

ESTIMATION OF DRAG ARISING FROM ASYMMETRY IN THRUST OR AIRFRAME CONFIGURATION

1. NOTATION AND UNITS*

		<i>SI</i>	<i>British</i>
A	wing aspect ratio, b^2/S		
A_F	effective aspect ratio of fin and rudder, $2h_F^2/S_F$		
b	wing span	m	ft
C_D	drag coefficient for aeroplane, D/qS		
C_{D_F}	drag coefficient for fin and rudder, D_F/qS_F		
$(C_{L_\alpha})_F$	lift-curve slope for straight-tapered wing of aspect ratio A_F , taper ratio, c_{t_F}/c_{r_F} , half-chord sweep angle $\Lambda_{1/2F}$, and area $2S_F$, estimated from Item No. 70011 (Reference 9), see Sections 6.1.1 and 6.1.2 here		
C_l	rolling moment coefficient for aeroplane, L/qSb		
C_n	yawing moment coefficient for aeroplane, N/qSb		
C_Y	sideforce coefficient for aeroplane, Y/qS		
C_{Y_F}	sideforce coefficient for fin and rudder, Y_F/qS_F		
c_r, c_t	wing root and tip chords	m	ft
c_{r_F}, c_{t_F}	fin root and tip chords	m	ft
D	drag of aeroplane	N	lbf
D_F	drag of fin and rudder	N	lbf
D_{wm}	windmilling drag, per engine	N	lbf
F_N	net thrust, per engine	N	lbf
g	acceleration due to gravity	m/s ²	ft/s ²
g_x, g_y, g_z	components of g in x-direction; y-direction; z-direction	m/s ²	ft/s ²
H	geopotential height	m	ft
h_B	fuselage maximum height	m	ft
h_F	fin height, measured from root chord, see Sketch 1.1, or height of equivalent single fin, see Equation (A2.9)	m	ft
J_B, J_T, J_W	sideforce correction factors defined in Reference 13		
K_F	induced drag factor for fin and rudder		
L	rolling moment	N m	lbf ft
L^Σ	resultant rolling moment	N m	lbf ft

* See also Section 1.1.

L_F	rolling moment due to fin and rudder	N m	lbf ft
L_v	rolling moment derivative due to sideslip*, $L_v = (\partial L / \partial v) / (\rho V S b / 2) = \partial C_l / \partial \beta$		
L_ζ	rolling moment derivative due to rudder deflection*, $(\partial L / \partial \zeta) / q S b$	rad ⁻¹	rad ⁻¹
L_ξ	rolling moment derivative due to aileron deflection*, $(\partial L / \partial \xi) / q S b$	rad ⁻¹	rad ⁻¹
l_F	moment arm (from wing aerodynamic centre) of sideforce due to fin and rudder; used in method of Section 3, see Sketch 3.1	m	ft
l_p	moment arm of engine gross thrust or propeller thrust	m	ft
M	free-stream Mach number		
m	aeroplane mass	kg	slug
N	yawing moment	N m	lbf ft
N^Σ	resultant yawing moment	N m	lbf ft
N_F	yawing moment due to fin and rudder	N m	lbf ft
N_v	yawing moment derivative due to sideslip*, $N_v = (\partial N / \partial v) / (\rho V S b / 2) = \partial C_n / \partial \beta$		
N_ζ	yawing moment derivative due to rudder deflection*, $(\partial N / \partial \zeta) / q S b$	rad ⁻¹	rad ⁻¹
N_ξ	yawing moment derivative due to aileron deflection*, $(\partial N / \partial \xi) / q S b$	rad ⁻¹	rad ⁻¹
$p; q; r$	angular velocity components about x -axis (rate of roll); y -axis (rate of pitch); z -axis (rate of yaw)	rad/s	rad/s
q	kinetic pressure, $\rho V^2 / 2$	N/m ²	lbf/ft ²
S	wing (reference) area	m ²	ft ²
S_F	fin and rudder area, see Sketch 1.1	m ²	ft ²
S_R	rudder area	m ²	ft ²
T	propeller thrust, per propeller	N	lbf
$u; v; w$	components of V in x -direction; y -direction; z -direction	m/s	ft/s
V	true airspeed (resultant velocity relative to air)	m/s	ft/s
x, y, z	aeroplane body-axis coordinates (origin at aeroplane centre of gravity), see Sketch 1.1	m	ft
x_F	moment arm (in yaw) for sideforce due to fin and rudder	m	ft
Y	sideforce, positive to starboard (in y -direction)	N	lbf
Y_F	sideforce due to fin and rudder	N	lbf
Y_v	sideforce derivative*, $Y_v = (\partial Y / \partial v) / (\rho V S / 2) = \partial C_Y / \partial \beta$		
$(Y_v)_F$	fin contribution to Y_v		
Y_ζ	sideforce derivative due to rudder deflection*, $(\partial Y / \partial \zeta) / q S$	rad ⁻¹	rad ⁻¹
Y_ξ	sideforce derivative due to aileron deflection*, $(\partial Y / \partial \xi) / q S$	rad ⁻¹	rad ⁻¹
z_F	moment arm (in roll) for sideforce due to fin and rudder	m	ft

