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Contribution of fin to sideforce, yawing moment and rolling moment derivatives due to rate of roll, $(Y_p)_F$, $(N_p)_F$, $(L_p)_F$, in the presence of body, wing and tailplane

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CONTRIBUTION OF FIN TO SIDEFORCE, YAWING MOMENT AND ROLLING MOMENT DERIVATIVES DUE TO RATE OF ROLL, $(Y_p)_F$, $(N_p)_F$, $(L_p)_F$, IN THE PRESENCE OF BODY, WING AND TAILPLANE

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1. NOTATION AND UNITS (see Sketch 1.1)

The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in Item No. 86021. Coefficients and aeronormalised derivatives are evaluated in aerodynamic body axes with origin at the aircraft centre of gravity and with the wing span as the characteristic length. The derivatives Y_p , N_p and L_p are often written as C_{Yp} , C_{np} and C_{lp} in other systems of notation, but attention must be paid to the reference dimensions used. In particular, in forming C_{Yp} , C_{np} and C_{lp} differentiation of C_Y , C_n and C_l may be carried out with respect to $pb/2V$ not pb/V as implied in the Hopkin system. It is also to be noted that a constant datum value of V is employed by Hopkin.

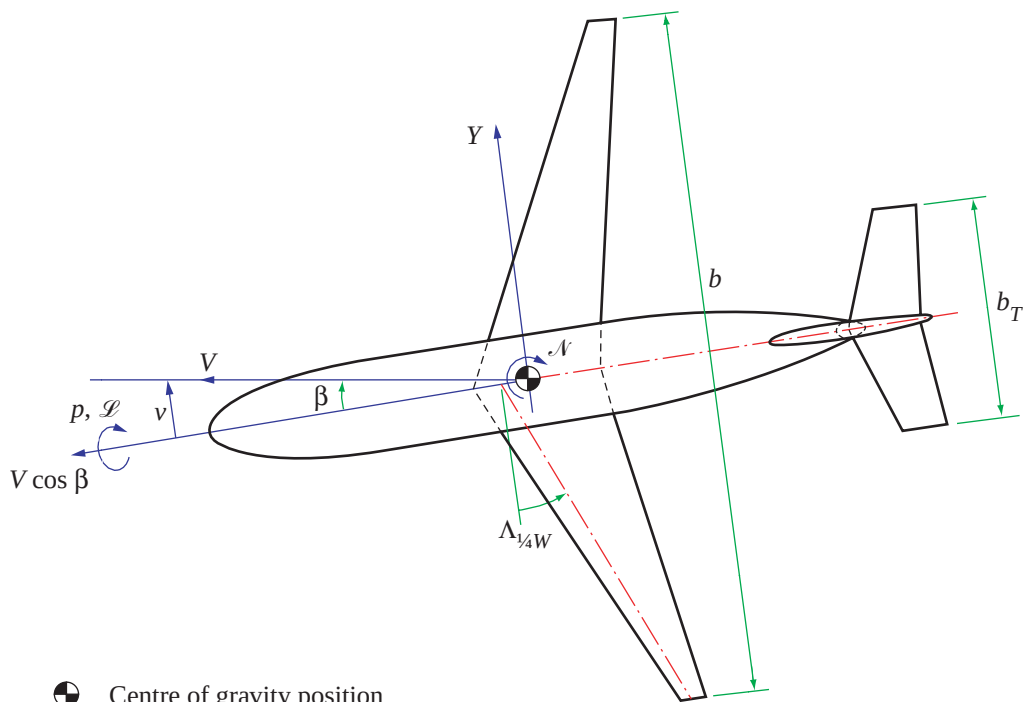
		SI	British
A_F	effective aspect ratio of fin, $2h_F^2/S_F$		
A_T	tailplane aspect ratio, b_T^2/S_T		
A_W	wing aspect ratio, b^2/S_W		
b	wing span	m	ft
b_T	tailplane span	m	ft
C_l	rolling moment coefficient, $\mathcal{L}/\frac{1}{2}\rho V^2 S_W b$		
C_n	yawing moment coefficient, $\mathcal{N}/\frac{1}{2}\rho V^2 S_W b$		
C_Y	sideforce coefficient, $Y/\frac{1}{2}\rho V^2 S_W$		
c_{0T}	tailplane centre-line chord (in plane of symmetry)	m	ft
c_{rF}	fin root chord, see Sketch 1.1	m	ft
c_{tF}	fin tip chord, see Sketch 1.1	m	ft
h_F	height of fin, measured from fin root chord in direction normal to longitudinal body axis, see Sketch 1.1	m	ft
K_1, K_2, K_3	factors used in estimating $(Y_p)_F$, see Sections 3.1 and 3.2		
$\mathcal{L}$	rolling moment	N m	lbf ft
L_p	rolling moment derivative due to rate of roll, $L_p = (\partial \mathcal{L} / \partial p) / \frac{1}{2} \rho V S_W b^2$		
$(L_p)_F$	fin contribution to L_p in presence of body, wing and tailplane		

