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Drag and yawing moment due to spoilers

Associated software: ESDUpac A9626



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THE PREPARATION OF THIS DATA ITEM

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Mr A. Miller	— Airbus UK, Filton, Bristol
Mr E. Totland*	— Saab AB, Linköping, Sweden
Mr J. Tweedie	— Short Brothers plc, Belfast

* Corresponding Member

The technical work in the assessment of the available information and the development and subsequent construction of the Data Item method was carried out under contract to ESDU by

Mr M.J. Green.

Further development of the Data Item was performed by

Mr C.J. Batt Senior Engineer.

The computer program was written by

Mr S.F. Wood Principal Engineer.

The person with overall responsibility for the work in this subject area is Mr A.J. Clarke, Head of Aircraft Aerodynamics Group.

DRAG AND YAWING MOMENT DUE TO SPOILERS

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DRAG AND YAWING MOMENT DUE TO SPOILERS

1. NOTATION AND UNITS

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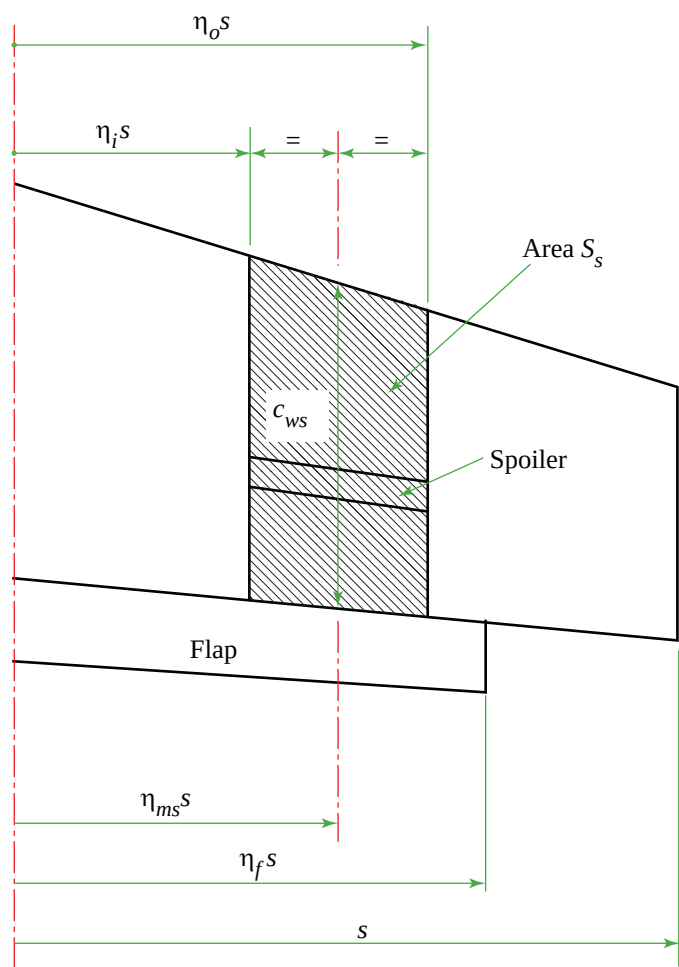
A	wing aspect ratio, $2s/\bar{c}$		
A_s	aspect ratio of shaded part of wing in Sketch 1.1, $(\eta_o - \eta_i)s/c_{ws}$		
C_D	drag coefficient (based on S_w)		
ΔC_{Ds}	increment in drag coefficient due to one spoiler (based on S_w)		
ΔC_{Dis}	increment in induced drag coefficient due to one spoiler (based on S_w)		
ΔC_{D0s}	increment in profile drag coefficient due to one spoiler (based on S_w)		
C_L	lift coefficient for wing (based on S_w)		
ΔC_{Lf}	increment in C_L due to flap deployment (based on S_w)		
ΔC_{Ls}	increment in C_L due to spoilers on both semi-spans of wing with trailing-edge flaps undeployed, see ESDU 14004		
ΔC_{Lsa}	increment in C_L due to one spoiler (based on S_w)		
ΔC_{Lstot}	increment in C_L due to spoilers on both semi-spans of wing with trailing-edge flaps deployed, see ESDU 14005		
ΔC_{ns}	increment in yawing moment coefficient due to one spoiler (based on $2sS_w$)		
$(\Delta C_{ns})_D$	contribution of spoiler drag to ΔC_{ns} , positive for spoiler deployed on starboard wing panel		
$(\Delta C_{ns})_F$	contribution of fin to ΔC_{ns}		
$(\Delta C_{n\beta})_F$	contribution of fin to yawing moment coefficient due to unit sideslip angle (based on $2sS_w$)	rad^{-1}	rad^{-1}
$\bar{c}$	geometric mean chord of wing	m	ft
c_s	spoiler chord (see Sketch 1.2)	m	ft
c_{ws}	wing chord at mid-spoiler location (see Sketch 1.1)	m	ft
h_F	height of fin centre of pressure above wing at $\alpha = 0$	m	ft
k_s	spoiler induced drag factor used in Equation (3.5)		