See footnote at end of Notation Section

β	angle of sideslip ($\sin\beta = v/V$)	deg	deg
ΔC_D	increment in aeroplane drag coefficient		
$(\Delta C_D)_F$	fin-and-rudder contribution to ΔC_D		
$\Delta C_{D_{asym\ thr}}$	increment in C_D due to thrust asymmetry		
$\Delta C_{D_{wm}}$	increment in C_D due to windmilling engine		
ΔC_L	change in wing lift coefficient needed to counteract rolling moment due to asymmetry, see Sections 6.4 and 6.5		
Δm	asymmetry in airframe mass	kg	slug
ζ	rudder deflection angle	rad	rad
η	spanwise coordinate, $y/(b/2)$		
Θ	inclination angle (elevation or angle of pitch) between horizontal and x -body-axis	deg	deg
$\Lambda_{1/4F}, \Lambda_{1/2F}$	fin and rudder quarter-chord and half-chord sweep angles	deg	deg
ξ	aileron deflection angle	rad	rad
ρ	density of air	kg/m ³	slug/ft ³
Φ	bank angle, ($\Phi = 0$, wings level; $\Phi > 0$, starboard wing down)	deg	deg

Subscripts

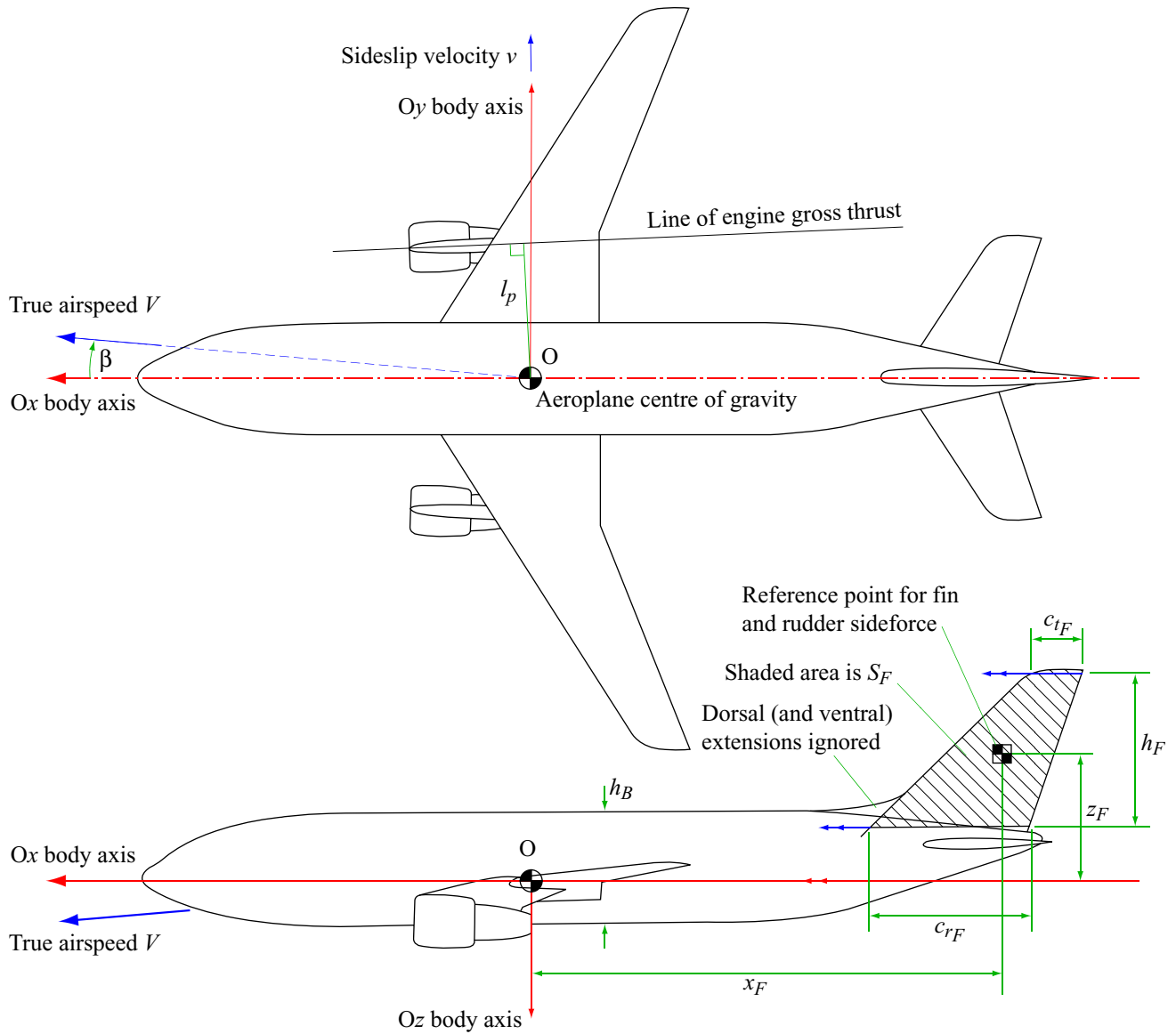
<i>aero</i>	denotes airframe aerodynamic force or moment, except for those imposed by asymmetry and denoted by “asym”
<i>aileron</i>	denotes value for aileron
<i>asym</i>	denotes asymmetric force or moment imposed on aircraft
<i>feathered</i>	denotes value with feathered propeller
<i>ind</i>	denotes induced drag component
<i>n</i>	denotes n 'th fin in multiple-fin configuration
<i>profile</i>	denotes profile drag component
<i>sideslip</i>	denotes value for flight in sideslip for aircraft minus fin
$\beta = 0$	denotes flight condition with zero sideslip
$\zeta = 0$	denotes flight condition with zero rudder deflection
$\Phi = 0$	denotes flight condition with wings level

