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Aircraft forces due to interference between a jet efflux and a slotted flap

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THE PREPARATION OF THIS DATA ITEM

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AIRCRAFT FORCES DUE TO INTERFERENCE BETWEEN A JET EFFLUX AND A SLOTTED FLAP

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AIRCRAFT FORCES DUE TO INTERFERENCE BETWEEN A JET EFFLUX AND A SLOTTED FLAP

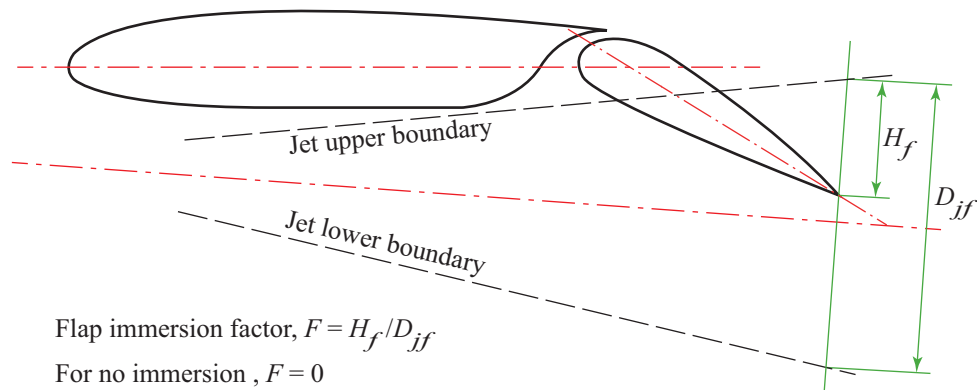
1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
A	wing aspect ratio, $4s^2/S_{ref}$		
A_1	annular area of secondary jet flow at exit of double stream nozzle, see Sketch 1.2b	m^2	ft^2
A_2	area of primary jet flow at exit of double stream nozzle, see Sketch 1.2b	m^2	ft^2
B	coefficient used in evaluating θ_{jc} in Equation (3.9)		
C_{Da}	aircraft drag coefficient resulting from aerodynamic forces, excluding contribution from jet/flap interference effects		
C_{Db}	drag coefficient increment resulting from aerodynamic forces arising from jet/flap interference effects		
C_{La}	aircraft lift coefficient resulting from aerodynamic forces, excluding contribution from jet/flap interference effects		
C_{Lb}	lift coefficient increment resulting from aerodynamic forces arising from jet/flap interference effects		
$C_{L\alpha}$	incidence-dependent component of C_{Lb}		
$C_{L\theta}$	flap-dependent component of C_{Lb}		
C_m	total aircraft pitching moment coefficient, see Sketch 1.3		
C_{ma}	pitching moment coefficient resulting from aerodynamic forces, excluding jet/flap interference effects		
C_{mb}	pitching moment coefficient increment resulting from aerodynamic forces arising from jet/flap interference effects		
C_{me}	propulsion contribution to pitching moment coefficient, excluding jet/flap interference effects		
C_{mp}	propulsion contribution to pitching moment coefficient including jet/flap interference		
C_{mT}	resultant pitching moment coefficient, see Sketch 1.3		

