



# ESDU 91042

Issued November 1991

With Amendment A

January 1993

Supersedes ESDU 68022

## Normal force of low aspect ratio wing-body combinations up to high angles of attack at supersonic speeds

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## THE PREPARATION OF THIS DATA ITEM

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NORMAL FORCE OF LOW ASPECT RATIO WING-BODY COMBINATIONS UP TO HIGH ANGLES OF ATTACK AT SUPERSONIC SPEEDS

CONTENTS

|                               | Page     |
|-------------------------------|----------|
| 1. NOTATION AND UNITS         | 1        |
| 2. INTRODUCTION               | 2        |
| 3. METHOD                     | 3        |
| 4. APPLICABILITY AND ACCURACY | 3        |
| 5. DERIVATION AND REFERENCES  | 5        |
| 5.1 Derivation                | 5        |
| 5.2 References                | 6        |
| 6. EXAMPLE                    | 8        |
| FIGURES 1 TO 3                | 11 to 16 |

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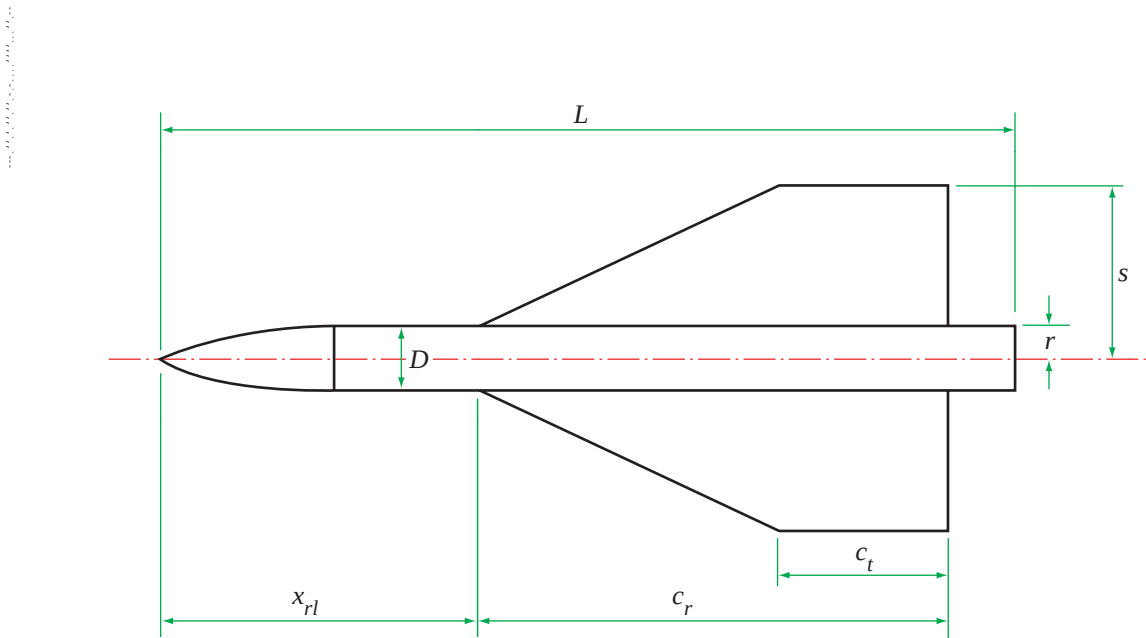
## NORMAL FORCE OF LOW ASPECT RATIO WING-BODY COMBINATIONS UP TO HIGH ANGLES OF ATTACK AT SUPERSONIC SPEEDS

