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Low-speed normal force and pitching moment of slender wings in ground effect

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LOW-SPEED NORMAL FORCE AND PITCHING MOMENT OF SLENDER WINGS IN GROUND EFFECT

CONTENTS

	Page
1. NOTATION AND UNITS (SEE SKETCHES 2.1 AND 2.2)	1
2. NOTES	2
3. DERIVATION	3
4. EXAMPLE	4
FIGURES 1 TO 3	6-7
APPENDIX A COMPUTER PROGRAM FOR ESTIMATION OF LOW-SPEED NORMAL FORCE AND PITCHING MOMENT OF SLENDER WINGS IN GROUND EFFECT	7
A1. INTRODUCTION	7
A2. PROGRAM	7
A2.1 Input	7
A2.2 Output	9
A2.3 Running the Program	9

LOW-SPEED NORMAL FORCE AND PITCHING MOMENT OF SLENDER WINGS IN GROUND EFFECT

1. NOTATION AND UNITS (see Sketches 2.1 and 2.2)

		<i>SI</i>	<i>British</i>
A	wing aspect ratio, $4s^2/S$		
a	normal-force-curve slope at zero wing incidence in free air ($dC_N/d\alpha$) $_{\alpha=0}$	rad^{-1}	rad^{-1}
C_m	pitching moment coefficient in free air based on S and c_r , positive nose-up, measured about pitching moment axis		
ΔC_m	total increase in C_m due to ground effect, measured about pitching moment axis		
δC_{mt}	correction term for wing thickness in Equation (2.3), see Sketch 2.1, measured about pitching moment axis, see Figure 2		
C_N	normal force coefficient in free air based on S , see Sketch 2.1		
ΔC_N	total increase in C_N due to ground effect		
δC_N	increase in C_N due to ground effect for thin wing, see Sketch 2.1 and Figure 1		
δC_{Nt}	correction in ΔC_N for wing thickness, see Sketch 2.1 and Figure 2		
c_r	wing centre-line chord, see Sketch 2.2	m	ft
F	ratio of actual value to "slender wing" theoretical value for normal-force-curve slope in free air, $(2/\pi A)(dC_N/d\alpha)$.		
h	height above ground of quarter-chord point of wing aerodynamic mean chord	m	ft
S	wing planform area	m^2	ft^2
S_f	wing frontal area at zero incidence	m^2	ft^2
s	wing semi-span, see Sketch 2.2	m	ft
x	chordwise distance rearwards from wing apex	m	ft
α	wing incidence, see Sketch 2.1	rad	rad
ξ	x/c_r , see Sketches 2.1 and 2.2		

ξ_{cp}	value of ξ at centre of pressure in free air, see Sketch 2.1
ξ_m	value of ξ at pitching moment axis, see Sketches 2.1 and 2.2
$\delta\xi_{cp}$	increase in ξ_{cp} due to ground effect for thin wing, see Sketch 2.1 and Figure 3

2. NOTES

This Item applies strictly to pointed slender wings of aspect ratio less than about 2 with an unswept trailing edge, only small amounts of camber or twist and with separation along the whole of the leading edge. Except at very small incidences the effect of the ground on a slender wing in subsonic flow is to cause an increase in the normal force and a rearward movement of the centre of pressure. The change in axial force is so small that increases in lift and drag are approximated by resolution of the normal force increment.

Curves are presented from which the changes to the normal force coefficient and the pitching moment coefficient may be calculated. The curves are based essentially on correlations in Derivation 6, in which references are given for most of the experimental data, together with data from Derivations 1 and 4. Further supporting data are contained in Derivations 2, 3, 5 and 7.

Near the ground, the increase in the normal force coefficient is given by

$$\Delta C_N = \delta C_N + \delta C_{Nt}. \quad (2.1)$$

The increment for a thin wing δC_N may be obtained from Figure 1 where $\delta C_N/(FC_N)$ is plotted against the span/height ratio $2s/h$; the correction for thickness δC_{Nt} in Figure 2 is plotted as $\delta C_{Nt}/a$ against the parameter $S_f c_r/Sh$, which is effectively a thickness/height ratio. The curve of Figure 1 is semi-empirical, being derived from experimental data in the range $0 \leq 2s/h \leq 6$ (see Derivation 6) and is represented by the expression

$$\frac{\delta C_N}{FC_N} = 0.05(2s/h)^{1.4}, \quad (2.2)$$

in which $F = (2/\pi A)(dC_N/d\alpha)$.

For a limited range of slender wings, C_N and $dC_N/d\alpha$ may be obtained from ESDU 71006.

Figure 3 gives the rearward movement of the centre of pressure due to the ground $\delta\xi_{cp}$ for a thin wing in terms of the centre-line chord/height ratio and wing incidence. The increment in pitching moment about an axis through $\xi = \xi_m$ may then be found from

$$\Delta C_m = -\Delta C_N(\xi_{cp} - \xi_m) - (C_N + \delta C_N)\delta\xi_{cp} + \delta C_{mt}, \quad (2.3)$$

where δC_{mt} , given in Figure 2, is the increment for wing thickness when $\xi_m = \xi_{cp}$. Sketch 2.1 illustrates the quantities in Equation (2.3). For a limited range of slender wings, the free-air pitching moment coefficient C_m and centre of pressure position ξ_{cp} may be obtained from ESDU 71006.