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Normal force and pitching moment of low aspect ratio cropped-delta wings up to high angles of attack at supersonic speeds

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NORMAL FORCE AND PITCHING MOMENT OF LOW ASPECT RATIO CROPPED-DELTA WINGS UP TO HIGH ANGLES OF ATTACK AT SUPERSONIC SPEEDS

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	2
3. METHOD	2
3.1 Normal Force	2
3.2 Pitching Moment	3
4. ACCURACY AND APPLICABILITY	4
5. DERIVATION AND REFERENCES	5
5.1 Derivation	5
5.2 References	6
6. EXAMPLE	6
6.1 Normal Force	7
6.2 Pitching Moment	7
FIGURES 1a to 5	10 to 19

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NORMAL FORCE AND PITCHING MOMENT OF LOW ASPECT RATIO CROPPED-DELTA WINGS UP TO HIGH ANGLES OF ATTACK AT SUPERSONIC SPEEDS

1. NOTATION AND UNITS

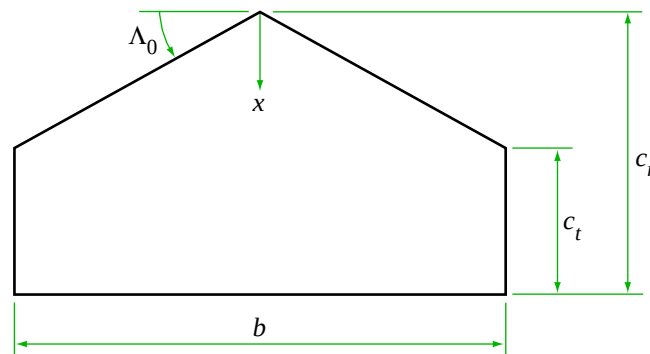
		SI	British
A	aspect ratio, b^2/S		
b	wing span, see Sketch 1.1	m	ft
C_L	lift coefficient, (lift) / $\frac{1}{2}\rho V^2 S$		
C_m	pitching moment coefficient, (pitching moment about x_m) / $\frac{1}{2}\rho V^2 S c$, where c is either c_r or $\bar{c}$, positive apex-up		
C_N	normal force coefficient, (normal force) / $\frac{1}{2}\rho V^2 S$		
c_r	root chord, see Sketch 1.1	m	ft
c_t	tip chord, see Sketch 1.1	m	ft
$\bar{c}$	aerodynamic mean chord	m	ft
F	interpolation factor in Equation (3.1) and Figure 5		
M	Mach number		
S	planform area	m ²	ft ²
V	free-stream velocity	m/s	ft/s
x_{ac}	distance of aerodynamic centre aft of wing apex at zero angle of attack	m	ft
x_{cp}	distance of centre of pressure position aft of wing apex	m	ft
x_m	distance of moment reference point aft of wing apex	m	ft
x_p	distance of centroid of planform area aft of wing apex, see Figure 4	m	ft
α	angle of attack	degree or radian	degree or radian
β	$(M^2 - 1)^{1/2}$		

Issued August 1990
With Amendments A and B, December 1995 – 19 pages
This page Amendment B

Λ_0	sweepback of leading edge, see Sketch 1.1	degree	degree
λ	taper ratio, c_t/c_r		
ρ	free-stream density	kg/m ³	slug/ft ³

Some relationships between various geometric parameters are

$$\lambda = \frac{c_t}{c_r}, A = \frac{b^2}{S} = \frac{2b}{c_t + c_r}, \tan \Lambda_0 = \frac{4(1 - \lambda)}{A(1 + \lambda)} \text{ and } \frac{\bar{c}}{c_r} = \frac{2}{3} \left(\frac{1 + \lambda + \lambda^2}{1 + \lambda} \right).$$



Sketch 1.1 Wing geometry

2. INTRODUCTION

This Item provides a simple semi-empirical means of estimating the normal force and pitching moment of thin, sharp-edged delta or cropped-delta wings of low aspect ratio without camber or twist at angles of attack up to 60° and Mach numbers between 1.2 and 5.

The method requires only the input of simple geometrical parameters and estimates of wing normal-force-curve slope and aerodynamic centre position at zero angle of attack. The method itself is described in Section 3, and a guide to its accuracy and applicability is given in Section 4. The use of the method is illustrated by means of a worked example in Section 6.

Corresponding methods for normal force and pitching moment of cropped-delta wings at subsonic speeds are given in Item Nos 93034 (Reference 19) and 95022 (Reference 20), respectively.

