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Lift and rolling moment due to spoilers on wings with flaps undeflected at subsonic speeds

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LIFT AND ROLLING MOMENT DUE TO SPOILERS ON WINGS WITH FLAPS UNDEFLECTED AT SUBSONIC SPEEDS

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LIFT AND ROLLING MOMENT DUE TO SPOILERS ON WINGS WITH FLAPS UNDEFLECTED AT SUBSONIC SPEEDS

1. NOTATIONS AND UNITS

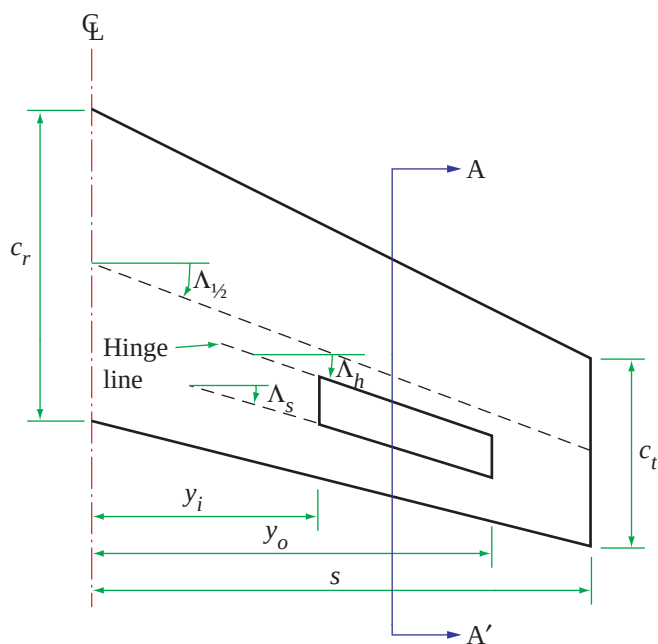
		SI	British
A	wing aspect ratio		
C_L	lift coefficient		
ΔC_{L_s}	increment in lift coefficient due to spoilers on both wings, flap undeflected		
$\Delta C_{L_{s\infty}}$	two-dimensional value of ΔC_{L_s} , see Figures 1a and 1b		
$dC_L/d\alpha$	wing lift-curve slope	rad ⁻¹	rad ⁻¹
C_l	rolling moment coefficient due to starboard spoiler, flaps undeflected		
C_p	pressure coefficient		
c	wing chord	m	ft
c_{hs}	spoiler chord aft of hinge (see Sketch 1.3)	m	ft
$\bar{c}$	wing geometric mean chord	m	ft
H	$h_{eff} + z_s$	m	ft
h	“height” of spoiler when deflected (see Sketches 1.2 and 1.3), taken as $c_{hs} \sin \delta_s$ for flap-type spoiler	m	ft
h_{eff}	effective height of spoiler, i.e. height of flat-plate type spoiler giving same lift decrement	m	ft
k	correction factor for flap-type spoilers (see Figure 2)		
M	free-stream Mach number		
S	wing planform area	m ²	ft ²
s	wing semi-span	m	ft
x_h	chordwise position of spoiler hinge (see Sketch 1.3)	m	ft
x_s	chordwise position of spoiler trailing edge (see Sketches 1.2 and 1.3), taken as $x_h + c_{hs} \cos \delta_s$ for flap-type spoiler	m	ft
y	lateral distance from wing centre-line	m	ft

