



# ESDU 04007

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## **Normal force and pitching moment of non-axisymmetric bodies: square and triangular cross-sections without corner rounding**

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## NORMAL FORCE AND PITCHING MOMENT OF NON-AXISYMMETRIC BODIES: SQUARE AND TRIANGULAR CROSS-SECTIONS WITHOUT CORNER ROUNDING

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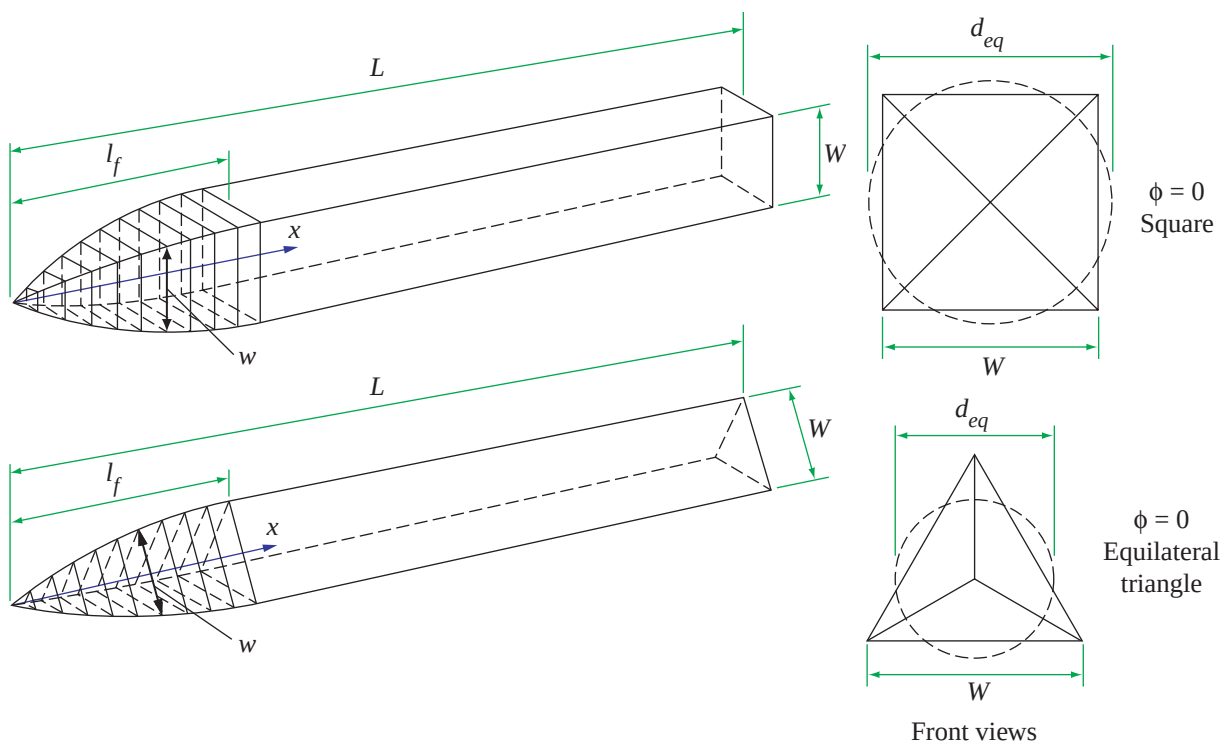
## NORMAL FORCE AND PITCHING MOMENT OF NON-AXISYMMETRIC BODIES: SQUARE AND TRIANGULAR CROSS-SECTIONS WITHOUT CORNER ROUNDING