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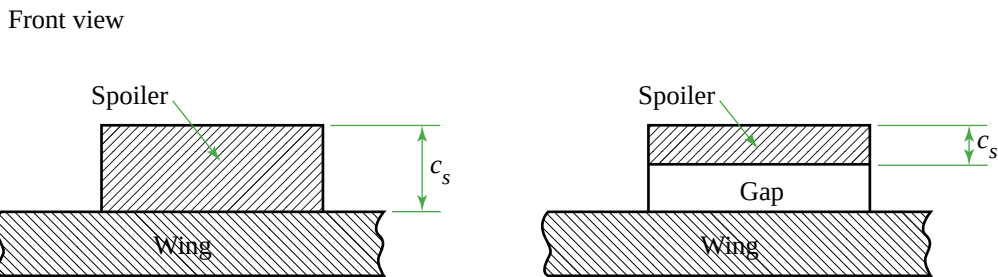
l_s	local lift increment per unit span due to one spoiler	N/m	lbf/ft
l_w	local lift per unit span on wing with spoiler undeployed over that region of wing affected by spoiler (see Sketch 3.1)	N/m	lbf/ft
S_s	area of wing bounded by spoiler (see Sketch 1.1)	m ²	ft ²
S_w	wing area, $2s\bar{c}$	m ²	ft ²
s	wing semi-span	m	ft
x_{Fi}	longitudinal distance between fin centre of pressure and origin of vortex trailing from inboard limit of spoiler (see Sketch 3.2)	m	ft
x_{Fo}	longitudinal distance between fin centre of pressure and origin of vortex trailing from outboard limit of spoiler (see Sketch 3.2)	m	ft
α	wing angle of attack	deg	deg
α_{if}	contribution to α_{iw} due to flap deployment	rad	rad
α_{is}	local induced downwash due to spoiler	rad	rad
α_{iw}	local induced downwash at spoiler location (spoiler undeployed)	rad	rad
β	sidewash angle at fin	deg, rad	deg, rad
δ_s	spoiler deflection angle, measured in streamwise plane	deg	deg
η	spanwise location as fraction of s		
η_c	spanwise location of centroid of spoiler area as a fraction of s (used in calculation of $(\Delta C_{ns})_D$, Equation (3.11))		
η_f	outboard spanwise limit of flap as fraction of s		
η_i	inboard spanwise limit of spoiler as fraction of s		
η_o	outboard spanwise limit of spoiler as fraction of s		
η_{ms}	mid-spoiler location as fraction of s , $(\eta_i + \eta_o)/2$		
κ_i	geometric parameter used in Equation (3.12) for estimation of sidewash angle at fin		
κ_o	geometric parameter used in Equation (3.12) for estimation of sidewash angle at fin		
λ	taper ratio of wing		

