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Estimation of sideforce and yawing moment derivatives due to sideslip for complete aircraft at subsonic speeds

Associated software: ESDUpac A0025
See ESDU 00025



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ESTIMATION OF SIDEFORCE AND YAWING MOMENT DERIVATIVES DUE TO SIDESLIP FOR COMPLETE AIRCRAFT AT SUBSONIC SPEEDS

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ESTIMATION OF SIDEFORCE AND YAWING MOMENT DERIVATIVES DUE TO SIDESLIP FOR COMPLETE AIRCRAFT AT SUBSONIC SPEEDS

1. NOTATION AND UNITS

The derivative notation used is that proposed in ARC R&M 3562 (Hopkin, 1970) and described in ESDU 86021. Coefficients and aero-normalised 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 and N_v are often written as $\partial C_Y / \partial \beta$ and $\partial C_n / \partial \beta$ or $C_{Y\beta}$ and $C_{n\beta}$ 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.

This Item makes use of several other Items which have been produced at different times over a period of many years. Although the nomenclature in these Items is consistent for the important parameters such as stability derivatives, it involves some variation and duplication for the less significant parameters. Because of this, and to avoid repetition, the Notation given here is limited to the major quantities appearing in the main text of this Item and to quantities not appearing in other Items. When referred to the method in another Item the user should consult the Notation at the front of that particular Item before carrying out any calculations.

The computer program ESDUpac A0025 associated with ESDU 00025, calculates the stability derivatives treated in this Item.

1.1 Notation

		SI	British
b	wing span	m	ft
C_L	lift coefficient $L / \frac{1}{2} \rho V^2 S$		
C_n	yawing moment coefficient, $\mathcal{N} / \frac{1}{2} \rho V^2 S b$		
C_Y	sideforce coefficient, $Y / \frac{1}{2} \rho V^2 S$		
L	lift	N	lbf
$\mathcal{N}$	yawing moment	N m	lbf ft
N_v	yawing moment derivative due to sideslip, $N_v = (\partial \mathcal{N} / \partial v) / \frac{1}{2} \rho V S b$		
S	wing planform 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 due to sideslip, $Y_v = (\partial Y / \partial v) / \frac{1}{2} \rho V S$		

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α	angle of attack of longitudinal body axis (see definition of reference axis in Section 1.2)	degree	degree
α_w	angle between wing zero-lift line and longitudinal body axis, so that angle of attack of wing zero-lift line is $\alpha + \alpha_w$ (see definition of reference axis in Section 1.2)	degree	degree
β	sideslip angle, $\sin^{-1}(v/V)$	radian	radian

Additional Symbols

$()_F$	denotes component due to fin (or fin and undeflected rudder), allowing for presence of body, wing and tailplane
$()_f$	denotes component due to deployment of trailing-edge flaps
$()_n$	denotes component due to nacelles
$()_{WB}$	denotes component due to wing-body combination

1.2 Longitudinal Body Reference Axis

The angle of attack of the body may be expressed in terms of any longitudinal axis which lies in the aircraft plane of symmetry and is fixed in the body, provided that the same axis is used in all calculations. Because the stability derivatives are defined in terms of a set of aerodynamic body axes with their origin at the aircraft centre of gravity (moment reference centre) the calculation of the fin contribution is considerably simplified if a body reference axis which passes through the aircraft centre of gravity is chosen. Aircraft dimensions are customarily defined with respect to some geometrically convenient "horizontal datum" axis which lies in the aircraft plane of symmetry and is fixed in the body but which does not necessarily pass through the centre of gravity position. Therefore, in practice, the best longitudinal body axis to choose for calculation purposes is one which is parallel to the "horizontal datum" axis but which is displaced vertically so as to pass through the centre of gravity position. Such a reference axis is assumed in this Item.

2. INTRODUCTION

The sideforce and yawing moment derivatives due to sideslip, Y_v and N_v , of an aircraft are customarily estimated by calculating the effects of the major components of the aircraft separately and adding together the part derivatives so obtained. This Item demonstrates how to combine the Data Items dealing with the major components and illustrates the overall accuracy of prediction by comparison with wind-tunnel data for complete aircraft models. It should be noted that the methods in the various Data Items are applicable over the range of aircraft incidences for which there is a linear variation of sideforce and yawing moment coefficients with angle of sideslip and of lift coefficient with angle of attack. They apply at subsonic speeds, for Mach numbers below that at which the aerodynamic characteristics start to diverge rapidly with Mach number.

