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## Normal force and pitching moment of conical boat-tails

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## THE PREPARATION OF THIS DATA ITEM

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NORMAL FORCE AND PITCHING MOMENT OF CONICAL BOAT-TAILS

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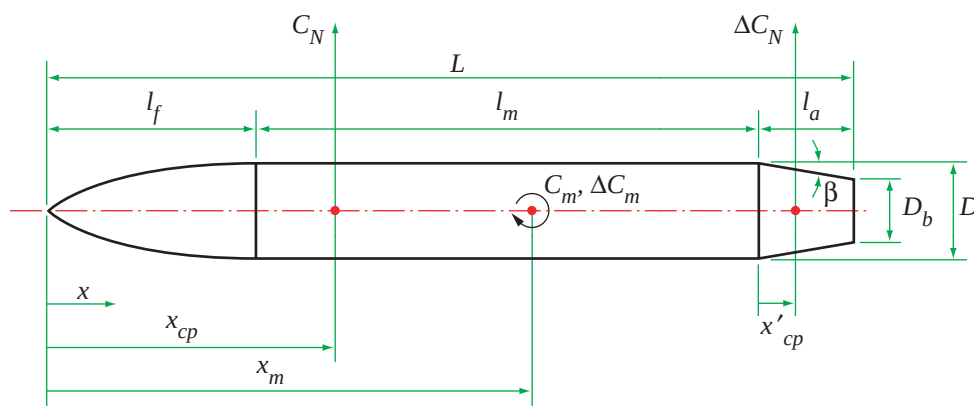
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## NORMAL FORCE AND PITCHING MOMENT OF CONICAL BOAT-TAILS

### 1. NOTATION AND UNITS (see Sketch 1.1)

|                      |                                                                                                                                                                    | SI                | British           |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------|
| $\Delta C_{Dc}$      | change in cross-flow drag coefficient due to boat-tailing, based on $S_{ref}$ (Figure 2)                                                                           |                   |                   |
| $C_m$                | pitching moment coefficient about axis $x = x_m$ for body with no boat-tailing ( $\beta = 0$ ), (pitching moment)/ $\frac{1}{2}\rho_\infty V_\infty^2 S_{ref} D$   |                   |                   |
| $(C_m)_{BT}$         | pitching moment coefficient about axis $x = x_m$ , for body with boat-tailing, (pitching moment)/ $\frac{1}{2}\rho_\infty V_\infty^2 S_{ref} D$ , positive nose-up |                   |                   |
| $\Delta C_m$         | change in pitching moment coefficient due to boat-tailing, $(C_m)_{BT} - C_m$                                                                                      |                   |                   |
| $C_N$                | normal force coefficient, (normal force)/ $\frac{1}{2}\rho_\infty V_\infty^2 S_{ref}$ , for body with no boat-tailing ( $\beta = 0$ )                              |                   |                   |
| $(C_N)_{BT}$         | normal force coefficient, (normal force)/ $\frac{1}{2}\rho_\infty V_\infty^2 S_{ref}$ , for body with boat-tailing                                                 |                   |                   |
| $\Delta C_N$         | change in normal force coefficient due to boat-tailing, $(C_N)_{BT} - C_N$                                                                                         |                   |                   |
| $\Delta C_{N\alpha}$ | change in normal-force-curve slope at zero angle of attack due to boat-tailing (Figure 1)                                                                          | rad <sup>-1</sup> | rad <sup>-1</sup> |
| $D$                  | body maximum diameter                                                                                                                                              | m                 | ft                |
| $D_b$                | body base diameter                                                                                                                                                 | m                 | ft                |
| $L$                  | body total length                                                                                                                                                  | m                 | ft                |
| $l_a$                | boat-tail length                                                                                                                                                   | m                 | ft                |
| $l_f$                | forebody length                                                                                                                                                    | m                 | ft                |
| $l_m$                | mid-body length                                                                                                                                                    | m                 | ft                |
| $M_\infty$           | free-stream Mach number                                                                                                                                            |                   |                   |
| $R_D$                | Reynolds number based on free-stream flow conditions and body maximum diameter                                                                                     |                   |                   |
| $R_L$                | Reynolds number based on free-stream flow conditions and body length                                                                                               |                   |                   |

