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and in part ESDU 70006

Contribution of fin to sideforce, yawing moment and rolling moment derivatives due to sideslip, $(Y_v)_F$, $(N_v)_F$, $(L_v)_F$, in the presence of body, wing and tailplane

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Item, which supersedes Item No. Aero. C.01.01.05 and, in part, Item No. 70006, was monitored and guided by the Aerodynamics Committee which first met in 1942 and now has the following membership:

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Mr H. Vogel	— British Aerospace, Weybridge-Bristol Division.

* Corresponding Member

The member of staff who undertook the technical work involved in the initial assessment of the available information and the construction and subsequent development of the Item was

Mr R.W. Gilbey — Senior Engineer.

CONTRIBUTION OF FIN TO SIDEFORCE, YAWING MOMENT AND ROLLING MOMENT DERIVATIVES DUE TO SIDESLIP, $(Y_v)_F$, $(N_v)_F$, $(L_v)_F$, 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 SIDESLIP, $(Y_v)_F$, $(N_v)_F$, $(L_v)_F$, IN THE PRESENCE OF BODY, WING AND TAILPLANE

1. NOTATION AND UNITS (see Sketches 1.1, 1.2 and 1.3)

The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in Item No. 86021. Coefficients and aerodynamical 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_v , N_v and L_v are often written as $\partial C_Y / \partial \beta$, $\partial C_n / \partial \beta$ and $\partial C_l / \partial \beta$ or $C_{Y\beta}$, $C_{n\beta}$ and $C_{l\beta}$ in other systems of notation, but attention must be paid to the reference dimensions used and it is to be noted that a constant datum value of V is employed in the Hopkin system.