3. METHOD

3.1 Normal Force

Figures 1a to 1f present data for the direct estimation of normal force coefficient for low aspect ratio wings as a function of aspect ratio, taper ratio and angle of attack at Mach numbers of 1.2, 1.5, 2, 3, 4 and 5, respectively. Each Figure provides C_N as series of carpets in terms of aspect ratio and taper ratio for $\alpha = 10^\circ, 20^\circ, 30^\circ, 40^\circ, 50^\circ$ and 60° . A cross-plot may be used to obtain values at intermediate Mach numbers. The Figures are based on the results of the three comprehensive parametric studies reported in Derivations 16, 17 and 18, and they have been validated, and where possible extended, by the smaller studies listed in Derivations 1 to 11, 13, 14 and 15.

This page Amendment B

To obtain the variation of normal force coefficient with α at a particular Mach number, the set of values of C_N at the specific values of angle of attack covered by Figure 1 are first obtained. A value for the normal-force-curve slope at zero angle of attack also is required, which may be obtained either from test data or from Figure 2, which was derived from Item No. 70012 (Derivation 12) by assuming that $[dC_N/d\alpha]_{\alpha=0} = [dC_L/d\alpha]_{\alpha=0}$. The C_N versus α curve may then be constructed by drawing a smooth curve through the set of values for C_N , ensuring that the gradient at zero angle of attack equals the estimated value of normal-force-curve slope. (In some instances it may be necessary to vary the estimated normal-force-curve slope within the $\pm 15\%$ tolerance quoted in Item No. 70012 to avoid an inflexion of the $C_N \sim \alpha$ curve.)

3.2 Pitching Moment

In order to estimate the pitching moment coefficient it is assumed that, as α increases, the centre of pressure position moves rearwards from its limiting position at the aerodynamic centre at zero angle of attack, back to the centroid of planform area as α approaches 90° . The centre of pressure position at intermediate angles of attack is given by the interpolation formula

$$\frac{x_{cp}}{c_r} = \frac{x_{ac}}{c_r} + F \left[\frac{x_p}{c_r} - \frac{x_{ac}}{c_r} \right]. \quad (3.1)$$

The limiting value as α tends to zero (the aerodynamic centre at zero angle of attack) may be obtained either from test data or from Figure 3, which was derived using data from Item No. 70012. The centroid of planform area, x_p , is given in Figure 4 as a function of taper ratio, and the interpolation factor, F , may be found in Figure 5 as a function of angle of attack.

It should be noted that for delta wings ($\lambda = 0$) the aerodynamic centre is located at the centroid of planform area and therefore the value $x_{cp}/c_r = 0.667$ is constant over the complete range of angle of attack. For cropped-delta wings the variation of F with α was determined by the use of test data and is discussed in Section 4.

The pitching moment coefficient about a reference point x_m is given by

$$C_m = C_N \left(\frac{x_m}{c_r} - \frac{x_{cp}}{c_r} \right), \quad (3.2)$$

based on wing root chord, or

$$C_m = C_N \left(\frac{x_m}{c_r} - \frac{x_{cp}}{c_r} \right) / \frac{\bar{c}}{c_r}, \quad (3.3)$$

based on aerodynamic mean chord, where $\bar{c}/c_r$ is given by the equation in Sketch 1.1.

4. ACCURACY AND APPLICABILITY

The method of this Item is restricted to thin, uncambered and untwisted wings with straight leading edges, straight unswept trailing edges and, where appropriate, streamwise tips. In terms of aspect ratio, taper ratio and angle of attack, the limitations of coverage are given below.

At angles of attack up to 20° , the experimental data applied to aspect ratios in the range

$$\begin{array}{ll} 0.2 \leq A \leq 4 & \text{for } \lambda \leq 0.5 \\ \text{and } 0.2 \leq A \leq 2 & \text{for } \lambda > 0.5, \end{array}$$

while, for angles of attack from 20° to 60° , the range was

$$\begin{array}{ll} 0.5 \leq A \leq 4 & \text{for } \lambda \leq 0.5 \\ \text{and } 0.5 \leq A \leq 2 & \text{for } \lambda > 0.5. \end{array}$$

The majority of the data used to produce Figures 1 and 5 were for flat-plate type wings with sharp chamfered edges. In the case of Derivations 16, 17 and 18, the chamfer angles were 30 degrees, measured normal to the leading and trailing edges. Test data for wings of different sectional shapes fell within the accuracy of the method, and so the Item may be presumed valid for wings with any reasonable symmetrical sharp-edged aerofoil section.