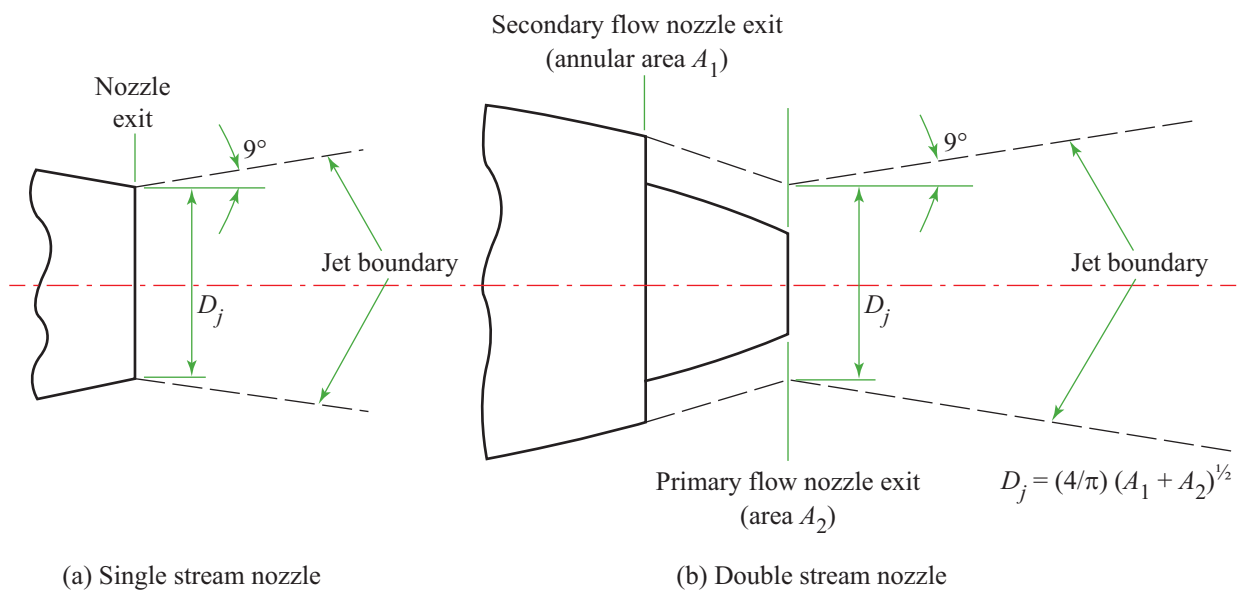
C_{TG}	gross thrust coefficient, (total engine gross thrust)/(free-stream kinetic pressure $\times S_{ref}$)		
C_{TN}	net thrust coefficient		
C_{XD}	momentum force coefficient associated with the air that passes through the engines, calculated at free-stream velocity		
C_{XT}	coefficient of resultant force parallel to free-stream, see Sketch 1.3a		
C_{ZT}	coefficient of resultant force normal to free-stream, see Sketch 1.3a		
C_{μ}	two-dimensional trailing-edge jet momentum coefficient, derived from Equation (4.1)		
c	local wing chord	m	ft
$\bar{c}$	wing aerodynamic mean chord for straight-tapered wing	m	ft
c'	extended wing chord, see Sketch 1.6	m	ft
c''	projected chord of extended wing, see Sketch 1.6	m	ft
c_f	flap chord, see Sketch 1.6	m	ft
c_{faux}	chord of flap final, or auxiliary, element, see Sketch 1.6b	m	ft
D_j	jet diameter at start of jet diffusion, see Sketch 1.2	m	ft
D_{jf}	jet diameter at flap trailing-edge, see Sketch 1.1	m	ft
E	coefficient used in evaluating θ_{jc} in Equation (3.9)		
F	flap immersion factor, see Sketch 1.1		
F_1, F_2	coefficients used in evaluating K_4 in Equation (4.19)		
G, G_1	coefficients used in evaluating $C_{L\alpha}$ in Equation (4.13)		
H_f	distance of flap trailing-edge from jet upper boundary, see Sketch 1.1	m	ft
h_e, h_i	moment arms associated with propulsion forces, see Sketch 1.5a	m	ft
h_f	moment arm associated with jet/flap interference forces, see Sketch 1.5	m	ft
K	part-span vortex drag factor		
K_1	coefficient used in evaluating $C_{L\alpha}$ in Equation (4.13)		

K_2	ratio of extended wing chord to local wing chord, c'/c		
K_3, K_{3aux}	coefficients used in evaluating $C_{L\theta}$ in Equation (4.17)		
K_4	coefficient used in evaluating K		
l_c	distance of centre-of-pressure measured from wing leading-edge, see Sketch 1.5a	m	ft
l_e	moment arm associated with propulsion forces, see Sketch 1.5a	m	ft
l_f	moment arm associated with jet/flap interference forces, see Sketch 1.5	m	ft
l_0	distance between wing leading-edge and aircraft centre-of-gravity, see Sketch 1.5a	m	ft
N	number of engines per wing		
S_{ref}	wing reference area, for straight-tapered wing	m ²	ft ²
S_j	wing area influenced by jets, see Equation (4.2)	m ²	ft ²
s	wing semi-span, see Sketch 1.7	m	ft
t	local wing maximum thickness	m	ft
Y	coefficient used in evaluating λ_1 in Equation (3.8)		
y_{eng}	spanwise distance of engine centre-line from aircraft centre-line, see Sketch 1.7	m	ft
α	aircraft incidence	degree	degree
α_l	inclination of local chord relative to aircraft reference plane, see Sketch 1.3a	degree	degree
δ_f	flap angle, see Sketch 1.3	degree	degree
δ_{faux}	flap angle for final, or auxiliary, element of flap, see Sketch 1.3c	degree	degree
ΔC_{mT}	change in resultant pitching moment coefficient		
ΔC_{XT}	change in C_{XT} due to jet/flap interference		
ΔC_{ZT}	change in C_{ZT} due to jet/flap interference		
η_i	distance from aircraft centre-line to inboard limit of jet(s), non-dimensionalised with respect to wing semi-span, see Sketch 1.7		