* See Section 1.1.

1.1 Use of Control and Stability Derivative Data

This Item follows the definitions and nomenclature used in the ESDU Aerodynamics Series for control and stability derivatives. The derivatives L_v , etc. are formally defined for a datum condition of steady, rectilinear flight at zero sideslip. The equivalence to coefficient derivatives, $\partial C_l / \partial \beta$, etc., holds for these conditions, see Reference 33. The subscript “e”, used to denote datum conditions in the Aerodynamics Series, is omitted here. Conversions to forms customarily used in the USA are as follows.

Derivative used here	L_v	L_ζ	L_ξ	N_v	N_ζ	N_ξ	Y_v	Y_ζ	Y_ξ
USA equivalent	C_{l_β}	$C_{l_{\delta R}}$	$C_{l_{\delta A}}$	C_{n_β}	$C_{n_{\delta R}}$	$C_{n_{\delta A}}$	C_{Y_β}	$C_{Y_{\delta R}}$	$C_{Y_{\delta A}}$



Sketch 1.1 Axes, dimensions and angles

2. INTRODUCTION

Methods are provided for estimating drag increments arising in steady trimmed flight as a consequence of asymmetry in thrust or airframe configuration. The primary application is to flight with one or more engines inoperative as, for example, in calculations of climb performance after take-off or a missed approach where the drag due to asymmetry can be greater than the drag due to the inoperative engine at low speeds, see Sketch 2.1. Thrust asymmetry may also be significant in range calculations if a long diversion becomes necessary because of engine failure.

The Data Item can, however, be used to consider asymmetries in thrust, drag, lift and mass since these are counteracted in related ways. The significant factors are the relative magnitudes of the yawing and rolling moments imposed on the aircraft and the piloting techniques used, that is, the combination of control inputs applied about the yaw and roll axes.

Section 3 provides a simple method, based on established data for a wide range of aeroplanes, for predicting the drag increment for flight with one or more engines inoperative (excluding the drag of the inoperative engine). The broad effects on drag of different flight techniques are shown but, because of a lack of detailed information for individual aeroplanes, no information is given on the breakdown of drag into components. The correlating parameter used is derived in Appendix A.

Section 4 gives the force and moment equations used to determine equilibrium flight conditions for use with aerodynamic data. Results of such calculations are shown in sketch form while a detailed example is given as Appendix B.