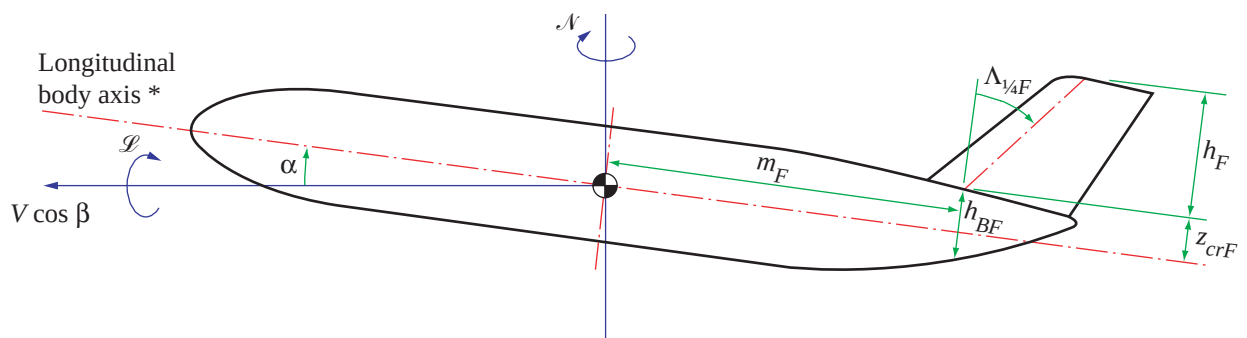
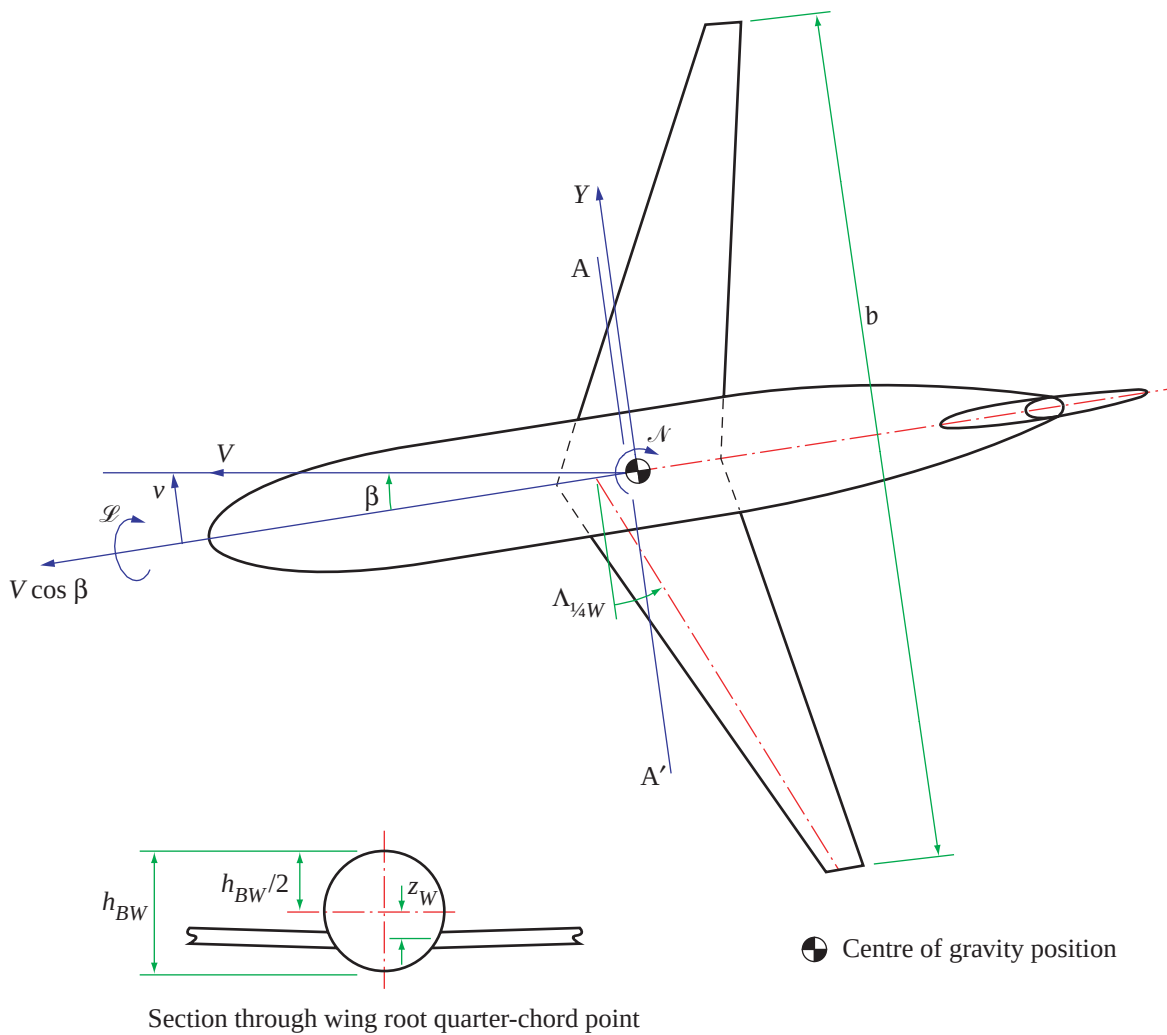
		SI	British
A_W	wing aspect ratio, b^2/S_W		
A_F	effective aspect ratio of fin, $2h_F^2/S_F$, see Section 3.2		
A_T	tailplane aspect ratio, b_T^2/S_T		
b	wing span	m	ft
b_T	tailplane span	m	ft
$(C_{L\alpha})_F$	lift-curve slope, $\partial C_L / \partial \alpha$, for straight-tapered wing of aspect ratio A_F , taper ratio λ_F , half-chord sweep angle $\Lambda_{1/2F}$ and area $2S_F$, estimated from Item No. 70011 (Derivation 33), see Section 3.2	radian ⁻¹	radian ⁻¹
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 through body centre-line	m	ft
c_{rF}	fin root chord, see Section 3.2	m	ft
c_{tF}	fin tip chord, see Section 3.2	m	ft
c_{tT}	tailplane tip chord	m	ft
d_{BF}	body width at fin root quarter-chord station	m	ft
h_{BF}	body height at fin root quarter-chord station	m	ft