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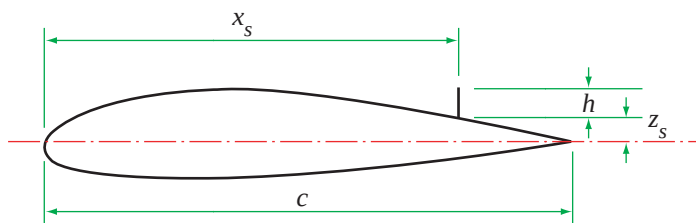
y_a	moment arm for lift increment due to single spoiler, flaps undeflected (see Section 3.2.2)	m	ft
z_s	ordinate of wing section at x_s (see Sketches 1.2 and 1.3)	m	ft
α	incidence (synonymous with angle of attack for purpose of this Item)	deg	deg
β	compressibility parameter, $(1 - M^2)^{1/2}$		
δ_h	spoiler deflection about hinge line	deg	deg
δ_s	spoiler deflection in streamwise plane, where $\tan \delta_s = \tan \delta_h \times \cos \Lambda_h$	deg	deg
η	y/s		
η_a	y_a/s		
$\bar{\eta}$	$\frac{1}{2}(\eta_i + \eta_o)$		
$\Delta\eta_1, \Delta\eta_2, \Delta\eta_3$	moment arm correction terms (see Section 3.2.2, Equation (3.11) and Figure 4)		
Λ_h	sweepback of spoiler hinge line (see Sketch 1.1)	deg	deg
Λ_s	sweepback of spoiler trailing edge (see Sketch 1.1)	deg	deg
$\Lambda_{1/2}$	sweepback of wing mid-chord line	deg	deg
λ	wing taper ratio, c_t/c_r		
σ	porosity, ratio of spoiler open area to spoiler total area (see Section 3.1)		
ϕ	part-span correction factor for lift (see Section 3.2.1 and Figure 3)		

Subscripts

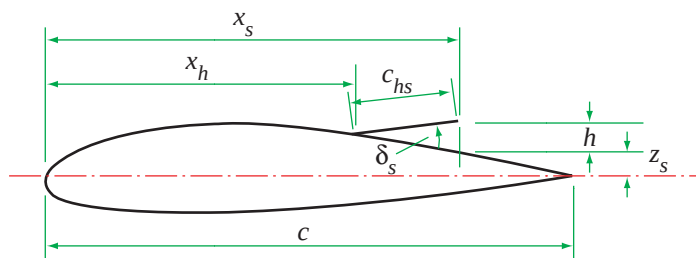
i	inboard end (of spoiler)
o	outboard end (of spoiler)
r	root
s	spoiler
t	tip
∞	two-dimensional value



Sketch 1.1 Wing and spoiler geometry



Sketch 1.2 Flat-plate spoiler (Section on AA')



Sketch 1.3 Flap-type spoiler (Section on AA')

2. INTRODUCTION

Spoilers may be used on both upper and lower surfaces of wings, but they are used most frequently on the upper surface. A “spoiler” attached to the upper surface of a wing will cause the flow to separate, literally “spoiling” the flow, and usually resulting in a loss of lift and increase in drag. The spoiler is usually a device that can be actuated very quickly. These three attributes, *i.e.* loss of lift, increase in drag and rapid actuation, lead to a variety of uses or potential uses on aircraft. These include use

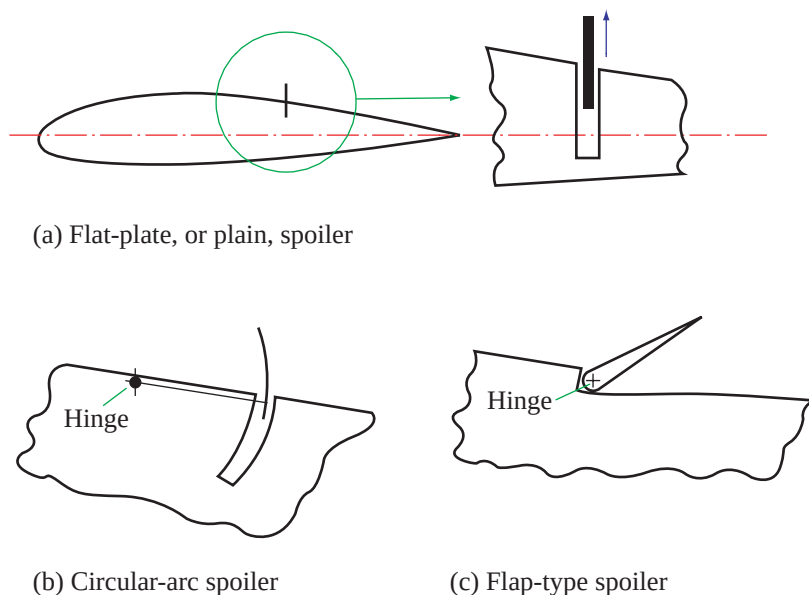
- (a) as roll control,
- (b) for lift dumping,
- (c) as an airbrake,
- (d) for direct lift control (DLC), *i.e.* controlling lift without change of attitude,
- (e) for load alleviation,
- (f) as a means of reducing the hazard of trailing vortices to following aircraft.