Section 5 provides a detailed discussion of the alternative ways in which an aircraft can be flown to achieve steady straight flight in the presence of thrust or airframe asymmetries. Practical aspects of obtaining and using flight-test and wind-tunnel data are discussed.

Section 6 lists the various drag components that can arise as a consequence of thrust and airframe asymmetries and gives methods for estimating some of them. Where the estimation procedure involves the use of Data Items from the ESDU Aerodynamics Series, typical values of the drag components are presented.

Appendix A derives the relationships between asymmetric forces tending to yaw the aircraft and the fin/rudder side force and induced drag corresponding to equilibrium flight.

Appendix B presents an example of the use of wind-tunnel data, in conjunction with the equations for equilibrium flight conditions from Section 4, to estimate the drag due to asymmetry in thrust.

2.1 Relationship Between Lateral/Directional Trim and Longitudinal Trim

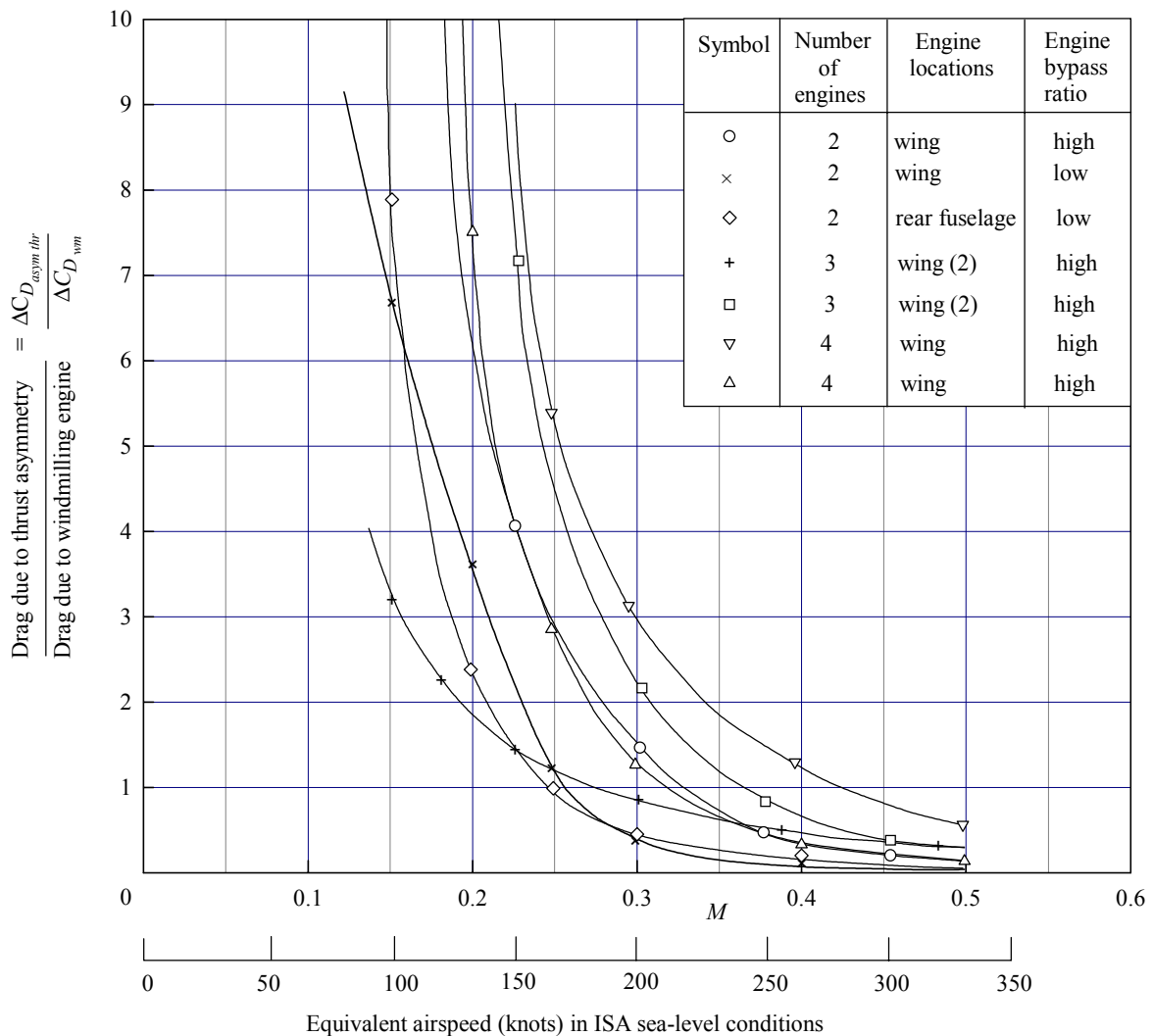
The methods given are concerned primarily with the effects, on drag, of establishing the lateral/directional trim of the aeroplane in the presence of thrust or airframe asymmetries. However, it is likely that changes in longitudinal trim will occur between corresponding symmetric and asymmetric flight conditions, for example, the loss of thrust of an engine may introduce a large change in pitching moment.

