked example in Section 6.

It should be noted that the method of this Item is applicable to configurations where the wing is mounted on a parallel cylindrical body which has a truncated rear end, as illustrated in Sketch 1.1. For configurations with smoothly tapered afterbodies, such as those found on transport-type aircraft, Item No. 76015 (Reference 5) provides a suitable empirical method, but only for subcritical speeds.

Item No. 92043 (Reference 9) presents a method for estimating the pitching moment coefficient of bodies in combination with delta, cropped delta and rectangular wings up to high angles of attack at supersonic speeds.

Item No. 95009 (Reference 10) presents a method for estimating the effect of wing height on lift and aerodynamic centre of slender wing-body combinations.

3. METHOD

On the basis of Derivation 1, the aerodynamic centre of a wing-body combination, measured aft of the wing root chord leading-edge, is given by

$$\frac{(x'_{ac})_C}{c_r} = \frac{-\left(\frac{\partial C_m}{\partial \alpha}\right)_B \frac{\pi D^3}{4 S c_r} + \left[K_{W(B)} \frac{(x'_{ac})_{W(B)}}{c_r} + K_{B(W)} \frac{(x'_{ac})_{B(W)}}{c_r} \right] \left(\frac{\partial C_L}{\partial \alpha}\right)_W}{\left(\frac{\partial C_L}{\partial \alpha}\right)_C}, \quad (3.1)$$

from which the aerodynamic centre about the nose as a fraction of body length may be obtained using

$$\frac{x_{ac}}{L} = \left[\frac{x_{rl}}{c_r} + \frac{(x'_{ac})_C}{c_r} \right] \frac{c_r}{L}. \quad (3.2)$$

In Equation (3.1) $(\partial C_m / \partial \alpha)_B$ is the body-alone pitching-moment-curve slope about the wing-root leading edge, based on maximum body cross-sectional area and body diameter, and may be found using the method of Item No. 89008 or the computer program of Item No. 90034. The wing alone lift-curve slope, $(\partial C_L / \partial \alpha)_W$, is calculated using Item No. 70011 or 70012 for subsonic or supersonic speeds, respectively. The interference factors $K_{W(B)}$ and $K_{B(W)}$ and the overall lift-curve slope for the combination,

$(\partial C_L / \partial \alpha)_C$, are calculated by means of Item No. 91007. The term $(x'_{ac})_{W(B)}/c_r$ is the aerodynamic centre of the wing in the presence of the body, which on the basis of Derivation 1 may be assumed to be equal to the wing-alone value, $(x'_{ac})_W/c_r$, and is thus obtained from Item No. 70011 or 70012*.

The term $(x'_{ac})_{B(W)}/c_r$ is the aerodynamic centre of the interference load on the body load due to the presence of the wing and requires different treatment for subsonic and supersonic speeds.

At subsonic speeds $(x'_{ac})_{B(W)}/c_r$ is given by

$$\frac{(x'_{ac})_{B(W)}}{c_r} = \frac{1}{4} + \frac{1 + \lambda}{4} F A \tan \Lambda_{1/4}, \quad (3.3)$$

which was obtained in Derivation 1. The function F has been introduced to aid ease of calculation and is presented in Figure 1 as a function of r/s . It should be noted that the full equation, given in Appendix A, is mathematically constrained to $r/s \leq 0.5$, but good results have been obtained up to $r/s = 0.8$ by extrapolation. Since slender-body theory is known to give more accurate values of $(x'_{ac})_{B(W)}/c_r$ at low aspect ratios, Derivation 1 recommends that for equivalent aspect ratios $\beta A < 4$, $(x'_{ac})_{B(W)}/c_r$ should be found by interpolating in βA between the value given by Equation (3.3), and the value for $\beta A = 0$ as obtained by slender-body theory and given in Figure 2. Equation (3.3) is invariant with βA and so the interpolated curve should have zero gradient for $\beta A \geq 4$. A suitable interpolation procedure is given in Appendix B.

At supersonic speeds $(x'_{ac})_{B(W)}/c_r$ is evaluated from Figure 3, which is based on equations from Derivations 1 and 2. Strictly, this Figure is valid only for cases where the Mach line originating from the wing-tip leading edge passes downstream of the root chord, *i.e.* for cases when

$$c_r < (s - r)(\tan \Lambda_0 + \beta) \text{ or, equivalently, } \beta A(1 + \lambda) \left(\frac{1}{\beta \cot \Lambda_0} + 1 \right) > 4. \quad (3.4)$$

During the development of Figure 3 it was found that $(x'_{ac})_{B(W)}/c_r$ was only a weak function of the parameter $\beta \cot \Lambda_0$ over the whole range of its practical values and those of the other parameters $2r\beta/c_r$ and $l_A/2r\beta$. In order to eliminate $\beta \cot \Lambda_0$, and thus simplify the calculation, Figure 3 was constructed by taking the average of the values for $(x'_{ac})_{B(W)}/c_r$ corresponding to $\beta \cot \Lambda_0$ equal to 0.1 and infinity, as obtained from the exact equations given in Appendix A. The resulting estimates were found to be within $\pm 5\%$ of the exact values of $(x'_{ac})_{B(W)}/c_r$. Derivation 1 advocates that for low aspect ratio wings ($\beta A < 2$), including those not satisfying the inequality (3.4), an interpolation should be performed in βA between the slender body result for $\beta A = 0$, given in Figure 2, and the values from Figure 3 for $\beta A \geq 2$. By varying the parameter $2r\beta/c_r$ the quantity $(x'_{ac})_{B(W)}/c_r$ is found to be so nearly linear in βA that the gradient of the curve at $\beta A = 2$ may be taken as the slope between $\beta A = 2$ and $\beta A = 3$. Appendix B provides a suitable interpolation procedure for the range $\beta A < 2$.

4. ACCURACY AND APPLICABILITY

The method of this Item is restricted to thin straight-tapered wings mounted at mid-height on an axisymmetric body. Although this Item may strictly be used only to estimate aerodynamic centres of wing-body combinations with wings having unswept or swept-forward trailing edges, it is expected that within the general accuracy of the Item estimates may be made for wings with moderately sweptback trailing-edges of up to 10° , say.

* The quantity $(x'_{ac})_{W(B)}/c_r$ is the equivalent of $(\bar{x} + \bar{x}_0)/c_r$ in the notation of Item No. 70011 or 70012 for the net wing values of βA , $A \tan \Lambda_{1/2}$ and λ .