



Pitching moment of low-aspect-ratio cropped-delta wings up to high angles of attack at subsonic speeds

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PITCHING MOMENT OF LOW-ASPECT-RATIO CROPPED-DELTA WINGS UP TO HIGH ANGLES OF ATTACK AT SUBSONIC SPEEDS

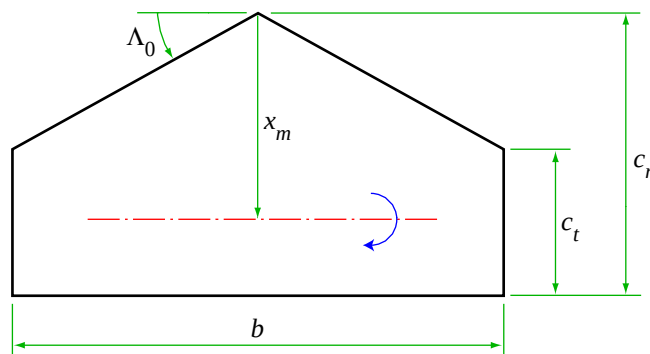
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PITCHING MOMENT OF LOW-ASPECT-RATIO CROPPED-DELTA WINGS UP TO HIGH ANGLES OF ATTACK AT SUBSONIC SPEEDS

1. NOTATION AND UNITS

		SI	British
A	aspect ratio, b^2/S		
b	wing span, see Sketch 1.1	m	ft
C_m	pitching moment coefficient, (pitching moment about moment reference point)/ $\frac{1}{2}\rho V^2 S c_r$		
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
F	factor in Equation (3.2)		
M	free-stream Mach number		
S	planform area	m ²	ft ²
t	wing maximum thickness	m	ft
V	free-stream velocity	m/s	ft/s
x_{ac}	distance of aerodynamic centre aft of wing apex	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, see Sketch 1.1	m	ft
x_p	distance of centroid of planform area aft of wing apex	m	ft
α	angle of attack	degree or radian	degree or radian
β	compressibility parameter, $(1 - M^2)^{1/2}$		
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



Sketch 1.1 Wing geometry

Some useful relationships between various geometrical parameters are

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

2. INTRODUCTION

This Item provides a simple semi-empirical means of estimating the pitching moment coefficient on thin, sharp-edged wings of delta, cropped-delta and rectangular planform at subsonic speeds up to high angles of attack. The method is applicable to wings without camber and twist and for aspect ratios up to 4. It may be applied at Mach numbers up to 0.95 in the case of delta wings, but application of the method for cropped-delta and rectangular wings at high speeds is tentative (see Section 4).

The method requires the input of simple geometrical parameters together with estimates of wing normal force coefficient and the aerodynamic centre position at zero angle of attack. The method is described in Section 3 and a discussion of its accuracy and applicability is provided in Section 4. Two examples of the use of the Item are given in Section 6.

A method for the prediction of normal force coefficient of low-aspect-ratio cropped-delta wings at subsonic speeds is given in Item No. 93034 (Reference 36), and corresponding methods for both normal force and pitching moment at supersonic speeds are given in Item No. 90013 (Reference 35).

3. METHOD

The pitching moment coefficient, based on root chord, about the chosen reference point located a distance x_m aft of the wing apex is given by

$$C_m = C_N \left(\frac{x_m}{c_r} - \frac{x_{cp}}{c_r} \right), \quad (3.1)$$

where C_N is the normal force coefficient which may be obtained from test data or Item No. 93034. The centre of pressure position, x_{cp}/c_r , may be found from Section 3.1 for delta and rectangular wings and Section 3.2 for cropped delta wings.

3.1 Centre of Pressure Position for Delta and Rectangular Wings at Low Speeds

Derivations 1 to 33 provide a sufficiently comprehensive data base for delta and rectangular wings at low speeds to allow the direct presentation of centre of pressure data for aspect ratios up to 4 and angles of attack up to 90 degrees. The values of x_{cp}/c_r for delta and rectangular wings are given in Figures 1 and 1 respectively. In both Figures the limiting centre of pressure position at zero angle of attack is the aerodynamic centre position as obtained from Item No. 70011 (Derivation 25).

3.2 Centre of Pressure for Cropped-delta Wings at Low Speeds

Fewer test data are available for cropped-delta wings and so a presentation of the form given in Figures 1 and 1 is not possible. However, the limited data available indicate that the simple formula

$$\frac{x_{cp}}{c_r} = \frac{x_{ac}}{c_r} + F \left(\frac{x_p}{c_r} - \frac{x_{ac}}{c_r} \right) \quad (3.2)$$

may be used effectively to correlate centre of pressure data for wings of different aspect ratio as a function of taper ratio and angle of attack at pre-stall angles of attack (see Section 4). In Equation (3.2) x_{ac}/c_r is the aerodynamic centre location, as given by Item No. 70011, which has been used to produce Figure 3 for the case of wings with unswept trailing edges as a function of βA and λ . Figure 4 gives the value for the location of the centroid of planform area, x_p/c_r , which is a function of λ only and is given by

$$\frac{x_p}{c_r} = \frac{2 + 2\lambda - \lambda^2}{3(1 + \lambda)}. \quad (3.3)$$

Figure 5 presents the empirical factor F as a function of α and λ for $\alpha \leq 30^\circ$ and $0.1 \leq \lambda \leq 0.5$.