Subscripts

$()_{expt}$	denotes experimental value
$()_{pred}$	denotes predicted value



Sketch 1.1 Wing Planform Geometry



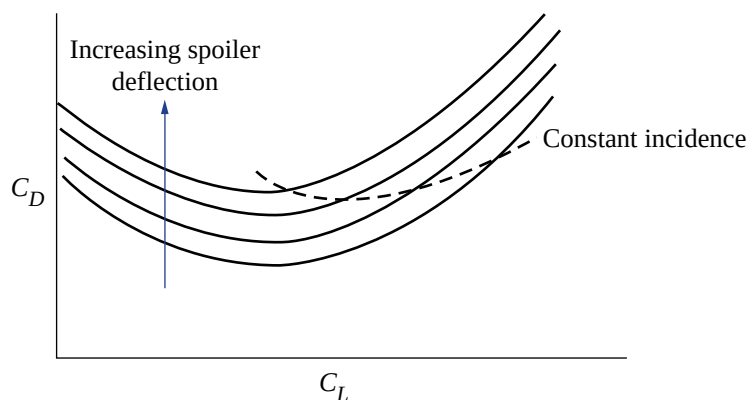
Sketch 1.2 Spoiler Geometry (shown for $\delta_s = 90^\circ$)

2. INTRODUCTION

Spoiler-type devices are fitted to the upper surface of aircraft wings for a variety of purposes as described in ESDU 14004, Reference 8. Of particular relevance to this Data Item is the distinction between those applications that require symmetrical spoiler deployment, *e.g.* airbrakes, and those that involve asymmetric deployment, *e.g.* roll control. Only the latter will give rise to a yawing moment, whereas all types produce drag. It should be noted that roll spoilers are single acting (unlike ailerons) in that they only destroy lift on the down-going wing panel. Due to this lack of symmetry this Data Item refers to spoilers on one wing panel. If deployed symmetrically on both wing panels, the incremental drag should be doubled.

The major part of this Data Item is devoted to the prediction of spoiler drag, which is important both in its own right and in the prediction of yawing moment. The drag of spoilers has two causes: the *profile drag* of the spoiler itself arising from its frontal aspect and large separated wake behind, and also the *induced drag* effects occurring as the spoiler modifies the lift distribution of the wing.

As a consequence of the two effects the production of drag by spoilers is a quite complex physical process and can give rise to non-intuitive behaviour. For example (see Sketch 2.1), if the drag of a spoiler is looked at in terms of drag polars at constant lift coefficient then drag will be seen to increase with spoiler angle. However, when viewed at constant incidence (a more realistic case for rapid deployment of roll spoilers) drag can decrease at small spoiler angles before increasing at large angles. This is due to the interplay between the profile and induced drag contributions.



Sketch 2.1 Drag Polars

Regarding yawing moments it is found that for a wing-body combination the yawing moment due to spoiler deflection correlates well with the effective arm of the incremental drag. However, the addition of the tail-unit gives rise to an additional yawing moment due to the asymmetric change in the flow-field behind the wing. Within this Item, the term 'tail-unit' embraces the complete empennage, *i.e.* both vertical and horizontal aft stabilising surfaces.

In this Data Item, Section 3 provides methods of estimating the profile and induced drag arising from spoiler deflection. It also treats the yawing moment due to spoiler, differentiating between the direct contribution from the incremental drag and the tail-unit effect which is accounted for as sidewash at the fin. Accuracy and applicability are discussed in Section 4, Derivations and References are listed in Section 5 and a worked example is given in Section 6. A program of the method is provided as ESDUpac A9626 and is described in Appendix A.