In all Sections except Section 3 it is assumed that forces along and moments about all three aircraft axes can be considered independently, *i.e.* that there is no cross coupling between lateral/directional and longitudinal trim changes, and no further consideration is given to longitudinal trim. Note that for some aeroplane configurations there may be significant interactions between lateral/directional and longitudinal trim changes, for example if wing downwash is affected by changes in directional and/or lateral control or in power settings.

In Section 3 and Figures 1, 2 and 3 the increment in drag coefficient due to asymmetry in thrust includes all drag components except the windmilling drag of the inoperative engine or propeller.

2.2 Methods For Estimating Drag of Inoperative Powerplants

The Performance Series includes methods of estimating windmilling drag of propellers (Item No. ED1/1, Reference 1), windmilling drag of jet and fan engines (Item No. 81009, Reference 2) and spillage drag of axisymmetric intakes (Item No. 84004, Reference 3). The combined usage of References 2 and 3 is demonstrated in Reference 4.



Sketch 2.1 Examples of relative magnitudes of drag due to thrust asymmetry and engine windmilling drag

3. FIRST APPROXIMATION TO AIRFRAME DRAG COEFFICIENT INCREMENT FOR STEADY STRAIGHT FLIGHT WITH FAILED ENGINE(S)

Figures 1, 2 and 3 present data for use in estimating values of $\Delta C_{D_{asym\ thr}}$, the increment in airframe drag coefficient due to thrust asymmetry.

3.1 Method of Estimating $\Delta C_{D_{asym\ thr}}$

Values of $\Delta C_{D_{asym\ thr}}$ are presented in Figures 1, 2, 3 as functions of the parameter

$$\frac{1}{2\pi} \left(\frac{N_{asym}}{q} \right)^2 \left(\frac{1}{l_F h_F} \right)^2 \frac{1}{S}.$$

The imposed yawing moment, N_{asym} , for a symmetrically located pair of powerplants, is

$$N_{asym} = (\text{thrust difference between powerplants}) l_p,$$

where the moment arm, l_p is defined in Sketch 1.1. Where one of the pair of powerplants is inoperative,

$$N_{asym} = (F_N + D_{wm}) l_p \text{ for jet and fan engines,}$$

$$N_{asym} = (T + D_{feathered}) l_p \text{ or } (T + D_{wm}) l_p \text{ for propellers.}$$

The wing (reference) area, S , used in the correlating parameter and in defining $\Delta C_{D_{asym\ thr}}$ is the equivalent straight-tapered gross wing defined in Sketch 3.1. Values of the fin and rudder moment arm, l_f , should be determined as indicated in Sketch 3.1.

For a single vertical fin the height h_F and area S_F are as shown in Sketch 1.1. For multiple-fin configurations,

$$\frac{1}{h_F^2} = \frac{\sum \left(\frac{S_{F_n}}{h_{F_n}} \right)^2}{(\sum S_{F_n})^2}.$$

See Section A2.3 of Appendix A for the derivation of this expression and for advice regarding the selection of appropriate values of h_{F_n} and S_{F_n} . For non-vertical fins, h_{F_n} and S_{F_n} are taken as the projected values in the aeroplane plane of symmetry.

3.2 Estimation of $\Delta C_{D_{asym\ thr}}$ for Different Flight Techniques* and Airframe/Powerplant Combinations

For jet- and fan-engined aeroplanes (Figures 1 and 2) it should be assumed that the only drag component excluded from $\Delta C_{D_{asym\ thr}}$ is the engine windmilling (*i.e.* internal) drag, D_{wm} , and that cowl spillage drag is included in Figures 1 and 2 (see Reference 2 for method of estimating windmilling drag).

For propeller-driven aeroplanes (Figures 2 and 3) it should be assumed that the only drag component excluded is that of the feathered or (less likely) windmilling propeller (see Reference 1 for method of estimating windmilling drag).