Values of x_{cp}/c_r for cropped-delta wings with values of λ outside the range of Figure 5 may be obtained from Equation (3.2), the value of F being obtained by a cross-plot against λ involving the data of Figure 5 and values of F for $\lambda = 0$ and 1. These values of F can be obtained from a rearrangement of Equation (3.2) with $x_p/c_r = 0.667$ and 0.5 for $\lambda = 0$ and 1 respectively.

For delta wings ($\lambda = 0$)

$$F = \left(\frac{x_{cp}}{c_r} - \frac{x_{ac}}{c_r} \right) / \left(0.667 - \frac{x_{ac}}{c_r} \right) \quad (3.4)$$

with x_{cp}/c_r from Figure 1 and x_{ac}/c_r from the top curve in Figure 3.

For rectangular wings ($\lambda = 1$)

$$F = \left(\frac{x_{cp}}{c_r} - \frac{x_{ac}}{c_r} \right) / \left(0.5 - \frac{x_{ac}}{c_r} \right) \quad (3.5)$$

with x_{cp}/c_r from Figure 1 and x_{ac}/c_r from the bottom curve in Figure 3.

This procedure is illustrated in Example 1 in Section 6.1.

3.3 Centre of Pressure at High Speeds

For delta wings, estimates of centre of pressure position at high subsonic speeds may be made by generating values of F from the low speed data in Figure 1 in combination with Equation (3.3) and substituting those values into Equation (3.2) together with the aerodynamic centre position at the Mach number of interest from Figure 3 and centroid of planform area value, $x_{cp}/c_r = 0.667$. This use of the method is illustrated in Example 2 in Section 6.2.

In principle, the low speed values of F for cropped-delta and rectangular wings can be applied at high subsonic Mach numbers, but this application of the method is tentative and should be used with caution (see Section 4).

4. ACCURACY AND APPLICABILITY

The method of this Item is restricted to thin, sharp-edged delta, cropped-delta and rectangular wings without camber or twist. The majority of the data used to obtain Figures 1, 1 and 5 were for flat-plate type wings with chamfered edges and $t/c_r \leq 0.05$, although for the very high angles of attack the range $t/c_r \leq 0.02$ was more representative. It should be noted that Figure 1, for delta wings, is almost wholly dependent on data from Derivation 21 for $\alpha > 30^\circ$. The apparent sudden forward movement of centre of pressure for the very low aspect ratio wings indicated in this Figure at $\alpha \approx 35^\circ$ is probably associated with vortex breakdown arriving at the trailing edge, producing a loss of normal force. Item No. 93034 provides a discussion of vortex breakdown. The data for cropped-delta wings in Figure 5 should only be used for angles of attack below the stall, which is dependent on aspect ratio, taper ratio and Mach number. The availability of data for normal force in Item No. 93034 should be used to determine the angle of attack to which the method may be applied.

Theoretical results for aerodynamic centre, as given by Figure 3, indicate a rearward movement of x_{ac}/c_r with increasing Mach number for delta wings, and this trend is substantiated by test data. However, as taper ratio increases from zero this movement is reduced in magnitude and, for taper ratios greater than about 0.25, is reversed to a forward movement with increasing Mach number. Nearly all of the available data for cropped-delta wings at high Mach number are from Derivations 32 and 33, and indicate a rearward movement of centre of pressure with increasing Mach number for all values of taper ratio and so cast some doubt over the applicability of the theoretical estimates of aerodynamic centre location for $\lambda > 0$. It should be noted, however, that the models employed in both of these test series had quite steeply chamfered leading and side edges (30° total angle measured normal to the edge) and in the case of Derivation 32 the models were relatively thick (t/c_r up to 0.125). Also, both data sets often indicate premature stall in comparison with data from other sources. Reference 34 contrasts centre of pressure data at $M = 0.8$ from Derivation 32 with data from another source for two cropped-delta wings of identical planform ($A = 2$, $\lambda = 0.5$), but with different thickness and chamfer. The data from Derivation 32 at low angles of attack imply an aerodynamic centre located some 15% of root chord further aft in comparison to the thinner, more sharply bevelled wing for which the method of this Item provides estimates accurate to within about $\pm 3\%$ of root chord over the pre-stall range of angle of attack. The wings of Derivation 33, although employing the same chamfer angle as that of Derivation 32, were much thinner ($t/c_r \leq 0.05$), but were tested in cruciform configuration, with a few models tested in a monoplane arrangement, which in some cases indicated a better agreement with the method. In the absence of other reliable data the method of this Item should, strictly, be limited to Mach numbers of 0.3 or less in the case of cropped-delta and rectangular wings. The limited data for cropped-delta wings with small chamfer angles suggest that, with caution, the method may be extended to Mach numbers up to 0.8.