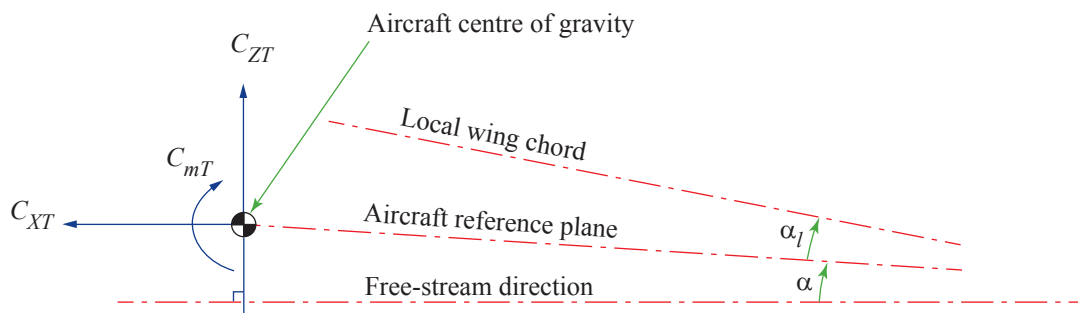
η_j	propulsive efficiency factor		
η_o	distance from aircraft centre-line to outboard limit of jet(s), non-dimensionalised with respect to wing semi-span, see Sketch 1.7		
θ_d	angle through which jet is deflected due to jet/flap interference	degree	degree
θ_e	inclination of powerplant thrust line relative to aircraft reference plane, $\theta_{ew} + \alpha_l$	degree	degree
θ_{ew}	inclination of powerplant thrust line relative to local wing chord (see Sketch 1.3b)	degree	degree
θ_f	inclination of flap trailing-edge upper-surface relative to local wing chord, see Sketch 1.3	degree	degree
θ_j	inclination of deflected jet relative to aircraft reference plane, $\theta_{jw} + \alpha_l$	degree	degree
θ_{jc}	theoretical deflection angle for that part of jet which impinges on flap, used in evaluating η_j in Equation (3.7)	degree	degree
θ_{jw}	inclination of deflected jet relative to local wing chord, see Sketch 1.3b	degree	degree
θ_m	theoretical maximum jet deflection angle, $\theta_f - \theta_{ew}$	degree	degree
$\Lambda_{1/2}$	wing sweepback angle of half-chord line	degree	degree
λ	wing taper ratio, tip chord/centre-line chord		
λ_1	fraction of jet area impinging on flap		
λ_2	fraction of λ_1 lost through scrubbing or by lateral spread of jet		
λ_m	jet momentum ratio, see Equation (3.1)		
Φ	part-span factor on lift coefficient		
<i>Subscripts</i>			
2D	denotes value for aerofoil		
3D	denotes value for wing		
<i>jfint</i>	denotes including jet/flap interference		