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$(L_p)_T$	tailplane contribution to L_p in presence of body, wing and fin		
$\bar{l}_F^*$	distance of centre of pressure position of fin sideforce due to rate of roll, measured aft from centre of gravity position and parallel to longitudinal body axis, see Sections 3.1 and 3.2	m	ft
M	free-stream Mach number		
m_F	distance of fin root quarter-chord station aft of centre of gravity position, measured parallel to aircraft longitudinal body axis, see Sketch 1.1	m	ft
$\mathcal{N}$	yawing moment	N m	lbf ft
N_p	yawing moment derivative due to rate of roll, $N_p = (\partial \mathcal{N} / \partial p) / \frac{1}{2} \rho V S_W b^2$		
$(N_p)_F$	fin contribution to N_p in presence of body, wing and tailplane		
p	roll rate	radian/s	radian/s
S_F	fin area between fin root and tip chords, $h_F(c_{rF} + c_{tF})/2$, see Sketch 1.1	m ²	ft ²
S_T	tailplane planform area	m ²	ft ²
S_W	wing planform (reference) area	m ²	ft ²
V	velocity of aircraft relative to air	m/s	ft/s
v	sideslip velocity	m/s	ft/s
Y	sideforce	N	lbf
Y_p	sideforce derivative due to rate of roll, $Y_p = (\partial Y / \partial p) / \frac{1}{2} \rho V S_W b$		
$(Y_p)_F$	fin contribution to Y_p in presence of body, wing and tailplane		
z_{crf}	height of fin root chord, measured from longitudinal body axis in direction normal to longitudinal body axis, see Sketch 1.1	m	ft
$\bar{z}_F^*$	distance of centre of pressure position of fin sideforce due to rate of roll, measured above and normal to longitudinal body axis, see Sections 3.1 and 3.2	m	ft
z_T	height of intersection of fin-mounted tailplane with fin, measured from fin root chord in direction normal to longitudinal body axis, see Sketch 1.1	m	ft
α	angle of attack	radian	radian
β	angle of sideslip, $\sin^{-1}(v/V)$	radian	radian

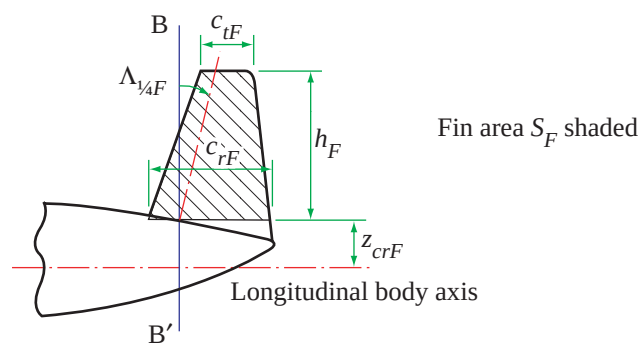
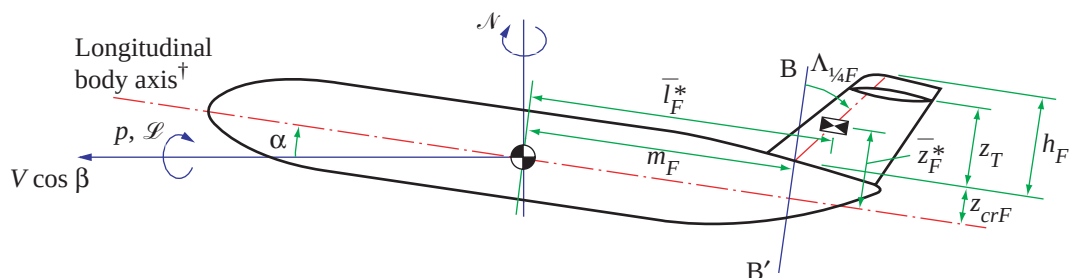
β_F	angle of sideslip at fin	radian	radian
$\Lambda_{\frac{1}{4}F}$	fin quarter-chord sweep angle	degree	degree
$\Lambda_{\frac{1}{4}T}$	tailplane quarter-chord sweep angle	degree	degree
$\Lambda_{\frac{1}{4}W}$	wing quarter-chord sweep angle	degree	degree
λ	ratio of wing tip chord to wing centre-line chord		
λ_F	ratio of fin tip chord to fin root chord		
λ_T	ratio of tailplane tip chord to tailplane centre-line chord		
ρ	density of air	kg/m ³	slug/ft ³
$\bar{\sigma}$	sidewash angle at fin due to rolling flight, positive when it decreases sideslip angle at fin, $\beta_F = \beta - \bar{\sigma}$	radian	radian
$\bar{\sigma}_W$	mean contribution to $\bar{\sigma}$ due to wing, see Section 3.3	radian	radian
$\bar{\sigma}_\alpha$	effective change in $\bar{\sigma}$ due to change in α and movement of fin relative to roll axis, see Section 3.4	radian	radian