### 1. NOTATION AND UNITS

|                   |                                                                                                                                                                          | SI                | British           |
|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------|
| $C_C$             | forebody centroid of planform area coefficient, $2x_{Pf}/l_f$ , see Table 3.2                                                                                            |                   |                   |
| $C_{Dc}$          | cross-flow drag coefficient, based on $S_P$ , see Figures 1 and 2                                                                                                        |                   |                   |
| $C_m$             | pitching moment coefficient, based on $S_m$ and $d_{eq}$ , about reference point $x_m$ , positive nose-up                                                                |                   |                   |
| $(C_m)_0$         | pitching moment coefficient, based on $S_m$ and $d_{eq}$ , about reference point $x_m = 0$ , positive nose-up                                                            |                   |                   |
| $(C_m)_{0\alpha}$ | pitching-moment-curve slope, $d(C_m)_0/d\alpha$                                                                                                                          | $\text{rad}^{-1}$ | $\text{rad}^{-1}$ |
| $C_N$             | normal force coefficient, based on $S_m$                                                                                                                                 |                   |                   |
| $C_{N\alpha}$     | normal-force-curve slope, $dC_N/d\alpha$                                                                                                                                 | $\text{rad}^{-1}$ | $\text{rad}^{-1}$ |
| $C_P$             | forebody planform area coefficient, $S_{Pf}/(l_f W)$ , see Table 3.2                                                                                                     |                   |                   |
| $d_{eq}$          | equivalent circular body diameter, see Table 3.1                                                                                                                         | m                 | ft                |
| $F$               | tangent ogive parameter, see Table 3.2                                                                                                                                   |                   |                   |
| $K_L$             | ratio of linear contribution to normal force of non-circular body to that of circular body with same cross-sectional area distribution, see Equation (3.1) and Table 3.1 |                   |                   |
| $K_M$             | empirical factor on linear contribution to pitching moment, see Equation (3.4) and Table 3.1                                                                             |                   |                   |
| $K_\phi$          | factor to allow for roll angle effect on $C_{Dc}$ , see Figures 3 and 4                                                                                                  |                   |                   |
| $l_f$             | forebody length, see Sketch 1.1                                                                                                                                          | m                 | ft                |
| $L$               | overall body length, see Sketch 1.1                                                                                                                                      | m                 | ft                |
| $M_\infty$        | freestream Mach number                                                                                                                                                   |                   |                   |
| $R_L$             | Reynolds number based on freestream conditions and body length                                                                                                           |                   |                   |

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|          |                                                                                |         |         |
|----------|--------------------------------------------------------------------------------|---------|---------|
| $S_m$    | maximum cross-sectional area of body                                           | $m^2$   | $ft^2$  |
| $S_p$    | planform area of body at $\phi = 0$ , see Table 3.1                            | $m^2$   | $ft^2$  |
| $S_{pf}$ | planform area of forebody at $\phi = 0$                                        | $m^2$   | $ft^2$  |
| $W$      | maximum width of side of square or triangular body, see Sketch 1.1             | m       | ft      |
| $w$      | local width of side of square or triangular body, see Sketch 1.1 and Table 3.2 | 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      |
| $x_p$    | distance of centroid of planform area aft of forebody apex, see Table 3.1      | m       | ft      |
| $x_{pf}$ | distance of centroid of forebody planform area aft of forebody apex            | m       | ft      |
| $\alpha$ | angle of attack                                                                | deg/rad | deg/rad |
| $\phi$   | body roll angle                                                                | deg     | deg     |



Sketch 1.1 Body geometry (oblique views illustrate tangent-ogival forebody)

## 2. INTRODUCTION

This Data Item presents a semi-empirical means of estimation for normal force and pitching moment of forebody-cylinder combinations whose cross-sections are either a square or an equilateral triangle, without corner rounding. Although the method is derived from test data for bodies with mostly tangent-ogival and some conical profile 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 Item No. 89008 (Derivation 8), which is programmed in part in Item No. 90034 (Derivation 9), and covers a range of typical forebody profiles, see Sections 3 and 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 Item No. 89014 (Reference 13) and presented as a computer program in Item No. 90034 (Derivation 9).

## 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 a second, viscous cross-flow contribution, which becomes increasingly important with higher angle of attack. The equation for normal force is given by

$$C_N = K_L C_{N\alpha} \sin \alpha \cos \alpha + C_{Dc} \frac{S_p}{S_m} \sin^2 \alpha. \quad (3.1)$$

In Equation (3.1) the factor  $K_L$  is the ratio of the linear contribution to normal force of the non-circular body to that of a circular body with the same cross-sectional area distribution and is calculated from slender-body theory. The values for  $K_L$  are given in Table 3.1 and are independent of roll angle.

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 calculated from Item No. 89008 (or ESDUpac A9034) for tangent-ogival, conical, paraboloidal, ellipsoidal profiles and other shapes including secant-ogival and spherically-blunted shapes. The equivalent circular body diameter,  $d_{eq}$ , for bodies of square and triangular cross-sections is given in Table 3.1.

The quantity  $S_p$  is the planform area of the body at  $\phi = 0$  and  $S_m$  is the maximum cross-sectional area. Equations for the ratio  $S_p/S_m$  are given in Table 3.1 and they require a value for the forebody planform area coefficient,  $C_p$ . These are presented in Table 3.2 for forebodies of tangent-ogival, conical, paraboloidal and ellipsoidal profiles, together with equations showing the variation of local body width,  $w$ , along the forebody. Values of  $C_p$  for a number of other profiles including secant-ogival and spherically-blunted shapes may be found in Item No. 77028 (Reference 12).

Equation (3.1) has been used to extract experimental values of the cross-flow drag coefficient,  $C_{Dc}$  (based on  $S_p$ ), from the test data for normal force coefficient of square bodies (Derivations 1, 2, 4, 5, 7, 10 and 11) at zero and 45 degrees of roll angle ('diamond shape') and for triangular bodies (Derivations 1, 3 and 6) at