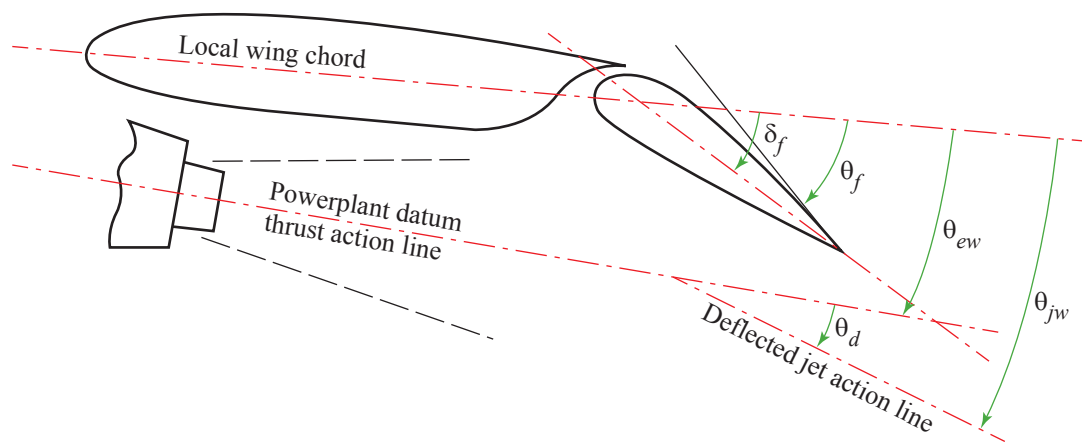
Sketch 1.1 Definition of flap immersion factor



Sketch 1.2 Illustration of method used to define jet boundary

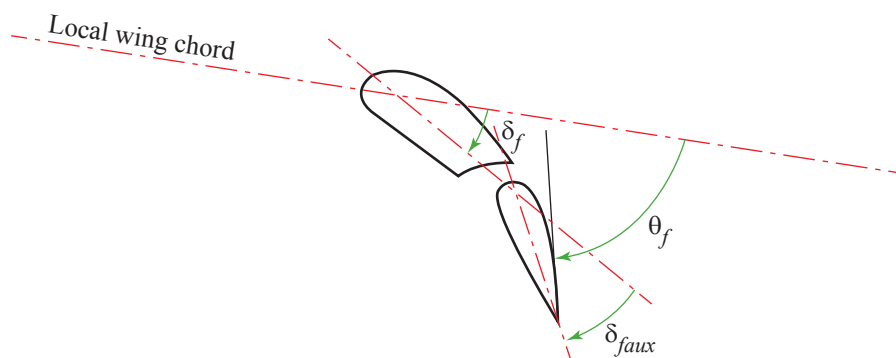


(a) Definition of incidence, wing twist and forces



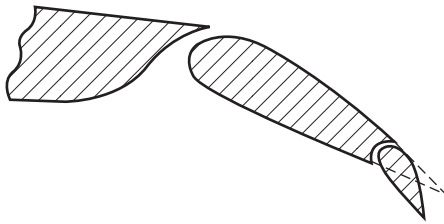
(b) Definition of angles for single-element flap