* See Section 5.1 and Sketches 5.1 to 5.4 regarding the various flight techniques.

For flight with “roll controls centralised”^{*}, for jet- and fan-engined aeroplanes, Figure 1 provides data for estimating values of $\Delta C_{D_{asym\ thr}}$ based on established data for 25 aeroplanes.

For flight with “significant sideslip, including wings level”^{*}, Figure 2 provides data for estimating values of $\Delta C_{D_{asym\ thr}}$ for both propeller-driven and jet- and fan-engined aeroplanes. The data for the 7 jet- and fan-engined aeroplanes used were for wings level. Of the 18 propeller-driven aeroplanes for which data are included in Figure 2, three were for wings level. The only data for propeller-driven aeroplanes excluded from Figure 2 were those (“for zero sideslip”^{*}) used in Figure 3. The use in Figure 2 of the parameter $(h_F/h_B)^2$ implies that much of the drag is induced by the aircraft body in sideslip.

For flight with “zero sideslip”^{*}, for propeller-driven aeroplanes, Figure 3 gives a rough guide, based on data for 4 aeroplanes.

For flight with “zero sideslip”^{*}, for jet- and fan-engined aeroplanes, the fin and rudder induced drag is the major component and a guide to its magnitude is given in Figures 1 and 2. More detailed estimates may be made using the methods of Section 6.1.2 and 6.2 for fin and rudder induced drag and profile drag, respectively.

For flight with zero rudder deflection^{*}, for jet- and fan-engined aeroplanes, limited data (for 2 very different configurations) suggest, as might be expected, that values of $\Delta C_{D_{asym\ thr}}$ lie between those obtained from Figure 1 for roll controls centralised^{*} and those from Figure 2 for flight with significant sideslip, including wings level.

3.3 Basis of Figures 1, 2 and 3

The data used to generate curves in Figures 1, 2 and 3 are either determined from, or confirmed by, flight tests and have been used in generating flight-manual data for the aircraft concerned. The primary correlating parameter is derived in Appendix A. Its use implies the following assumptions.

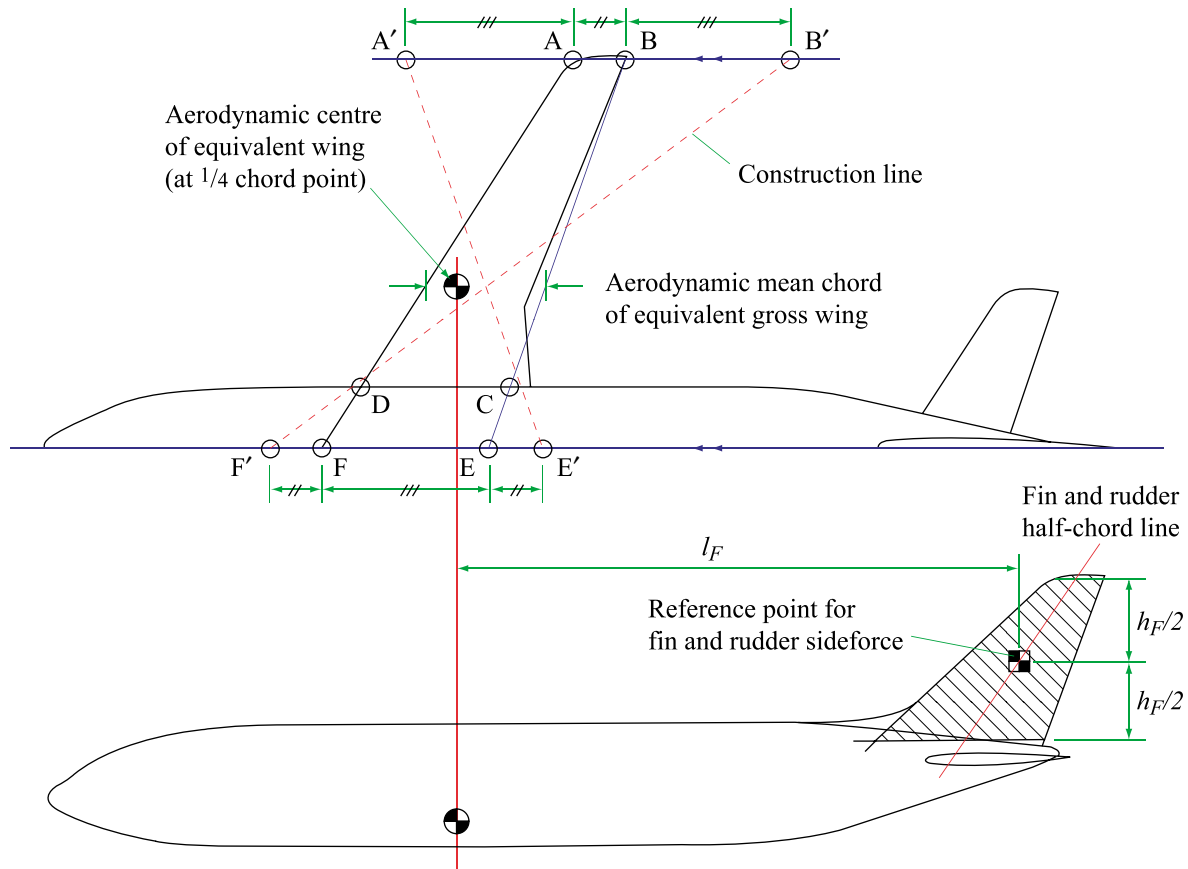
- (i) The yawing moment due to asymmetric engine or propeller thrust is balanced by the moment due to fin and rudder sideforce.
- (ii) The drag due to asymmetry is made up entirely of the induced drag corresponding to the fin and rudder sideforce.