The major contributions to Y_v and N_v and the Data Items from which they may be estimated are listed in Table 2.1. The Items dealing specifically with Y_v and N_v will often require the introduction of additional information from Items of a more general nature. These are also identified in Table 2.1. Comparisons between the total values of Y_v and N_v predicted by the Data Item methods and wind-tunnel data, for a variety of different types of aircraft, are discussed in Section 3. The Derivation and References are given

in Section 4. Section 5 contains a detailed worked example which demonstrates the calculation of the various components of Y_v and N_v for a particular aircraft for both the cruise (clean) configuration and the landing configuration. The example devotes a separate subsection to the calculation of each component of Y_v and N_v and describes at which stages in the calculation the additional Data Items listed in Table 2.1 may be needed to complement those dealing specifically with Y_v and N_v . It also provides guidance and information on particular points which are not covered in other Data Items. It is therefore useful to refer to the appropriate subsection in the example when each Data Item dealing with the separate components of Y_v and N_v is used.

TABLE 2.1

<i>Component*</i>	<i>Due to</i>	<i>Calculated from Item No.</i>	<i>Possible additional Item Nos</i>
$(Y_v)_{WB}$ $(N_v)_{WB}$	wing-body combination	79006 ¹⁸	76003 ¹⁷
$(Y_v)_n$ $(N_v)_n$	nacelles	79006 ¹⁸	—
$(Y_v)_F$ $(N_v)_F$	fin sideforce (in presence of body, wing and tailplane), rudder undeflected	82010 ²⁰ Aero C.01.01.01 ⁸ Aero C.01.01.02 ⁹	70011 ¹¹
$(Y_v)_f$ $(N_v)_f$	trailing-edge flap deployment	81013 ¹⁹	Aero C.01.01.01 ⁸ Aero F.01.01.08 ⁵ and 09 ⁴ Aero F.02.01.06 ² and 07 ¹ Aero W.01.01.01 ⁶ and 05 ⁷ 66032 ¹⁰ 70011 ¹¹ 74009 ¹² , 10 ¹³ , 11 ¹⁴ and 12 ¹⁵ 75013 ¹⁶ 76003 ¹⁷ 82010 ²⁰ 87024 ⁴⁷
* ESDU Aero A.07.01.00 ³ gives a brief introduction to the various components of the yawing-moment stability derivatives and their related Data Items.			

(Derivation numbers are given as indices.)

The total values of Y_v and N_v for an aircraft are obtained by evaluating each of the components in Table 2.1, for the same angle of attack, and summing the results. This is usually sufficient for providing initial estimates. (It may be noted that no direct contribution is estimated for the tailplane, which is assumed to influence Y_v and N_v only through its effect on the magnitude and centre of pressure position of the fin sideforce, see Section 3.2.2.)