|                 |                                                                                                              |               |               |
|-----------------|--------------------------------------------------------------------------------------------------------------|---------------|---------------|
| $S_{ref}$       | reference area, $\pi D^2/4$                                                                                  | $m^2$         | $ft^2$        |
| $V_\infty$      | free-stream velocity                                                                                         | $m/s$         | $ft/s$        |
| $x$             | body axial co-ordinate, origin at nose                                                                       | $m$           | $ft$          |
| $x_{cp}$        | axial location of centre of pressure for body with no boat-tailing ( $\beta = 0$ )                           | $m$           | $ft$          |
| $(x_{cp})_{BT}$ | axial location of centre of pressure for body with boat-tailing                                              | $m$           | $ft$          |
| $\Delta x_{cp}$ | shift in location of centre of pressure due to boat-tailing,<br>$(x_{cp})_{BT} - x_{cp}$                     | $m$           | $ft$          |
| $x'_{cp}$       | axial location of centre of normal force due to boat-tailing,<br>measured positive aft of boat-tail shoulder | $m$           | $ft$          |
| $x_m$           | axial distance from nose to pitching axis                                                                    | $m$           | $ft$          |
| $\alpha$        | body angle of attack                                                                                         | rad or<br>deg | rad or<br>deg |
| $\beta$         | boat-tail angle                                                                                              | deg           | deg           |
| $\rho_\infty$   | free-stream density                                                                                          | $kg/m^3$      | $slug/ft^3$   |



**Sketch 1.1 Body geometry**

The relationship between the various boat-tail geometrical parameters is given by

$$\frac{D_b}{D} = 1 - 2 \frac{l_a}{D} \tan \beta. \quad (1.1)$$

## 2. INTRODUCTION

This Item provides a simple empirical method of estimating the effects of moderate conical boat-tailing on the normal force and pitching moment of any axisymmetric forebody-cylinder combination at Mach numbers up to 5.0 and angles of attack up to 90 degrees\*.

The main object of boat-tailing a missile or projectile body is to reduce its drag. However, there are accompanying penalties in that the normal force is reduced and the centre of pressure is moved forward, thereby reducing the static stability of the configuration. The effect on normal force of the moderate amounts of boat-tailing typical of missiles or projectiles is usually relatively minor. The effect on pitching moment is obviously dependent on the moment arm; for a long missile body considerable movements of the centre of pressure can be imposed, sometimes resulting in locations ahead of the nose at low angles of attack.

Estimates for the normal force and pitching moment of forebody-cylinders without boat-tailing may be obtained from Item Nos 89008 and 89014 (References 8 and 9).

## 3. METHOD

The traditional mathematical model for the normal force on a forebody-cylinder can be modified to model the normal force change due to conical boat-tailing as

$$\Delta C_N = \Delta C_{N\alpha} \sin \alpha \cos \alpha (1 - \sin^{0.6} \alpha) + \Delta C_{Dc} \sin^2 \alpha, \quad (3.1)$$

in which the first term is the inviscid contribution based on slender-body theory and the second term is the viscous cross-flow contribution. In Equation (3.1) the quantity  $\Delta C_{N\alpha}$  is the change in normal-force-curve slope at zero angle of attack due to conical boat-tailing, given by Figure 1. That Figure, which presents  $\Delta C_{N\alpha}/[1 - (D_b/D)^2]$  against Mach number was obtained from a correlation of experimental data (Derivations 1 to 7) for projectile-type bodies over a wide range of Mach number ( $0.2 \leq M_\infty \leq 5.0$ ). At subsonic speeds the data correlated well at a constant value of  $\Delta C_{N\alpha}/[1 - (D_b/D)^2]$  equal to -2, which is the value predicted by slender-body theory. At Mach numbers greater than unity, however, the data indicated decreasing magnitudes of  $\Delta C_{N\alpha}/[1 - (D_b/D)^2]$  with increasing Mach number at a rate which varied systematically with boat-tail fineness ratio (see Figure 1). The factor  $(1 - \sin^{0.6} \alpha)$  accounts for the decrease in the inviscid contribution to normal force at angle of attack due to losses arising from the thickening of the boundary layer and flow separation on the boat-tail (see Section 4).

The change in cross-flow drag coefficient due to conical boat-tailing,  $\Delta C_{Dc}$ , is given by Figure 2, which presents  $\Delta C_{Dc}/[(l_a/D)(1 - D_b/D)]$  against the cross-flow Mach number,  $M_\infty \sin \alpha$ . The curve was obtained from a correlation of experimental data for  $\Delta C_N$  at angle of attack, analysed using Equation (3.1) and Figure 1. The effect of the denominator  $(l_a/D)(1 - D_b/D)$  in the ordinate parameter is associated with the conversion of the cross-flow drag coefficient from one based on body maximum cross-sectional area to one based on the loss in planform area due to boat-tailing. Figure 2 should be treated with caution, however, since the only data available with significant cross-flow effects (Derivations 6 and 7) relate to two bodies each tested with only one boat-tail geometry (see Section 4).

The normal force coefficient for a boat-tailed body is given by

$$(C_N)_{BT} = C_N + \Delta C_N, \quad (3.2)$$

\* The method of this Item is incorporated in a computer program written by the Computer Products Group of ESDU International (see Item No. 90034, Reference 10), available on diskette in the Aerodynamics Software Volume and on the CD-Rom.