

ESDU Controls 08.01.01

RATE OF CHANGE OF PITCHING MOMENT COEFFICIENT WITH CONTROL DEFLECTION FOR A PLAIN CONTROL IN INCOMPRESSIBLE TWO-DIMENSIONAL FLOW, m_0

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
$(a_2)_0$	slope of lift coefficient increment curve with control deflection for two-dimensional aerofoil in incompressible flow	rad^{-1}	rad^{-1}
$(a_2)_{0T}$	theoretical slope of lift coefficient increment curve with control deflection for two-dimensional aerofoil in inviscid incompressible flow	rad^{-1}	rad^{-1}
C_L	lift coefficient		
$(C_m)_0$	pitching moment coefficient for two-dimensional aerofoil in incompressible flow, $M_0/(\frac{1}{2}\rho V^2 c^2)$, measured about quarter-chord point		
c	aerofoil chord, see sketch on Figure 1	m	ft
c_f	control chord aft of hinge-line, see sketch on Figure 1	m	ft
M_0	nose-up pitching moment per unit span for two-dimensional aerofoil in incompressible flow, measured about quarter-chord point	N m/m	lbf ft/ft
m_0	rate of change of pitching moment coefficient with control deflection at constant lift coefficient for two-dimensional aerofoil in incompressible flow, $-\partial(C_m)_0/\partial\delta$, measured about quarter-chord point	rad^{-1}	rad^{-1}
m_{0T}	theoretical rate of change of pitching moment coefficient with control deflection at constant lift coefficient for two-dimensional aerofoil in inviscid incompressible flow, measured about quarter-chord point, see Figure 1	rad^{-1}	rad^{-1}
t	maximum thickness of aerofoil	m	ft
t_{90}	thickness of aerofoil at 90 per cent chord	m	ft
t_{99}	thickness of aerofoil at 99 per cent chord	m	ft
V	free-stream velocity	m/s	ft/s
δ	control surface deflection, see sketch on Figure 1	rad	rad
ρ	density of air	kg/m^3	slug/ft ³
τ_a	trailing-edge angle of aerofoil, as defined by $\tan \frac{1}{2}\tau_a = (t_{90} - t_{99})/0.18c$	degree	degree

Issued June 1956

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2. NOTES

The rate of change of pitching moment coefficient with control deflection at constant lift coefficient for a two-dimensional aerofoil in incompressible flow, m_0 , is given by

$$m_0 = m_{0T} \left(\frac{m_0}{m_{0T}} \right), \quad (2.1)$$

where, in Figure 1 m_{0T} is plotted against c_f/c for various values of t/c , whilst in Figure 2 m_0/m_{0T} is plotted against $(a_2)_0/(a_2)_{0T}$ for various values of the trailing-edge parameter $\tan(\frac{1}{2}\tau_a)$, see Derivations 1 and 3. The ratio $(a_2)_0/(a_2)_{0T}$ for any particular aerofoil may be obtained from ESDU Aero C.01.01.03, see Reference 4.

The method and curves of Figures 1 and 2 apply within the linear range of the pitching moment-incidence curve and over the range of control deflections for which the increment of pitching moment is linear with control deflection, *i.e.* in general for values of incidence and control deflection for which there is no separation of flow over the aerofoil or control.

It may be noted that the theoretical rate of change of pitching moment coefficient with control deflection at constant lift coefficient, m_{0T} , is dependent to a certain extent on the aerofoil profile. The curves presented in Figure 1 apply, however, to a sufficient degree of accuracy for a wide range of profiles.

The derivative m_0 is required mainly in connection with the calculation of aileron reversal speed and, provided that the aspect ratio is greater than about 4 and the sweep of the wing is small, normal practice is to apply strip theory to that part of the wing covered by the aileron. For aspect ratios less than 4 there is evidence that strip theory appreciably overestimates the pitching moment due to control deflection. The available evidence on the effect of wing sweep is inconclusive. Whilst there are insufficient data available to generalise on the effects of wing sweep or aspect ratio, the pitching moment for a particular planform may be calculated by the use of a lifting-surface theory such as that given in Derivation 2.

A program of the method is provided as ESDUpac AC811 and is described in Appendix A.

3. DERIVATION AND REFERENCES

3.1 Derivation

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

1. WOODS, L.C. The theory of aerofoils with hinged flaps in two-dimensional compressible flow.
ARC CP 138, 1952.
2. MULTHOPP, H. Methods for calculating the lift distribution of wings (subsonic lifting-surface theory).
ARC R&M 2885, 1955.
3. GARNER, H.C. Charts for low speed characteristics of two-dimensional trailing-edge flaps.
ARC R&M 3174, 1960.

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3.2 References

The References are sources of information supplementary to that in this Item.

4. ESDU Rate of change of lift coefficient with control deflection in incompressible two-dimensional flow, $(a_2)_0$.
ESDU Aero C.01.01.03, London, 1956.

4. EXAMPLE

Find the rate of change of pitching moment coefficient with plain control deflection at constant lift coefficient for a two-dimensional aerofoil for which $c_f/c = 0.35$, $t/c = 0.10$, $\tan(\frac{1}{2}\tau_a) = 0.10$ and $(a_2)_0/(a_2)_{0T} = 0.85$.

From Figure 1, for $t/c = 0.10$ and $c_f/c = 0.35$,

$$m_{0T} = 0.642 \text{ rad}^{-1}.$$

From Figure 2, for $\tan(\frac{1}{2}\tau_a) = 0.10$ and $(a_2)_0/(a_2)_{0T} = 0.85$,

$$\frac{m_0}{m_{0T}} = 0.98.$$

Equation (2.1) gives m_0 as

$$\begin{aligned} m_0 &= m_{0T} \left(\frac{m_0}{m_{0T}} \right) \\ &= 0.642 \times 0.98 \\ &= 0.629 \text{ rad}^{-1}. \end{aligned}$$