



Normal force and pitching moment of non-axisymmetric bodies: square cross-sections with corner rounding

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NORMAL FORCE AND PITCHING MOMENT OF NON-AXISYMMETRIC BODIES: SQUARE CROSS-SECTIONS WITH CORNER ROUNDING

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NORMAL FORCE AND PITCHING MOMENT OF NON-AXISYMMETRIC BODIES: SQUARE CROSS-SECTIONS WITH CORNER ROUNDING

1. NOTATION AND UNITS

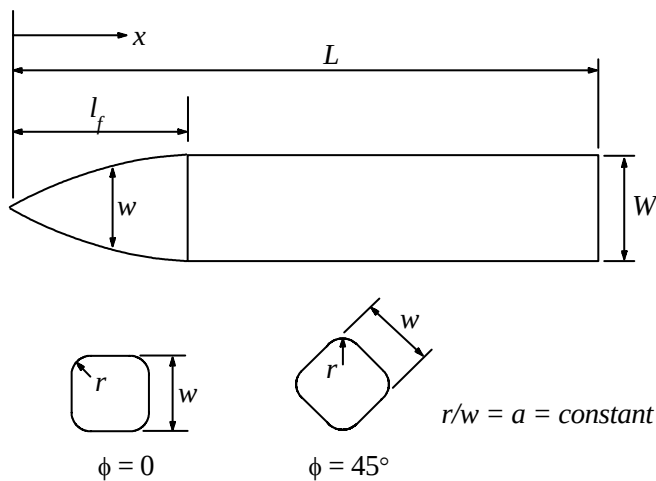
		<i>SI</i>	<i>British</i>
A_m	maximum cross-sectional area of body	m ²	ft ²
a	rounding parameter, r/w		
C_m	pitching moment coefficient, based on A_m and W , about reference point x_m , positive nose-up		
$(C_m)_0$	pitching moment coefficient, based on A_m and W , about reference point $x_m = 0$, positive nose-up		
$(C_m)_{0\alpha}$	pitching-moment-curve slope, $d(C_m)_0/d\alpha$	rad ⁻¹	rad ⁻¹
C_N	normal force coefficient, based on A_m		
$C_{N\alpha}$	normal-force-curve slope, $dC_N/d\alpha$	rad ⁻¹	rad ⁻¹
d	circular body diameter, see Section 3	m	ft
d_{eq}	equivalent circular body diameter, see Equation (3.3)	m	ft
F	tangent ogive parameter, see Table 3.1		
F_a	interpolation factor, see Section 3		
K_L	ratio of linear contribution to normal force of non-circular body to that of circular body with same cross-sectional area distribution, see Equation (3.2)		
K_M	empirical factor on linear contribution to pitching moment, see Equation (3.7)		
K_ϕ	factor to allow for roll angle, see Sketch 4.1		
L	overall body length, see Sketch 1.1	m	ft
l_f	forebody length, see Sketch 1.1	m	ft
M_∞	freestream Mach number		
R_L	Reynolds number based on freestream conditions and body length		
r	local corner radius, see Sketch 1.1	m	ft

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W	maximum width of body, see Sketch 1.1	m	ft
w	local width of body, see Sketch 1.1 and Table 3.1	m	ft
x	distance aft of forebody apex	m	ft
x_{cp}	distance of centre of pressure position aft of forebody apex	m	ft
x_m	distance of moment reference point aft of forebody apex	m	ft
α	angle of attack	deg/rad	deg/rad
ϕ	body roll angle	deg	deg

Subscripts

$[]_{NL,a=0}$	denotes non-linear contribution for square body
$[]_{NL,a=0.5}$	denotes non-linear contribution for circular body
$[]_{NL,a,\phi=0}$	denotes non-linear contribution for body with corner rounding at $\phi = 0$
$[]_{NL,a,\phi=45^\circ}$	denotes non-linear contribution for body with corner rounding at $\phi = 45^\circ$



Sketch 1.1 Body geometry

2. INTRODUCTION

This Item presents a semi-empirical means of estimation for normal force and pitching moment of forebody-cylinder combinations whose cross-sections are square with corner rounding, the cross-sectional shape being maintained along the entire body length ($r/w = \text{constant}$). Although the method is derived from test data for bodies with tangent-ogival and conical forebodies, the method can, with care, be applied to other forebody profiles. A primary requirement of the method is that the distribution of cross-sectional area along the non-circular body can be modelled by an 'equivalent' axisymmetric body for which normal-force-curve and pitching-moment-curve slopes at zero angle of attack are either known or can be calculated. Such data may be found in ESDU 89008 (Derivation 3), which is programmed in part in ESDUpac A9034 (the user guide is ESDU 90034, Derivation 5), and covers a range of typical forebody profiles, see Section 4.

The method for normal force and pitching moment is given in Section 3 and its accuracy and applicability are discussed in Section 4. The use of the method is illustrated in Section 6 by means of a worked example.

A method for the prediction of normal force and pitching moment for bodies of circular cross-section is given in ESDU 89014 (Derivation 4) and presented as a computer program in ESDUpac A9034. A method for square bodies without corner rounding is given in ESDU 04007 (Derivation 7) and a method for bodies of elliptical cross-section at supersonic speeds is given in ESDU 05015 (Reference 10).

3. METHOD

3.1 Normal Force Coefficient

The method assumes that the variation of normal force with angle of attack may be represented using the classic two-component model. The first component is a potential flow contribution, which dominates at low angle of attack, and the second is a viscous cross-flow contribution, which becomes increasingly important with higher angle of attack. The equation for normal force coefficient is

$$C_N = K_L C_{N\alpha} \sin \alpha \cos \alpha + F_a \left\{ [C_N]_{NL,a=0} - [C_N]_{NL,a=0.5} \right\} + [C_N]_{NL,a=0.5} \quad (3.1)$$

In Equation (3.1) the factor K_L is the ratio of linear contribution to normal force of the non-circular body to that of a circular body with the same cross-sectional area. The values for K_L are taken as those predicted by slender-body theory and vary linearly from 1.19 for zero corner rounding ($a = 0$) to unity for a circular body ($a = 0.5$), and are thus given by Equation (3.2) which is independent of roll angle,

$$K_L = 1.19 - 0.38a \quad (3.2)$$

The quantity $C_{N\alpha}$ is the normal-force-curve slope of the equivalent circular body, which is defined as the axisymmetric body with the same distribution of cross-sectional area, and may be either calculated by hand using ESDU 89008 or computed using ESDUpac A9034 for tangent-ogival, conical, paraboloidal or ellipsoidal forebody profiles (see Table 3.1) and other shapes including secant ogival and spherically-blunted. The equivalent circular body diameter, d_{eq} , for bodies of square cross-sections with circular corner rounding is given by

$$\frac{d_{eq}}{W} = 2 \sqrt{\frac{1 - (4 - \pi)a^2}{\pi}} \quad (3.3)$$