### 1. NOTATION AND UNITS

|            |                                                                                             | <i>SI</i>        | <i>British</i>      |
|------------|---------------------------------------------------------------------------------------------|------------------|---------------------|
| $A$        | aspect ratio of net wing, $4(s-r)/(c_r + c_t)$                                              |                  |                     |
| $C_{NB}$   | body-alone normal force coefficient, based on $S_B$ and $q$                                 |                  |                     |
| $C_{NC}$   | normal force coefficient of wing-body combination, based on $S_B$ and $q$                   |                  |                     |
| $C_{NW}$   | wing-alone normal force coefficient, based on $S_W$ and $q$                                 |                  |                     |
| $c_r$      | wing root chord, see Sketch 1.1                                                             | m                | ft                  |
| $c_t$      | wing tip chord, see Sketch 1.1                                                              | m                | ft                  |
| $D$        | maximum diameter of body, $2r$ , see Sketch 1.1                                             | m                | ft                  |
| $K$        | factor applied to $C_{NW}$ , see Section 3                                                  |                  |                     |
| $K_{B(W)}$ | linear normal force interference factor due to effect of wing on body (from Item No. 91007) |                  |                     |
| $K_{W(B)}$ | linear normal force interference factor due to effect of body on wing (from Item No. 91007) |                  |                     |
| $K_{W(V)}$ | normal force interference factor due to effect of body vortices on wing                     |                  |                     |
| $k$        | compressibility factor on $K_{W(B)}$                                                        |                  |                     |
| $L$        | total length of body, see Sketch 1.1                                                        | m                | ft                  |
| $M$        | free-stream Mach number                                                                     |                  |                     |
| $p$        | free-stream static pressure                                                                 | N/m <sup>2</sup> | lbf/ft <sup>2</sup> |
| $q$        | kinetic pressure, $\frac{1}{2}\rho V^2$ or $\frac{1}{2}\gamma p M^2$                        | N/m <sup>2</sup> | lbf/ft <sup>2</sup> |
| $r$        | maximum radius of body, $D/2$ , see Sketch 1.1                                              | m                | ft                  |
| $S_B$      | body maximum cross-sectional area, $\pi r^2$                                                | m <sup>2</sup>   | ft <sup>2</sup>     |
| $S_W$      | net wing area, $(s-r)(c_r + c_t)$                                                           | m <sup>2</sup>   | ft <sup>2</sup>     |
| $s$        | wing semi-span, see Sketch 1.1                                                              | m                | ft                  |

Issued November 1991  
With Amendment A, January 1993 – 16 pages

|           |                                                                                                   |                   |                      |
|-----------|---------------------------------------------------------------------------------------------------|-------------------|----------------------|
| $V$       | free-stream velocity                                                                              | m/s               | ft/s                 |
| $x_{rl}$  | axial distance from tip of nose to wing root leading-edge, see Sketch 1.1                         | m                 | ft                   |
| $x_s$     | axial distance from tip of nose to vortex separation point                                        | m                 | ft                   |
| $\alpha$  | angle of attack                                                                                   | degrees           | degrees              |
| $\gamma$  | ratio of specific heat capacity at constant pressure to specific heat capacity at constant volume |                   |                      |
| $\lambda$ | taper ratio of net wing, $c_t/c_r$                                                                |                   |                      |
| $\rho$    | free-stream density                                                                               | kg/m <sup>3</sup> | slug/ft <sup>3</sup> |



Sketch 1.1 Wing-body geometry

2. INTRODUCTION

This Item presents a method for estimating the normal force coefficient for delta, cropped delta and rectangular wings mounted at mid-height on an axisymmetric body. The method is applicable, within the Mach number range 1.2 to 5.0, to configurations having thin, sharp-edged wings with no camber or twist with an aspect ratio in the range 0.2 to 4.0, at angles of attack up to 60 degrees, and it is based primarily on Derivation 6, modified in the light of subsequent work reported in Derivations 11 and 14. The method is for the condition of zero roll and can therefore also be applied to cruciform wings at this condition.

The method is outlined in Section 3 and is illustrated by means of a worked example in Section 6. A guide to the accuracy and applicability of the method may be found in Section 4.

A method for the pitching moment coefficient up to high angles of attack at supersonic speeds may be found in Item No. 92043 (Reference 27).