Note: All angles are drawn in the positive direction

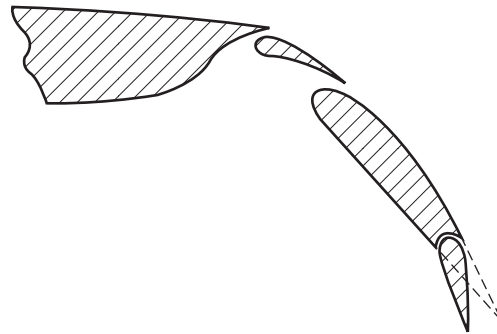


(c) Definition of angles for double-element flap

Sketch 1.3 Definition of angles and forces

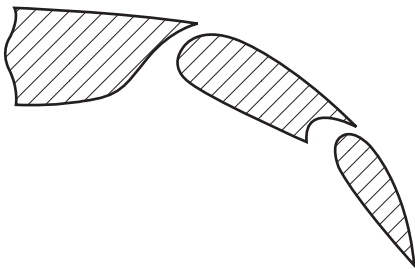


(i) Single-slotted

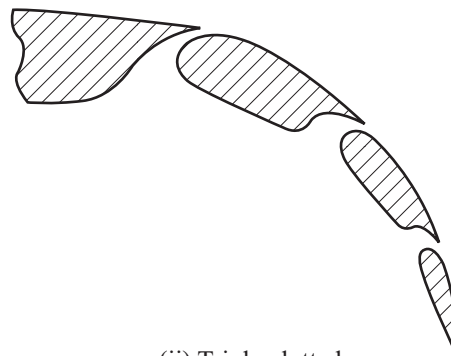


(ii) Double-slotted

(a) Type A: single main element



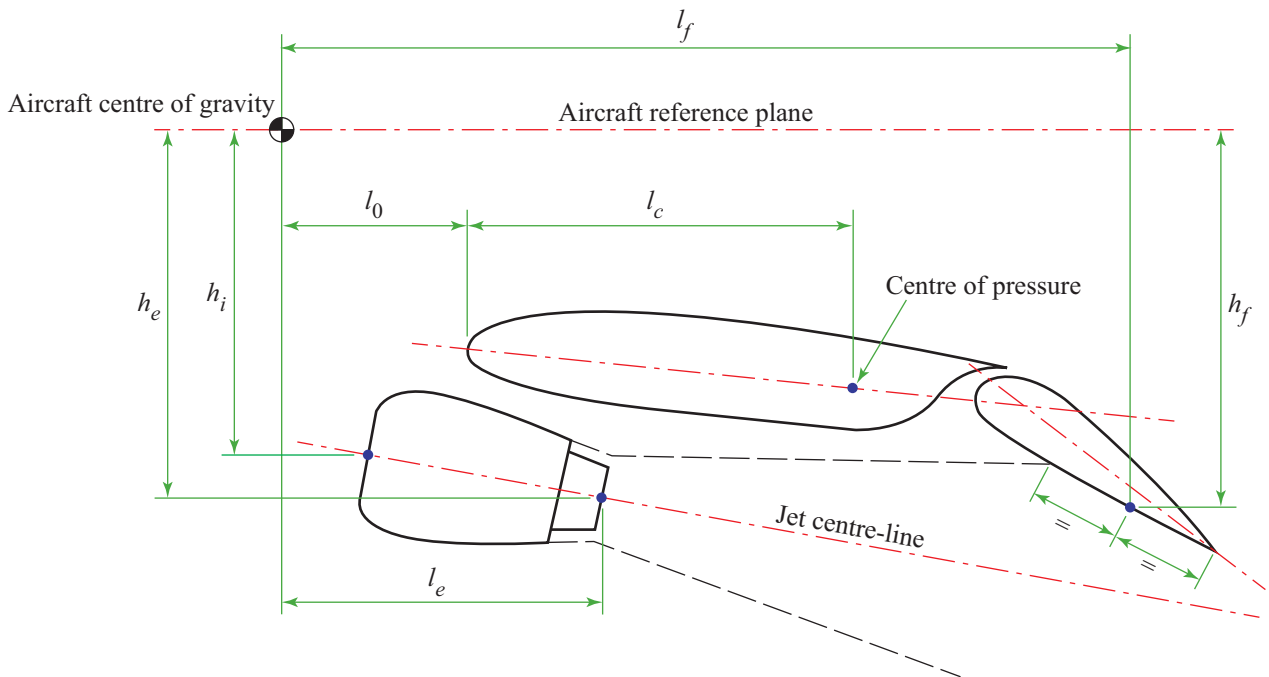
(i) Double-slotted



(ii) Triple-slotted

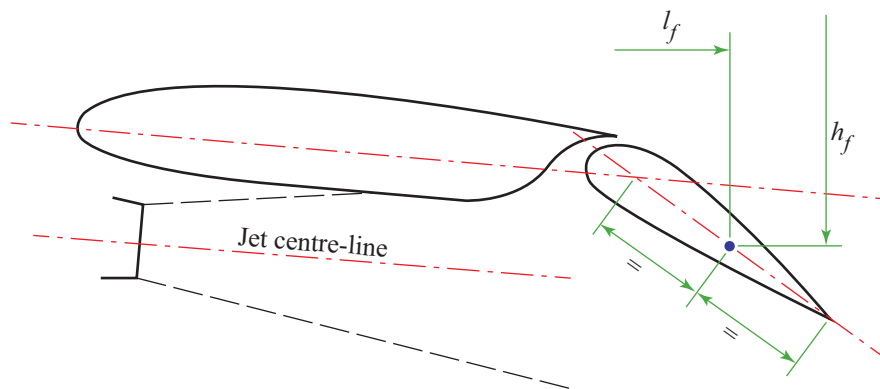
(b) Type B: multi-element

Sketch 1.4 Illustration of flap types



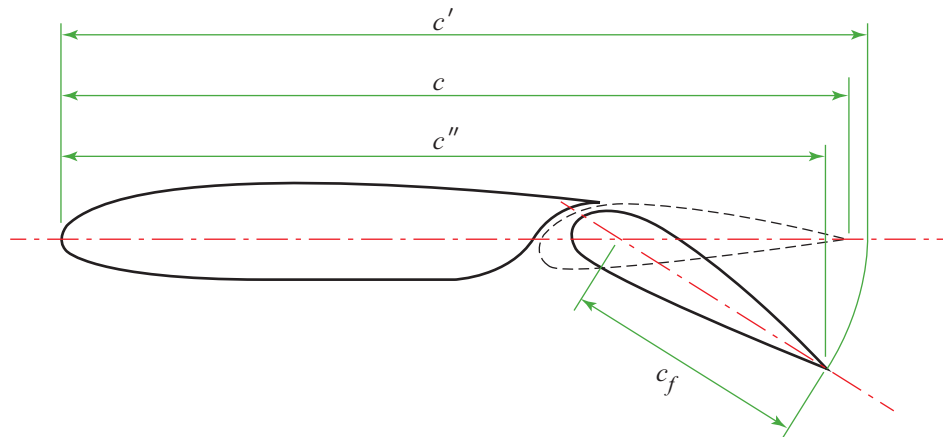
(a) General case

Note: All moment arms are drawn as positive values

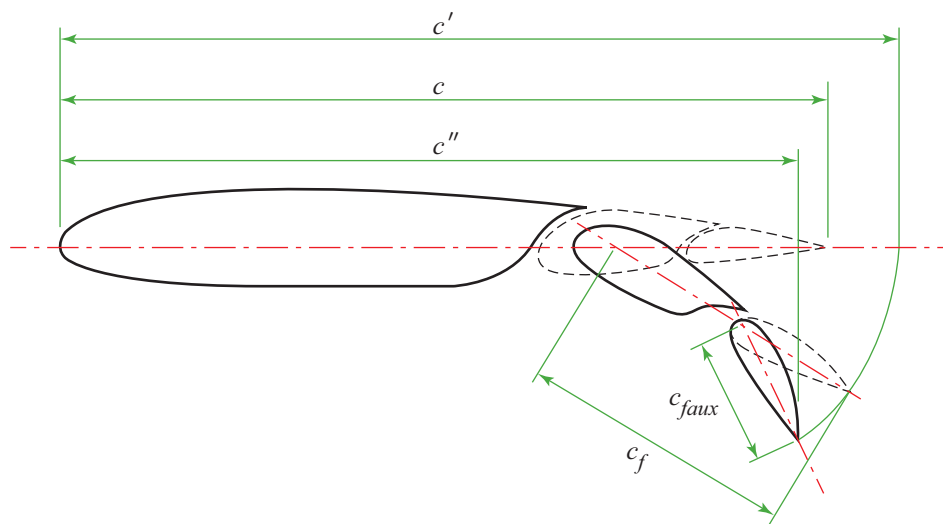


(b) Case of high flap immersion

Sketch 1.5 Moment arm definition

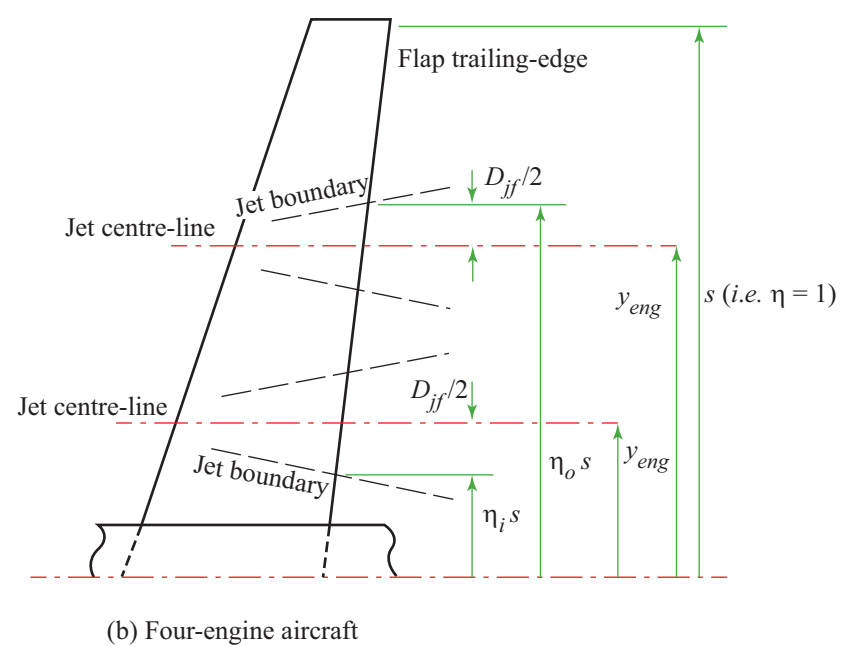
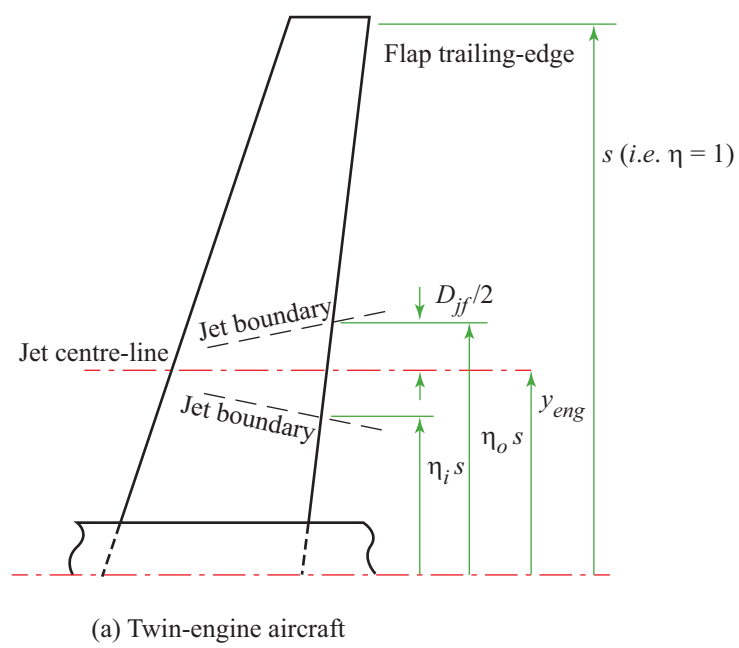


(a) Single-element flap



(b) Double-element flap

Sketch 1.6 Definition of wing and flap chords