3. METHOD

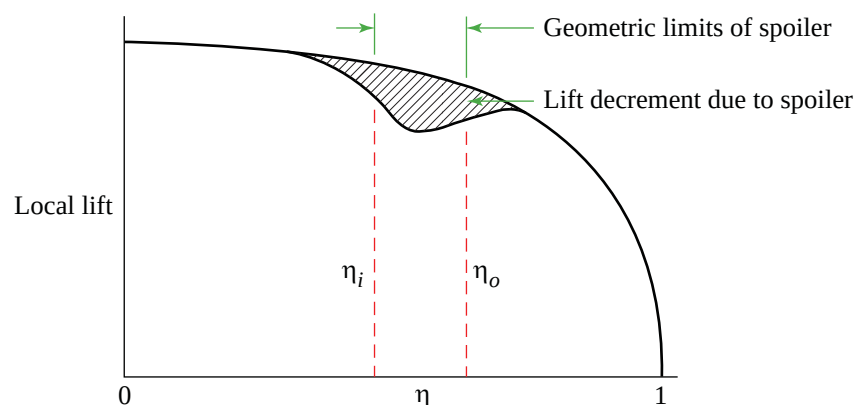
The basis of the method is to distinguish between the induced drag and profile drag terms. The former are treated as a function of the lift coefficient increment due to a single spoiler (ΔC_{Lsa} , typically negative) and the profile drag is given as a function of spoiler angle. The lift coefficient increments due to spoiler deployment on both semi-span wing panels where trailing-edge flaps are undeployed, ΔC_{Ls} , and where flaps are deployed, ΔC_{Lstot} , are obtained using ESDU 14004 (Reference 8) and ESDU 14005 (Reference 9), respectively. For spoilers deployed on one wing panel only, a simplifying assumption is made that the coefficients are halved, as illustrated in the worked example. Hence in this Item $\Delta C_{Lsa} = \Delta C_{Ls}/2$ for wings with undeployed flaps and $\Delta C_{Lsa} = \Delta C_{Lstot}/2$ for wings with deployed flaps.

3.1 Induced Drag

Sketch 1.1 depicts a typical wing with a spoiler. A rigorous analysis of the induced drag due to the spoiler would require complex computational methods beyond the scope of this Data Item. To give a practical means of estimation, the following simplifying assumptions are considered to be justified for typical geometries.

- (1) The spoiler is small compared with the wing as a whole.
- (2) The spoiler is in a region of the wing where the local lift is changing gradually (*i.e.* well away from the tip).
- (3) The spoiler on one wing panel only affects that panel. Thus asymmetric effects can be treated additively.

These assumptions imply that the effects of the spoiler are concentrated in a region around (but not confined to) the spoiler itself. The spoiler gives rise to a change in spanwise loading (see Sketch 3.1) that spreads outside the geometric limits of the spoiler.



Sketch 3.1 Spanwise Load Distribution

To estimate the induced drag, the spoiler is considered to be deflected at constant incidence and a lifting-line approach is applied over the region affected by the spoiler.

- | | | |
|-----|---------------|---|
| Let | l_w | be the local lift per unit span on the wing without spoiler deployment, |
| | l_s | be the local lift increment per unit span due to spoiler deployment, |
| | α_{iw} | be the local induced downwash on the wing without spoiler deployment, |
| and | α_{is} | be the local induced downwash distribution due to spoiler deployment. |

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Then in that region, the induced drag is given by

$$(\text{induced drag}) = \int l_w \alpha_{iw} s d\eta + \int l_s \alpha_{iw} s d\eta + \int l_w \alpha_{is} s d\eta + \int l_s \alpha_{is} s d\eta \quad (3.1)$$

integrated over the region influenced by the spoiler. Each of the integrals is considered in turn.

The first is embodied in the overall induced drag of the wing and so can be neglected in defining the incremental effects of the spoiler.

The second is retained and gives rise to a drag that is proportional to the spoiler lift coefficient increment ΔC_{Lsa} . In line with the assumptions stated above, α_{iw} is constant over the region of interest and its empirical formula is given in Section 3.2.

The third is neglected. With the assumption that l_w is approximately constant over the spoiler region, this contribution is proportional to the integral of the spoiler downwash distribution. For an isolated spoiler on an infinitely big wing this integral is zero as the upwash and downwash contributions cancel each other. For practical cases it is considered to be negligibly small.