### 3. METHOD

The normal force coefficient,  $C_{NC}$ , of a wing-body combination at supersonic speed can be considered to consist of a component due to the body, a component due to the wing, components due to interference effects of the wing on the body, the body on the wing, and the body vortices on the wing. In this method the body-alone normal force is considered as the starting point and it is assumed that the wing-body and vortex-wing interference effects can be accounted for as factors on the isolated net wing normal force. Thus the equation for  $C_{NC}$  is

$$C_{NC} = C_{NB} + KC_{NW}, \quad (3.1)$$

where  $C_{NB}$  is the body-alone contribution, and may be obtained from test data or calculated from Item No. 89014 (Reference 23) or 90034 (Reference 25). The net wing-alone normal force,  $C_{NW}$ , may be obtained from test data or calculated from Item No. 90013 (Reference 24). The derived wing contribution to normal force is  $KC_{NW}$ , where

$$K = [K_{B(W)} + 1 + k(K_{W(B)} - 1) + K_{W(V)}] \frac{S_W}{S_B}. \quad (3.2)$$

In Equation (3.2)  $K_{B(W)}$  and  $K_{W(B)}$  are normal force ratio factors which are obtained from Item No. 91007 (Reference 26) and  $k$  is a compressibility factor due to the cross-flow Mach number, taken directly from Derivation 11 and reproduced in Figure 1.

The effect of the body vortices on the wing is dependent on the position of the vortices in the plane of the wing root leading edge which, in turn, is dependent on the location of the point of separation of the vortices from the body. Figure 2 gives the location of separation of the vortices in the non-dimensional form  $x_s/r$  as a function of angle of attack for laminar and turbulent boundary layers. This figure is based on work in Derivation 5 and includes data from various sources. If the location of vortex separation is aft of the wing root leading edge, there is no vortex contribution. Figures 3a to 3e present the vortex interference factor,  $K_{W(V)}$ , as a function of  $[(x_{rl}/r) - (x_s/r)] \sin \alpha$  and  $r/s$  for taper ratios ( $\lambda$ ) of 0, 0.25, 0.5, 0.75 and 1, respectively. These Figures were developed by combining the methods for estimating vortex position, strength and interference given in Derivations 3 and 14 to enable a rapid evaluation of  $K_{W(V)}$  to be made. Estimates of  $K_{W(V)}$  at intermediate values of  $\lambda$  may be obtained by cross-plotting.

### 4. APPLICABILITY AND ACCURACY

The method of this Item is applicable to configurations employing thin, sharp-edged wings, without camber or twist, mounted at mid-height on an axisymmetric forebody-cylinder combination. The root chord of the wing must not extend beyond the parallel section of the body. The method is for the “zero” roll angle condition, but roll angles of up to  $\pm 5^\circ$ , say, can be expected to have a negligible effect.