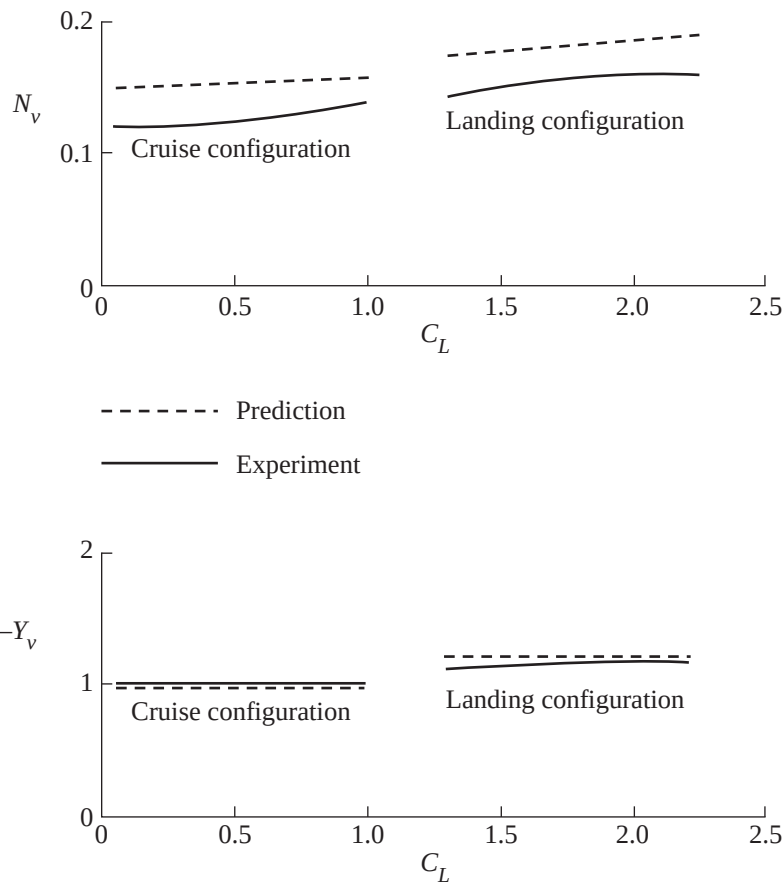
3. COMPARISONS WITH EXPERIMENTAL DATA

The accuracy with which the methods in the Data Items listed in Section 2 predict Y_v and N_v for complete aircraft has been assessed by making comparisons with the values measured in the wind-tunnel tests reported in Derivations 21 to 45 (Section 4.1). Data have been studied for a wide variety of different aircraft models representing civil transport aircraft, high performance fighter aircraft and light and general aviation aircraft, and also for many simpler wind-tunnel models employed to examine the effect of systematic variations of geometric parameters. The great majority of these data have been taken from low-speed tests but a limited number of results from tests at high subsonic speeds (Mach number ≈ 0.8) have also been considered. Comparisons of predicted and experimental values have been made for the cruise (clean) configuration and, when available, for configurations with trailing-edge flaps deployed as for landing or take-off.

It should be noted that the experimental derivatives are defined on the usually reliable assumption that the sideforce and yawing moment coefficients vary linearly with the angle of sideslip for a small range of sideslip angles about zero (typically $|\beta| \leq 2^\circ$ or $|\beta| \leq 5^\circ$). The Data Item methods predict values which are consistent with this definition of the derivatives. As the angle of sideslip increases the experimental sideforce and yawing moment coefficients eventually diverge from the linear variation. The extent of the divergence and the point at which it becomes significant vary from aircraft to aircraft but it is usually apparent at $\beta = 10^\circ$, with high-wing aircraft tending to show an earlier divergence than low-wing aircraft. The Data Item methods make no attempt to predict these variations.

3.1 Variation with α and C_L

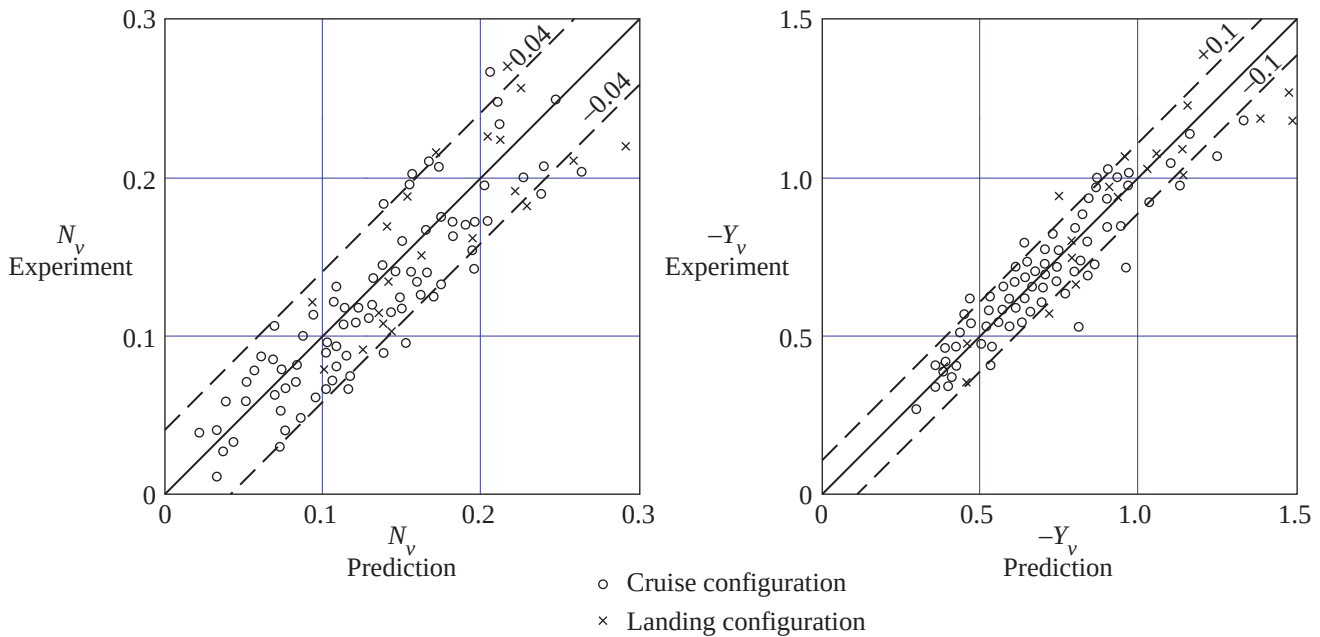
The predicted values of Y_v and N_v are almost constant with angle of attack and lift coefficient (see Example, Section 5), and in this respect they are in agreement with the experimental trends, although the latter occasionally show fluctuations and variations which are not predicted. These variations in the experimental data are not systematic but are particular to individual configurations and can be attributed to changes in flow interference effects, particularly when flaps are deployed, or to small regions of separated flow occurring as the angle of attack and lift coefficient increase. Sketch 3.1 shows a typical example of predicted and experimental values, plotted against lift coefficient, for an aircraft in both the cruise configuration and the landing configuration. Changes in wing aspect ratio and sweep, body size and tail assembly serve only to alter the overall magnitudes of Y_v and N_v and, subject to the preceding remarks on the particular characteristics of individual aircraft, they do not alter the variation with lift coefficient.