The data relate to monoplane wings, but will be applicable to cruciform configurations with a pair of wings in the vertical plane of symmetry. However, it should be noted that the edges of the vertical wings do contribute to normal force. This contribution is relatively minor for most of the wing geometries covered by this Item, but may become significant in the case of wings of very low aspect ratio where the vertical wing occupies a significant proportion of the planform area. The data indicate that the effect of the vertical wing on centre of pressure position is negligible.

Figure 1 represents the test data for C_N of Derivations 16, 17 and 18 generally to within a few per cent. Comparisons with other test data indicate an accuracy of about $\pm 10\%$. At very low angles of attack the accuracy is determined by the reliability of the normal-force-curve slope estimate, which in the case of Item No. 70012 is $\pm 15\%$.

In the method for pitching moment it was assumed that over the range of angle of attack $0 \leq \alpha \leq 90^\circ$ the centre of pressure position moves rearwards from the aerodynamic centre at $\alpha = 0$ to the centroid of planform area. In order to obtain a reasonable correlation for the interpolation factor, F , it was necessary for the distance between the limits of travel of centre of pressure to be a significant proportion of the root chord, because of the general scatter of the experimental values for x_{cp} . In practice it was only possible to obtain a correlation for F for wings of aspect ratios of 1 or less with taper ratio values greater than about 0.3. Within these ranges the correlation showed no significant variation of F with A , λ or M and so a single curve has been given as a function of α only. For wings whose planforms are outside the ranges quoted above, the distances between the limits of centre of pressure position are sufficiently small for the precise variation of F with α to have no significant effect on accuracy, and so Figure 5 may be used for all planforms.

Comparisons of test data with the predictions of Equation (3.1) indicate an accuracy for $x_{cp} / \bar{c}$ about ± 0.05 , which is consistent with the accuracy quoted in Item No. 70012.

The estimates of pitching moment coefficient about the centroid of planform area, based on wing root chord, are generally within about ± 0.03 .

5. DERIVATION AND REFERENCES

5.1 Derivation

The Derivation lists selected sources of information that have assisted in the preparation of this Item.

1. ULMANN, E.F.
DUNNING, R.W. Aerodynamic characteristics of two delta wings at Mach number 4.04 and correlations of lift and minimum drag data for delta wings at Mach numbers from 1.62 to 6.9
NACA RM L52K19 (TIL 3551), 1952.
2. DUNNING, R.W.
SMITH, F.M. Aerodynamic characteristics of two delta wings and two trapezoidal wings at Mach number 4.04.
NACA RM L53D30a (TIL 3762), 1953.
3. KAATTARI, G.E. Pressure distributions on triangular and rectangular wings to high angles of attack. Mach numbers 1.45 and 1.97.
NACA RM A54D19 (TIL 4264), 1954.
4. LABERGE, J.G. Supersonic wind tunnel tests of eleven small aspect ratio wings.
NAE Canada Report LR 97, 1954.
5. SPAHR, J.R. Longitudinal aerodynamic characteristics to large angles of attack of a cruciform missile configuration at a Mach number of 2.
NACA RM A54H27 (TIL 4508), 1954.
6. DAVIS, J.G.
SINSABAUGH, S.M. Presentation of force and moment data from a supersonic wind tunnel test of a wing-body interference panel load model.
Douglas Aircraft Company Report SM 18824, 1954.
7. KAATTARI, G.E. Pressure distributions on triangular and rectangular wings to high angles of attack. Mach numbers 2.46 and 3.36.
NACA RM A54J12 (TIL 4532), 1955.
8. PITTS, W.C. Force, moment and pressure distribution characteristics of rectangular wings at high angles of attack and supersonic speeds.
NACA RM A55K09 (TIL 4972), 1956.
9. SMITH, F.M. Experimental and theoretical aerodynamic characteristics of two low aspect ratio delta wings at large angles of attack to 50° at $M = 4.07$.
NACA RM L57E02 (TIL 5588), 1957.
10. LANDRUM, E.J. A tabulation of wind tunnel pressure data and section aerodynamic characteristics at Mach numbers of 1.61 and 2.01 for two trapezoidal and three delta wings having different surface shapes.
NASA TN D-1394, 1962.
11. COLLINGBOURNE, J.R. An empirical prediction method for non-linear normal force on thin wings at supersonic speeds.
ARC CP 622, 1963.
12. ESDU Lift-curve slope and aerodynamic centre position of wings in inviscid supersonic flow. ESDU International, Item No. 70012, 1970.
ESDUpac A7012.

This page Amendment B