Sketch 1.7 Jet spanwise extent for use in evaluating part-span factors

2. SCOPE AND APPLICATION OF THE DATA ITEM

2.1 Scope and Introduction

This Item presents a method for estimating the changes in the forces acting on an aircraft due to the impingement of the jet efflux from the engine on the wing trailing-edge flap. The use of the method is limited to flight at speeds below that at which compressibility effects become important, for attached flow conditions and for aircraft with engines having circular exhaust jets which pass under the wing. Although the method presented has been based on measured data for wings with flaps deployed, the approach used does permit estimates to be made for the case of jet impingement on the lower surface of a wing with flaps retracted.

In the analysis of the experimental data used to derive the methods presented in this Item a simple approach has been used. It has been assumed that the interaction between the jet and flap has two main effects on the aircraft characteristics. The first has been defined as a change in the propulsive forces due to the deflection of the jet by the flap, and has been obtained from analysis of static wind-tunnel tests. The second effect has been defined as a change in wing aerodynamic forces, and has been obtained from analysis of wind-on-tunnel tests, suitably corrected for power effects. It should be noted that because the change in propulsive force results from the interaction of the jet with the wing, there will be a pressure distribution imposed on the wing which reflects these force changes. Thus, the change in propulsive force could also be described as aerodynamic in nature. However, in the simple procedure used to analyse the experimental data referred to above it was most convenient to break down the measured data into the terms defined as propulsive and aerodynamic forces. This approach has been retained for the data presented in this Item.