Assumption (i) is reasonable for flight with zero sideslip^{*} but for straight flight this implies that the aircraft must be banked. In practice, some combination of bank and sideslip is likely but for most of the aircraft for which data were available these angles were unknown. In general, bank angles are of order 2 to 4 degrees and for civil transport aeroplanes some airworthiness requirements stipulate a maximum bank angle of 5 degrees. In practice, it may be preferred to fly with roll controls centralised (to avoid actuation of spoilers and/or to enhance the repeatability of flight-test results) or with wings level (to simplify piloting technique – particularly in instrument flight conditions).

Given that a combination of bank and sideslip angles is likely, the list of possible components of drag given in Section 6 indicates that while the fin and rudder induced drag may be the dominant term for flight with zero sideslip, this is unlikely to be true for other flight conditions. The extent to which assumption (ii) is invalid can be gauged from Figures 1, 2 and 3 by noting the departure of the aircraft data from the region labelled “fin and rudder induced drag”.

^{*} See Section 5.1 and Sketches 5.1 to 5.4 regarding the various flight techniques.

Difficulties associated with obtaining consistent measurements of drag due to asymmetry are discussed in Section 5. These are accentuated if no system of thrust and drag accounting is specified in the sources of data used. In particular, when analysing data for some aeroplanes it was not clear whether cowl spillage drag (if present) was included in “engine windmilling drag” or in the drag due to asymmetry. The analyses of data supporting Figures 1 to 3 (and other aspects of the Data Item) are reported in Reference 35.



Procedure

- (i) Construct equivalent straight-tapered wing ABCD having same exposed area as actual wing.
- (ii) Extend AD to F and BC to E on centre line to give equivalent straight-tapered gross wing ABEF.
- (iii) Identify A', B' at distances EF from A and B. Identify E', F' at distances AB from E and F.
- (iv) Locate mean chord of equivalent gross wing at intersection of A'E' and B'F'.
- (v) Aerodynamic centre is located at 1/4 chord point.

Sketch 3.1 Approximate method used to estimate fin and rudder moment arm l_F
(Section 3 and Figures 1 and 2 only)

4. ESTIMATION OF EQUILIBRIUM FLIGHT CONDITIONS AND ASSOCIATED DRAG

Systematic methods of estimating the drag due to asymmetry utilise aerodynamic data for sideforce and for yawing and rolling moments to determine sideslip angles, bank angles and control deflections for steady straight flight and, then, evaluate the corresponding airframe drag increments. Equations for establishing the equilibrium flight conditions are presented in Section 4.1 while Section 4.2 discusses methods of solution and presents some simplifications for particular flight cases.