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● Centre of gravity position

⊗ Centre of pressure on fin



Sketch 1.1 Body, wing and fin geometries

[†] The longitudinal body axis is a reference axis, fixed in the body in the plane of symmetry and passing through the centre of gravity position. The exact direction of the axis in the plane of symmetry is conventionally determined by considerations of mid-body geometry, the axis being taken parallel to some convenient 'horizontal' datum.

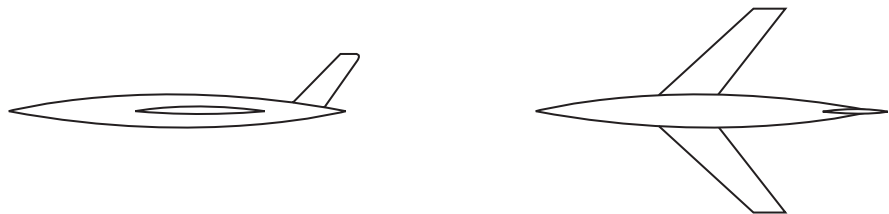
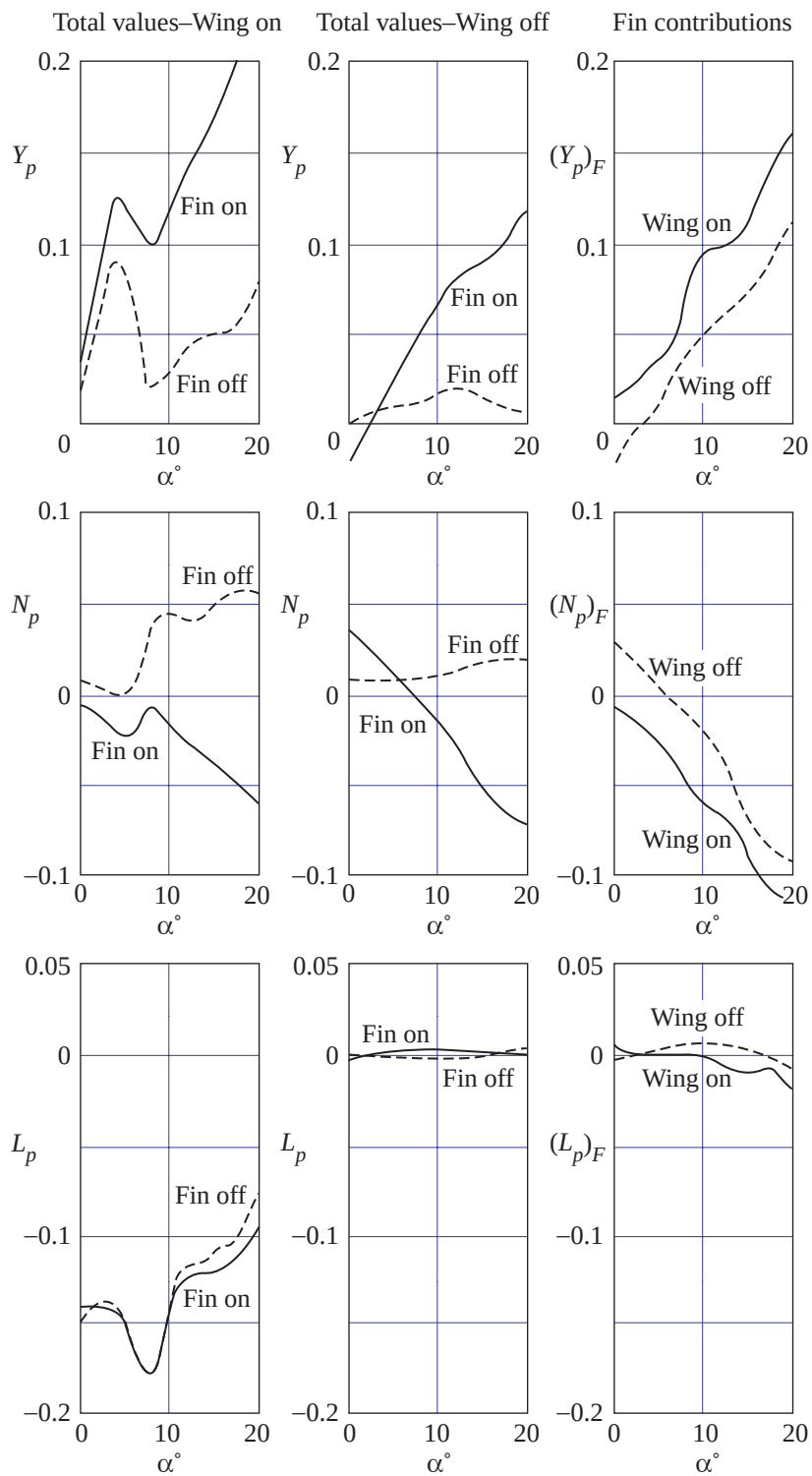
2. INTRODUCTION