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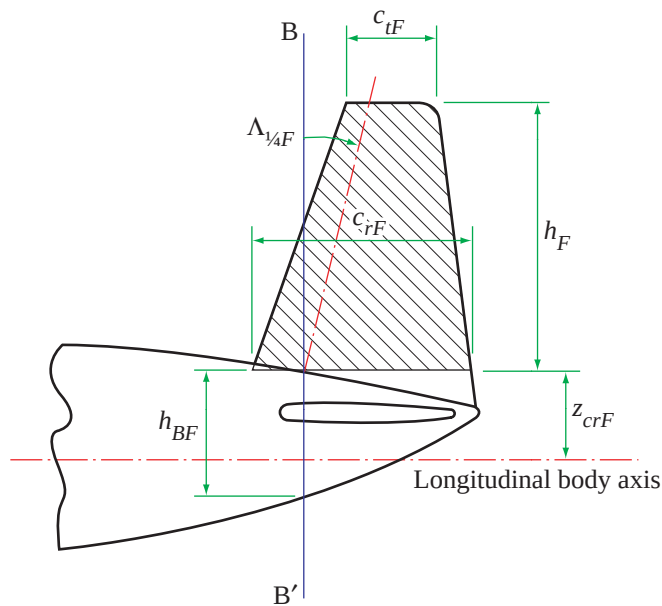
h_{BW}	body height at wing root quarter-chord station, see Sketch 1.1	m	ft
h_F	height of fin, measured from fin root chord in direction normal to longitudinal body axis see Section 3.2	m	ft
J_B	sideforce correction factor allowing for presence of body		
J_T	sideforce correction factor allowing for presence of tailplane		
J_W	sideforce correction factor allowing for presence of wing		
$\mathcal{L}$	rolling moment	N m	lbf ft
L_v	rolling moment derivative due to sideslip, $L_v = (\partial \mathcal{L} / \partial v) / \frac{1}{2} \rho V S_W b$		
$(L_v)_F$	fin contribution to L_v in presence of body, wing and tailplane		
M	free-stream Mach number		
m_F	distance of fin root quarter-chord station aft of centre of gravity position (moment reference centre), measured parallel to aircraft longitudinal body axis	m	ft
$\mathcal{N}$	yawing moment	N m	lbf ft
N_v	yawing moment derivative due to sideslip, $N_v = (\partial \mathcal{N} / \partial v) / \frac{1}{2} \rho V S_W b$		
$(N_v)_F$	fin contribution to N_v in presence of body, wing and tailplane		
S_F	fin area, $h_F(c_{rF} + c_{tF})/2$, see Section 3.2	m ²	ft ²
S_T	tailplane area, $b_T(c_{0T} + c_{tT})/2$	m ²	ft ²
S_W	wing (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_v	sideforce derivative, $Y_v = (\partial Y / \partial v) / \frac{1}{2} \rho V S_W$		
$(Y_v)_F$	fin contribution to Y_v 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	m	ft

$\bar{z}_F$	height of centre of pressure position of load distribution on fin, measured from fin root chord in direction normal to longitudinal body axis, see Section 3.6	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	m	ft
z_W	height of wing root quarter-chord point above local body centre-line, positive for low wings, see Sketch 1.1	m	ft
α	angle of attack	radian	radian
β	angle of sideslip	radian	radian
$\Lambda_{\frac{1}{4}F}$	fin quarter-chord sweep angle	degree	degree
$\Lambda_{\frac{1}{2}F}$	fin half-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_F	ratio c_{tF}/c_{rF}		
λ_T	ratio c_{tT}/c_{0T}		
ρ	density of air	kg/m ³	slug/ft ³