In Section 3 a method is given for estimating the effect of flap immersion in the jet on the propulsive forces acting on the aircraft. The effect of the interaction is to deflect the jet, giving a change in the direction of propulsive force together with some loss in propulsive efficiency. The angle turned through by the deflected jet is given as a function of the flap trailing-edge upper-surface angle, the flap type and that part of the jet which impinges on the wing and flap. The propulsive efficiency factor is then obtained from a semi-empirical method based on simple momentum theory.

In Section 4 a method is given for estimating the effect of the jet interaction with the flap on the aerodynamic forces acting upon the aircraft. The impingement of the jet on the flap results in changes in the aerodynamic lift, drag and pitching moment. The magnitude of these changes is dependent upon the proportion of the jet that impinges on the wing and flap and its spanwise extent. The method given for estimating these changes in aerodynamic forces is based on two-dimensional external-flow jet-flap theory applied to the three-dimensional part-span case by the use of empirical coefficients. The momentum of the jet at the flap trailing-edge used in the jet-flap theory is obtained from the parameters determined in Section 3. Therefore, in this approach there is a direct link between the methods used to estimate the changes in propulsive and aerodynamic forces.

2.2 Application of the Data Item

In the application of the method given in this Item the following equations must be used to give the pitching moment and force coefficients acting on the aircraft. These equations have been formulated by considering the case of one engine per wing. The equations can be applied to the case of two engines per wing as outlined in Section 2.3.

(i) With no jet/flap interference

$$C_{mT} = C_{ma} + C_{me}, \quad (2.1)$$

$$C_{ZT} = C_{La} + C_{TG} \sin(\alpha + \theta_e) \quad (2.2)$$

and
$$C_{XT} = C_{TG} \cos(\alpha + \theta_e) - C_{XD} - C_{Da} \quad (2.3)$$

(ii) With jet/flap interference

$$C_{mT} = C_{ma} + C_{mb} + C_{mp}, \quad (2.4)$$

$$C_{ZT} = C_{La} + C_{Lb} + C_{TG} \eta_j \sin(\alpha + \theta_j) \quad (2.5)$$

and
$$C_{XT} = C_{TG} \eta_j \cos(\alpha + \theta_j) - C_{XD} - C_{Da} - C_{Db}. \quad (2.6)$$

In Equations (2.1) to (2.6)

C_{mT}	is the resultant pitching moment coefficient,
C_{ZT}	is the coefficient of resultant force normal to the free-stream,
C_{XT}	is the coefficient of resultant force parallel to the free-stream,
C_{TG}	is the gross thrust coefficient,
C_{XD}	is the momentum force coefficient associated with the free-stream air that passes through the engines,
η_j	is the propulsive efficiency factor associated with the jet/flap interference and is evaluated in Section 3.2,
θ_j	is the inclination of the deflected jet relative to the aircraft reference plane and is estimated in Section 3.1,
α	is the aircraft incidence,
θ_e	is the inclination of the powerplant thrust line relative to the aircraft reference plane,
C_{ma}, C_{La}, C_{Da}	are the aircraft pitching moment, lift and drag coefficients, respectively, obtained at the given incidence for the case of zero jet/flap interference,
C_{me}, C_{mp}	are the pitching moment coefficients due to propulsive forces estimated using Section 3.3,
C_{mb}, C_{Lb}, C_{Db}	are the pitching moment, lift and drag coefficient increments, respectively, resulting from the effect of the jet on the flap and are estimated using Section 4

and h_e, l_e, h_f, h_e, h_i are moment arms defined in Section 3.3.

It follows from Equations (2.1) to (2.6) that the changes in the force coefficients, due to jet/flap interference effects, are given by

$$\Delta C_{ZT} = C_{TG} [\eta_j \sin(\alpha + \theta_j) - \sin(\alpha + \theta_e)] + C_{Lb} \quad (2.7)$$

and
$$\Delta C_{XT} = C_{TG} [\eta_j \cos(\alpha + \theta_j) - \cos(\alpha + \theta_e)] - C_{Db}. \quad (2.8)$$

For some applications of the data obtained from this Item it may be necessary to break down these forces into “thrust” and “drag” components for use in aircraft performance calculations. However the breakdown of forces that may be used is to some extent arbitrary and will depend upon the precise definition of thrust and drag adopted. The definition of “thrust” and “drag” for the case of an aircraft with jet/flap interference

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