Sketch 3.1 Comparison of typical predicted and experimental variations with lift coefficient

3.2 Overall Accuracy

In general, for both cruise and flaps-deployed configurations, Y_v is predicted to within about ± 0.1 and N_v to within about ± 0.04 . These levels of accuracy are consistent with those to which the individual components of Y_v and N_v are predicted, although in the case of N_v the overall errors in prediction can be a significant proportion of the total derivative. This is a consequence of the fact that the total value of N_v is primarily the resultant of the destabilising wing-body component and the stabilising fin component (the nacelle and flap contributions being comparatively small). The magnitudes of each of these components exceeds the magnitude of the resultant and thus any error in predicting the individual components increases in importance in terms of the overall accuracy. (This is well illustrated by Sketch 5.4 in the Example.) Sketch 3.2 summarises the overall levels of agreement between the predicted and experimental values of Y_v and N_v , with each configuration studied being represented in the cruise or the landing configuration by a single point taken at an appropriate value of lift coefficient. There is no difference in the overall accuracy of prediction between the low-speed wind-tunnel test data and the (less numerous) data obtained from tests at high-subsonic speeds.



Sketch 3.2 Comparison of experimental and predicted total values

3.2.1 Wing-body contribution

Examination of part-model test data has shown that the wing-body contribution to Y_v and N_v is usually quite well estimated by the method in ESDU 79006 but that the predicted values tend to decrease in reliability if the centre of gravity position is a long way from the body mid-point. This is due to a tendency to overestimate the magnitude of the assumed variation of N_v with the centre of gravity position which, in some cases, results in too large a departure from the value of N_v appropriate to a mid-body centre of gravity position (see Section 5.2 of the Example). However, the overestimate is only significant when the variation due to the centre of gravity position is large and it should be noted that the method in ESDU 79006 was developed only to cater for small changes in N_v . The method should therefore only be used with caution if predicted variations are in excess of 0.03, or if the centre of gravity position is well away from the body mid-point, $(l - 0.5l_b) \geq 0.1l_b$. (Variations greater than 0.03 are, for example, sometimes predicted for small wing-span aircraft with centre of gravity positions well to the rear of the body mid-point.)

Part-model data for bodies with non-circular cross-sections have confirmed that the body cross-section shape has an important effect on the wing-body contribution, as discussed in ESDU 79006. (The effect of cross-section shape on the other components is negligible and, where necessary, a mean value can be taken for the body diameter.) ESDU 79006 contains a table giving examples of typical correction factors for converting the wing-body components of Y_v and N_v from values appropriate to circular cross-sections to values appropriate to non-circular cross-sections. The data studied have shown that the use of correction factors deduced from this table results in an overall improvement in the accuracy of prediction of the total values of Y_v and N_v for some fighter and light and general aviation aircraft with non-circular cross-sections. It should, however, be remembered that the factors in the table are intended only to show the sort of changes that can occur, being based on a small number of data, and for most practical configurations the selection of a correction factor is not an exact process and can only be made as an approximation after comparing the actual configuration of interest with the examples given in ESDU 79006.