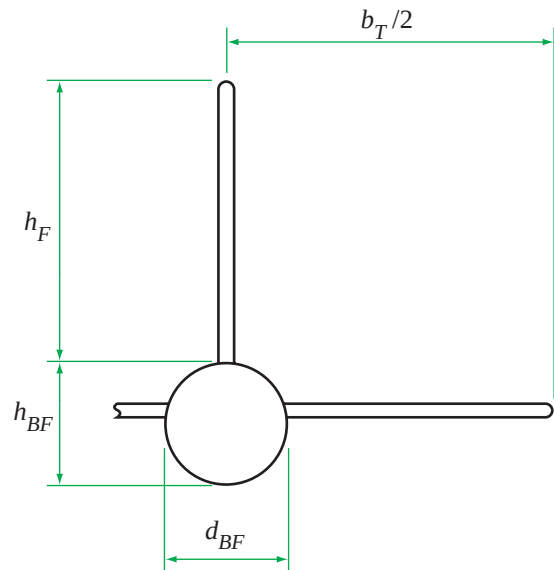


Sketch 1.1 Body, wing and fin geometries

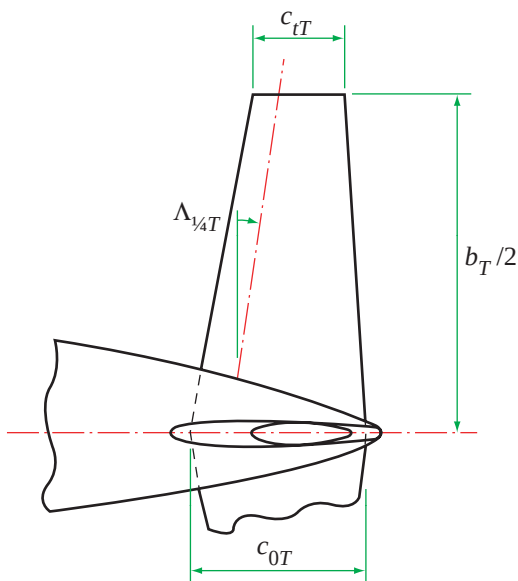
* The longitudinal body axis is a reference axis, fixed in the body in the plane of symmetry and passing through the centre of gravity position. The exact direction of the axis in the plane of symmetry is conventionally determined by considerations of mid-body geometry, the axis being taken parallel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



(a) Side view



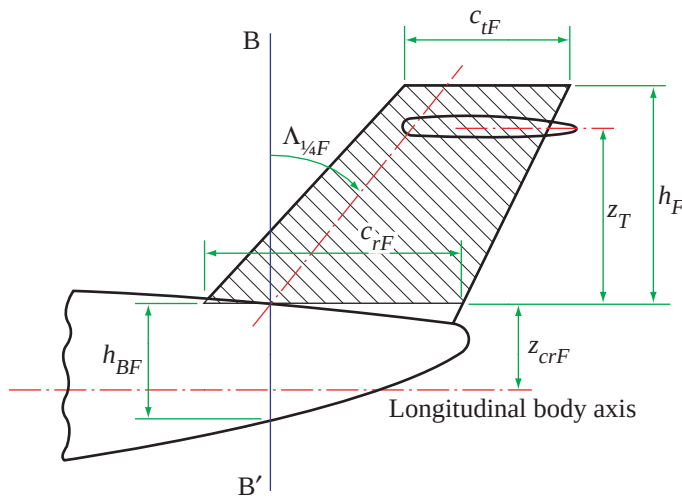
(c) View on B-B'



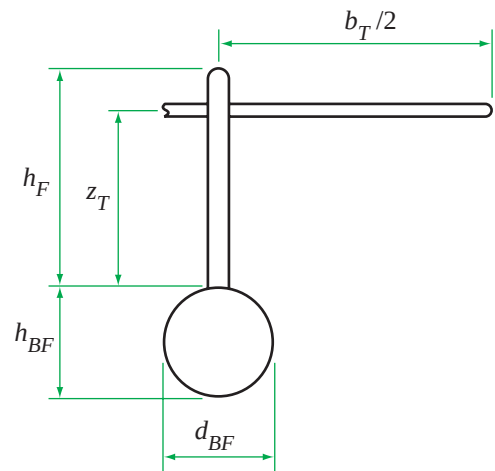
(b) Plan view

- NOTES
- (i) Area S_F is shown shaded.
 - (ii) BB' indicates the fin root quarter-chord station, defined by the plane normal to the longitudinal body axis which passes through the point at which the fin quarter-chord line intersects the body. The body height and width, h_{BF} and d_{BF} , are defined at this station.
 - (iii) Fin chords are defined parallel to the longitudinal body axis and fin, tailplane and body heights are defined perpendicular to it.