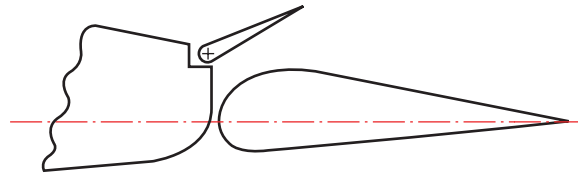
Spoilers also have other, non-aeronautical uses, such as the prevention of overspeeding of wind turbines.

Spoilers may be placed at any chordwise position, have various spanwise extents, and be used in isolation or in combination with flaps and ailerons. The parameters of interest will depend upon the particular application. In addition to steady lift, drag and rolling moment there may be interest in the time varying characteristics (for (e) above), in pitching and yawing moments, and in the hinge moments and power required for actuation. This Item presents a method for predicting the lift and rolling moment due to upper-surface spoiler deflection, but without trailing-edge flap deflection, the effects of which are covered in Item No. 92002 (Reference 48). The method is based on information contained in Derivations 1 to 32. Additional useful descriptive or supplementary information is contained in References 33 to 47.

2.1 Types of Spoiler

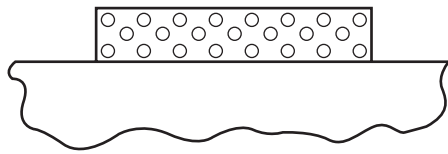
Various types of spoiler are illustrated on the upper surface of an aerofoil or wing in Sketch 2.1.



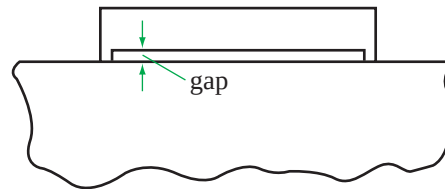


(d) Spoiler with lower-surface venting

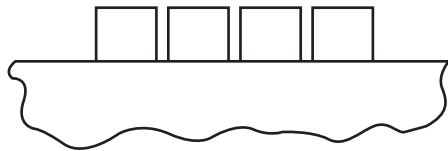
Spoiler face variations



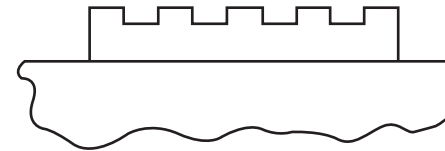
(e) Perforated spoiler



(f) Spoiler with hinge-line gap



(g) Segmented spoiler



(e) Spoiler with notched edge

Sketch 2.1 Types of spoiler

The flat-plate, perpendicular to the surface (a) is geometrically the simplest, and often used in wind-tunnel testing.

The circular arc (b) approximates to the flat plate, rotation is more convenient than the sliding motion of the flat plate, but a deep cut through the wing structure is still required.