This Item gives a method for calculating $(Y_p)_F$, $(N_p)_F$, and $(L_p)_F$, the contributions of the vertical stabilising fin of an aircraft to the sideforce, yawing moment and rolling moment derivatives due to rate of roll. The method is applicable for subsonic flight speeds when the flow over the aircraft is wholly subsonic and fully attached. The tail assemblies covered are those where a single fin is located on top of the aircraft rear body and in the plane of symmetry, with a tailplane, if present, mounted either on the fin itself or on the rear body. The aircraft is assumed to be in the 'clean' configuration with no flaps or slats deployed. The method is semi-empirical; it makes use of the theoretical calculations performed for isolated fin-tailplane arrangements at zero angle of attack that are reported in Derivations 10, 16 and 20, and applies corrections to allow for the presence of the wing and body and for angle of attack variations. These corrections are made in terms of the mean sidewash occurring at the fin in rolling flight, as suggested in Derivations 3 and 5, with the magnitudes of the corrections being deduced from comparisons with the wind-tunnel test results given in Derivations 1 to 4, 6 to 9, 11 to 15, 17 to 19, 21 and 22. A method for calculating $(L_p)_T$, the contribution of the tailplane to L_p , is also included in the Item.

The method is described in detail in Section 3 (see Section 3.1 for $(Y_p)_F$, $(N_p)_F$, and $(L_p)_F$, and Section 3.1.2 for $(L_p)_T$). The accuracy and applicability are assessed in Section 4 on the basis of comparisons with wind-tunnel data. The Derivation and References are given in Section 5 and a worked example which illustrates the agreement between prediction and experiment is given in Section 6.

2.1 General Behaviour of Derivatives

As an introduction to the fin contributions to the roll rate derivatives, Sketch 2.1 shows the total (experimental) values of Y_p , N_p and L_p and the (experimental) fin contributions to these derivatives for a wind-tunnel model tested both with and without a wing (Derivation 3). The sketch demonstrates the important influence of the wing on the fin contributions, the interference being sufficient to change the sign of the derivatives at low angles of attack. Note also that the fin contribution to L_p is only a small part of the total aircraft value, and so it is subject to more uncertainty than the other two derivatives when deduced from fin-on and fin-off model tests. The method in this Item has therefore concentrated on predicting $(N_p)_F$, this being more important than $(Y_p)_F$ in stability calculations. (The substantial non-linear variation with α of the wing-on derivatives is attributable to the contribution of the wing planform, as described in Item No. 81014, Reference 25.)



Sketch 2.1 Typical variations of roll rate derivatives (Derivation 3)