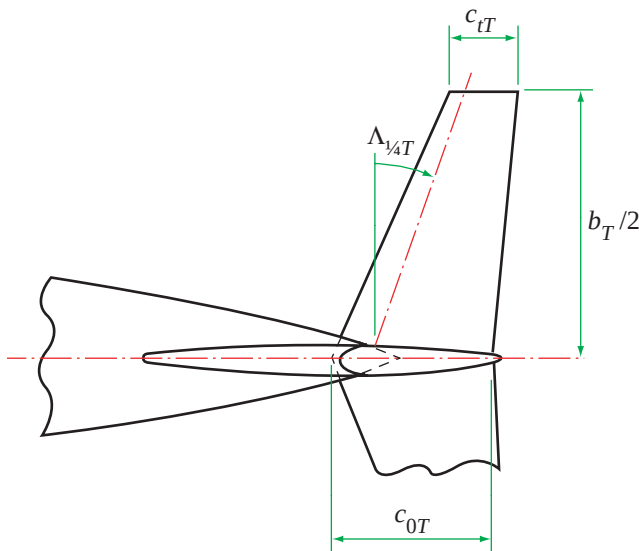
Sketch 1.2 Fin and tailplane geometries for body-mounted tailplanes



(a) Side view



(c) View on B-B'



(b) Plan view

- NOTES (i) Area S_F is shown shaded.
(ii) BB' indicates the fin root quarter-chord station, defined by the plane normal to the longitudinal body axis which passes through the point at which the fin quarter-chord line intersects the body. The body height and width, h_{BF} and d_{BF} , are defined at this station.
(iii) Fin chords are defined parallel to the longitudinal body axis and fin, tailplane and body heights are defined perpendicular to it.

Sketch 1.3 Fin and tailplane geometries for fin-mounted tailplanes

2. INTRODUCTION

This Item gives a semi-empirical method for calculating $(Y_v)_F$, $(N_v)_F$, and $(L_v)_F$, the contributions of the vertical stabilising fin of an aircraft to the sideforce, yawing moment and rolling moment derivatives due to sideslip, at subsonic speeds. The aircraft geometries covered by the method are those where a single fin is located on top of the aircraft rear-body, and in the plane of symmetry, with the tailplane mounted either on the fin itself or on the rear-body. The shape of the fin is assumed to approximate to a trapezium. The method was developed for bodies with circular or nearly-circular cross-sections. It may be used, with caution, for bodies with elliptical or near-rectangular cross-sections by using a mean body diameter provided that the body height to width ratio in the region of the fin is close to unity. Otherwise the method of Item No. 93007 (Reference 39) that covers a wide range of body height to width ratios and both single and twin fins should be used.

The method was established on the basis of a large number of comparisons with the wind-tunnel data in Derivations 1 to 31, with the theoretical method given in Derivation 32 being used to provide some guidance on the effect of systematic variations of body, fin and tailplane geometries in areas where the experimental data were sparse or highly scattered. (Derivation 32 uses a potential-flow calculation to determine the side-load distribution over body-fin-tailplane assemblies, see Section 2.1.)

The predicted contributions $(Y_v)_F$, $(N_v)_F$ and $(L_v)_F$ include allowances for interference between the body, wing, tailplane and fin and represent the effect of adding a fin. In particular the additional load induced on the body by the fin is taken into account. To estimate the total values of the stability derivatives for an aircraft the predicted contributions from the wing, body, nacelles and trailing-edge flaps must be added to the fin contributions predicted herein, as described in Item No. 82011 (Reference 38) for Y_v and N_v and Item No. 81032 (Reference 37) for L_v .*

The method is described in detail in Section 3. The accuracy and applicability, including comments on body cross-section shape and dorsal fin extensions, are discussed in Section 4. The Derivation and References are given in Section 5, and a worked example is given in Section 6.

2.1 Note on Method in Derivation 32

In Derivation 32 the sideforce distributions on body-fin-tailplane assemblies are calculated for configurations where there is constant induced sidewash across the fin span. The distributions are calculated from the two-dimensional flow around the cross-section of the wake in the Trefftz-plane, with conformal mappings being used to transform this flow into the flow past a flat plate, for which the potential flow function is known. The local difference of the potential flow function to either side of the flat plate gives the sideforce distributions.