The fourth is the “conventional” induced drag term due to spoiler lift. As α_{is} is proportional to ΔC_{Lsa} , this can be written as a term in ΔC_{Lsa}^2 .

Thus the increment in induced drag coefficient due to the spoiler is

$$\Delta C_{Dis} = \alpha_{iw} \Delta C_{Lsa} + (\text{constant}) \Delta C_{Lsa}^2. \quad (3.2)$$

It should be noted that, as ΔC_{Lsa} is typically negative, at small values of ΔC_{Lsa} the gradient of this function will also be negative. In dealing with the term in ΔC_{Lsa}^2 it is necessary to re-define the incremental lift and drag coefficients due to the spoiler in terms of local values. This is because to a large extent the induced drag of the spoiler (for a given lift) depends on spoiler geometry rather than wing geometry.

The shaded area of wing in Sketch 1.1 is defined as a reference area

$$S_s = (\eta_o - \eta_i) s c_{ws}. \quad (3.3)$$

An aspect ratio, A_s , is then defined as

$$A_s = \frac{[(\eta_o - \eta_i)s]^2}{S_s} = \frac{(\eta_o - \eta_i)s}{c_{ws}}. \quad (3.4)$$

The constant in Equation (3.2) has been found to take the form $2k_s \bar{c}/S_s$ where k_s is the empirical function of A_s given in Figure 1.

Thus,

$$\Delta C_{Dis} = \alpha_{iw} \Delta C_{Lsa} + \frac{2k_s (\bar{c}/c_{ws}) \Delta C_{Lsa}^2}{(\eta_o - \eta_i)}. \quad (3.5)$$

3.2 Wing Downwash

The term α_{iw} , the wing downwash in the region of the spoiler, can be calculated with sufficient accuracy as follows.

3.2.1 Wing without flap

For a wing of aspect ratio A flying at a lift coefficient C_L

$$\alpha_{iw} = 1.2 \frac{C_L}{\pi A}, \quad (3.6)$$

where 1.2 is an empirically derived constant to give the best match to data.

3.2.2 Wing with flap deployed

If the wing has a flap deployed such that at a given incidence the contribution to lift coefficient due to the flap is ΔC_{Lf} , and if the flap extends symmetrically from the centre-line with total span $2\eta_f$ s (see Sketch 1.1), the increment in downwash due to the flap is given by

$$\alpha_{if} = \frac{\Delta C_{Lf}}{\pi A \eta_f^2}. \quad (3.7)$$

This is added to the contribution from the wing without flap to give

$$\alpha_{iw} = 1.2 \frac{(C_L - \Delta C_{Lf})}{\pi A} + \frac{\Delta C_{Lf}}{\pi A \eta_f^2}. \quad (3.8)$$

3.3 Profile Drag

To the induced drag in Equation (3.5) there must be added the profile drag of the spoiler. Examination of wind-tunnel data (Derivation 6), after extraction of the induced effects estimated as above, shows a variation of drag with spoiler angle that could be accounted for in a number of ways. In this Data Item it is calculated by using a drag coefficient based on projected frontal area. This approach is adopted by a number of authors; for example Mitchell (Derivation 4) suggests a coefficient of 1.4. However, other sources would suggest that a similar but lower value be used. ESDU 70015 (Derivation 3) gives 1.2 for a plate normal to a surface for geometries typical of spoilers. ESDU 74010 (Derivation 5) indicates a similar value for split flaps at 90° deflection if the profile drag coefficient from that Item is based on frontal area. ESDU 74010 also indicates a 'sine-squared' relationship for lesser angles. Analysis of wind-tunnel data in Derivation 2 for a progressive family of spoiler sizes also confirms the value of 1.2, which is assumed to be applicable at all subsonic Mach numbers.

Thus,

$$\Delta C_{D0s} = 1.2 (\sin^2 \delta_s) (\eta_o - \eta_i) \frac{c_s}{S_w}. \quad (3.9)$$

where c_s is the spoiler chord (see Sketch 1.2). Perforated spoilers are to be treated as if they were solid, with the same factor of 1.2.