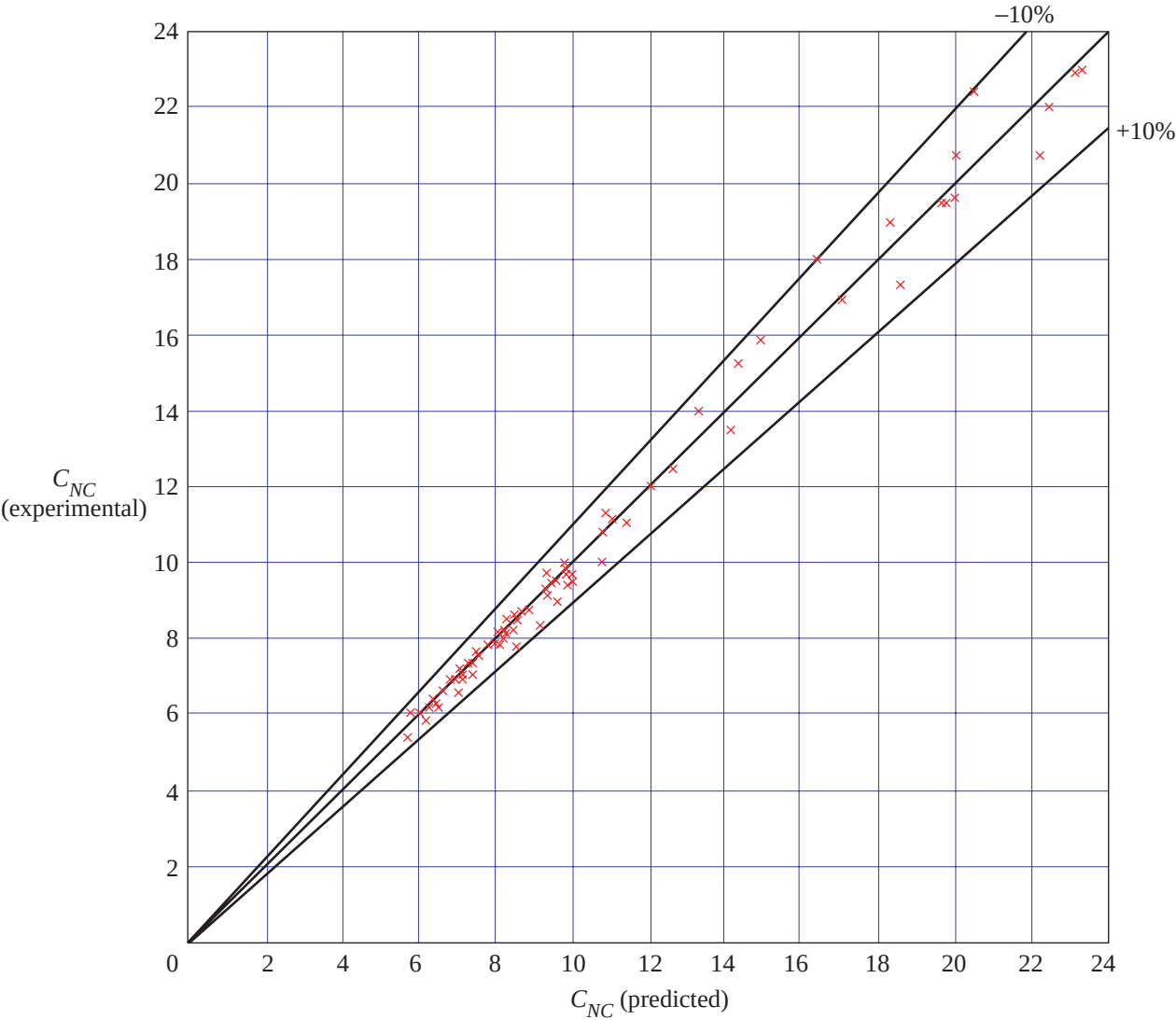
During the development of the Item many data sources were collected, from which Derivations 1, 2, 4, 6 to 10, 12, 13 and 15 to 22 were selected for the purpose of evaluating the method over a wide range of parameters, see Table 4.1. Item Nos 90034 and 90013 were used to predict the body-alone and net wing-alone normal force coefficients.

When the predicted values of  $C_{NC}$  were compared with the experimental data from all sources over the full ranges of angle of attack and Mach number, an accuracy of  $\pm 10\%$  was indicated. As an illustration, Sketch 4.1 shows that predicted and experimental values of normal force coefficient at angles of attack between 20 and 25 degrees agree within this accuracy.

TABLE 4.1 Ranges of experimental data

| $\alpha$ (degrees) | $M$        | $A$        | $\lambda$ | $s/r$      | $L/D$    |
|--------------------|------------|------------|-----------|------------|----------|
| 0 to 60            | 1.2 to 5.0 | 0.2 to 4.0 | 0 to 1    | 2.1 to 8.0 | 10 to 20 |

The method should be used with caution outside the range of parameters given in Table 4.1.



Sketch 4.1 Correlation for  $20^{\circ} \leq \alpha \leq 25^{\circ}$