The assumption of constant induced sidewash imposes a restriction on the planforms of the fin and the tailplane, the twist of the tailplane and the shape of the body. As the aspect ratios of the tailplane and fin become very small the condition of constant induced sidewash is satisfied whatever the shape of the fin and tailplane, provided that they are plane surfaces, that the twist of the tailplane tends to zero and that the body tends to a cylindrical cross-section. The calculation is therefore exact in the limiting case of very small fins and tailplanes and differences between any given arrangement and the constant induced sidewash arrangement appear only when the aspect ratio is not small. However, Derivation 32 suggests that at least approximate calculations can be made even for arrangements of large aspect ratio when the differences between a given arrangement and the constant induced sidewash arrangement can be expected to be appreciable. The method was therefore considered suitable for use in this Item to obtain smooth variations through scattered data and to provide guidance in areas where there were few data, provided experimental data were used as a check on magnitudes.

* Contributions from the tailplane in addition to the interference effects considered in this Item are discussed in Item No. 82011 (Section 3.2.2) and Item No. 81032. They are generally small enough to be neglected. If the tailplane has a large dihedral angle Item No. 81032 describes how the small tailplane-dihedral component of L_v can be calculated using the isolated wing data in Item No. Aero A.06.01.03 (Reference 35).

3. METHOD

3.1 General Description

3.1.1 Sideforce derivative $(Y_v)_F$

The derivative $(Y_v)_F$ is calculated by applying a series of correction factors to a basic lift-curve slope, $(C_{L\alpha})_F$, estimated for the fin. The correction factors allow, separately, for the presence of the body, tailplane and wing and are denoted by J_B , J_T and J_W respectively. The derivative $(Y_v)_F$ is given by

$$(Y_v)_F = -J_B J_T J_W (C_{L\alpha})_F S_F / S_W. \quad (3.1)$$

The establishment of the fin geometry and the calculation of $(C_{L\alpha})_F$ are described in Section 3.2, and the interference factors J_B , J_T and J_W are described in Sections 3.3 to 3.5, respectively.

3.1.2 Yawing moment and rolling moment derivatives $(N_v)_F$ and $(L_v)_F$

The derivatives $(N_v)_F$ and $(L_v)_F$ are calculated by estimating an approximate centre of pressure position for the sideforce generating $(Y_v)_F$ and thence determining the yawing and rolling moments produced relative to the centre of gravity position. Section 3.6 describes how the centre of pressure position is calculated by initially considering a simple spanwise loading distribution over the fin and then applying two numerical constants to modify the vertical and longitudinal moment arms in order to improve the accuracy of prediction of $(N_v)_F$ and $(L_v)_F$. The effect of the numerical constants is to allow empirically for the division of the sideforce between the fin and the body. The centre of pressure position of the fin loading is expressed in terms of its height $\bar{z}_F$ perpendicularly above the fin root chord and its longitudinal distance $\bar{z}_F \tan \Lambda_{1/4F}$ aft of the fin root quarter-chord station. The numerical constants modify these distances to $0.85\bar{z}_F$ and $0.7\bar{z}_F \tan \Lambda_{1/4F}$. Relative to the centre of gravity position the moment arms of the sideforce in directions perpendicular and parallel to the longitudinal body axis become $z_{crF} + 0.85\bar{z}_F$ and $m_F + 0.7\bar{z}_F \tan \Lambda_{1/4F}$ respectively. In the aerodynamic body axis system the yawing and rolling moment derivatives are therefore

$$(N_v)_F = - (Y_v)_F [(m_F + 0.7\bar{z}_F \tan \Lambda_{1/4F}) \cos \alpha + (z_{crF} + 0.85\bar{z}_F) \sin \alpha] / b \quad (3.2)$$

and

$$(L_v)_F = (Y_v)_F [(z_{crF} + 0.85\bar{z}_F) \cos \alpha - (m_F + 0.7\bar{z}_F \tan \Lambda_{1/4F}) \sin \alpha] / b. \quad (3.3)$$

At low values of α , since the resolved component of the longitudinal moment arm is usually much greater than the resolved component of the vertical moment arm, $(N_v)_F$ can normally be approximated by

$$(N_v)_F = - (Y_v)_F (m_F + 0.7\bar{z}_F \tan \Lambda_{1/4F}) / b. \quad (3.4)$$

No such simplification is possible in the case of $(L_v)_F$ since the resolved components of the moment arms are of comparable magnitudes.