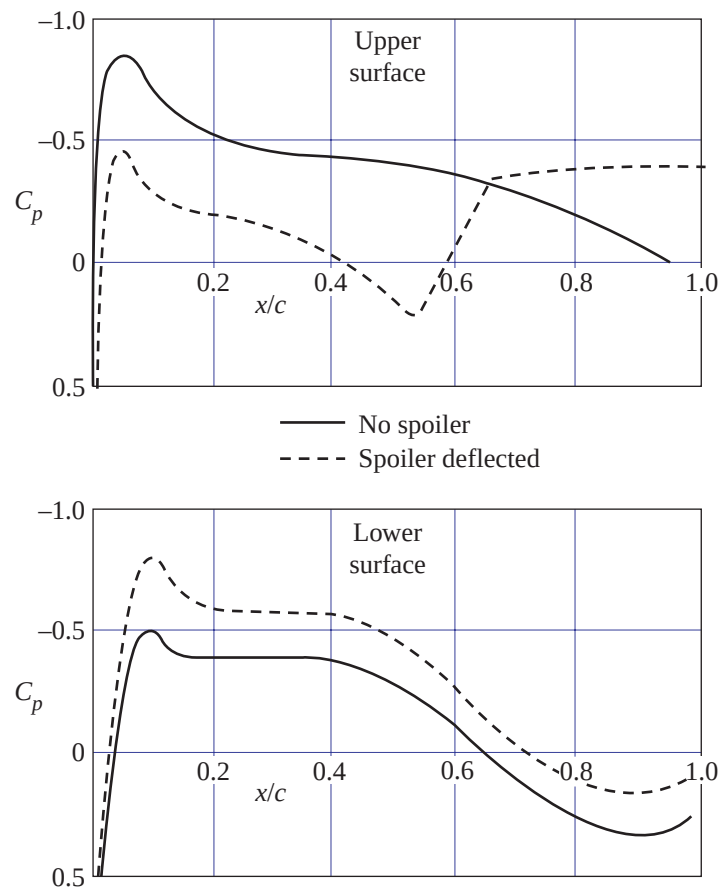
The flap-type spoiler (c) is the one usually used on aircraft. Other more complicated forms of spoilers include venting of air from the lower surface of the wing (d), or the use of air jets.

The non-linear and buffeting characteristics of spoilers can often be improved by the use of some porosity, either in the form of a perforated surface (e), hinge-line gap (f), or segmentation (g). Trailing-edge notching (h) has also been tried.

The method outlined in this Item is based on the flat-plate type spoiler, with factors to incorporate flap-type spoilers and porosity. Neither venting from the lower surface, nor the combination of spoiler with trailing-edge flap deflection, is considered here, but see Item No. 92002 (Reference 48) which treats those topics.

2.2 Spoiler Characteristics

The action of a spoiler on an aerofoil is to create separated flow. The extent of the separation in a two-dimensional flow depends upon the deflection and shape of the spoiler, its chordwise position, the aerofoil section and incidence, Mach number, and Reynolds number. With finite wings the separation will also depend upon the wing planform (aspect ratio, taper ratio, sweep) and the spanwise position and extent of the spoilers. The separation may extend upstream of the spoiler, and the downstream separation may re-attach for small deflections and forward spoiler positions. The boundary for the free-stream flow is hence changed, the free stream is effectively displaced from the original surface and thus the aerofoil generates a different lift and has a different zero-lift angle. The pressure distribution around the aerofoil is changed, typically as shown in Sketch 2.2. Ahead of the spoiler pressure is increased resulting in a download; behind the spoiler pressure is decreased giving an upward force; on the lower surface pressure is decreased, again giving a download. The loss of lift can come as much from the lower surface as the upper.



Sketch 2.2 Typical pressure distribution with spoiler

The depth of separation at the trailing edge is in part related to the spoiler deflection, and in part to the section shape and incidence (see Sketch 2.3). The change in zero-lift angle can be correlated against a total height equivalent to the spoiler height plus the section ordinate at the spoiler position (as in Derivation 12). The variation due to incidence can be related to spoiler chordwise position.