Where wind-tunnel data are used as the basis of estimation, the resulting increment in airframe drag coefficient (for a given configuration and values of angle of attack and Mach and Reynolds numbers) is

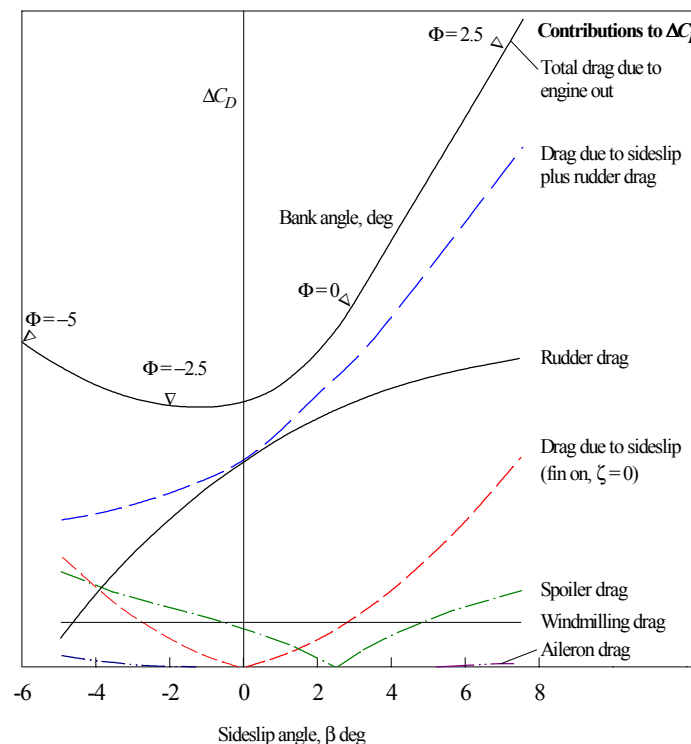
$$\Delta C_D = f(\beta, \zeta, \xi). \quad (4.1)$$

Appendix B presents an example based on wind-tunnel data.

Where estimated aerodynamic data are used, individual contributions to drag are likely to be evaluated separately. If the contributions to drag are those considered in Section 6 then, for example,

$$\Delta C_D = (\Delta C_D)_F + \Delta C_{D_{\text{sideslip}}} + \Delta C_{D_{\text{aileron}}} + \Delta C_{D_{\text{spoiler}}} + \Delta C_{D_{\text{slipstream}}}. \quad (4.2)$$

Other subdivisions of drag due to asymmetry are possible. Sketch 4.1 shows an example of the variation, with sideslip angle, of estimated values of contributions to drag due to asymmetric thrust for a large transport aeroplane in the take-off configuration (Reference 31). The sketch illustrates an alternative subdivision of the terms $[(\Delta C_D)_F + \Delta C_{D_{\text{sideslip}}}]$ in that the broken line which passes through the origin represents the “drag due to sideslip” of the whole aircraft at zero rudder deflection, to which a “rudder drag” contribution is added.



Sketch 4.1 Example of drag coefficient increments resulting from balancing lateral-directional asymmetry due to failed engine in take-off climb configuration

4.1 Equations for Equilibrium Flight Conditions

For trimmed, steady straight flight the resultant sideforce, rolling moment and yawing moment acting on the aeroplane must be zero. These conditions may be expressed in terms of forces along the y -body axis and moments about the x - and z -body axes, as follows.

$$Y^{\Sigma} = Y_{aero} + mg \sin \Phi \cos \Theta + Y_{asym} = 0, \quad (4.3)$$

$$L^{\Sigma} = L_{aero} + L_{asym} = 0, \quad (4.4)$$

$$N^{\Sigma} = N_{aero} + N_{asym} = 0. \quad (4.5)$$

If wind-tunnel data are used as the basis for solving Equations (4.3) to (4.5), these data may be expressed in the form of sideforce, rolling and yawing moment coefficients* C_Y , C_l , C_n . For a given airframe configuration, and fixed values of angle of attack and Mach and Reynolds numbers, these coefficients are functions of β , ζ , ξ . The corresponding terms in Equations (4.3) to (4.5) are

$$Y_{aero} = qSC_Y, \quad (4.6)$$

$$L_{aero} = qSbC_l, \quad (4.7)$$

$$N_{aero} = qSbC_n. \quad (4.8)$$

Where estimated aerodynamic data are used as the basis for solving Equations (4.3) to (4.5), one method of expanding the equations to represent the various force and moment components is as follows:

$$Y^{\Sigma} = Y_F + Y_{sideslip} + Y_{aileron} + mg \sin \Phi \cos \Theta + Y_{asym} = 0, \quad (4.9)$$

$$L^{\Sigma} = L_F + L_{sideslip} + L_{aileron} + L_{asym} = 0, \quad (4.10)$$

$$N^{\Sigma} = N_F + N_{sideslip} + N_{aileron} + N_{asym} = 0. \quad (4.11)$$

If control and stability derivative data are to be used to obtain solutions to Equations (4.3) to (4.5) (as in Appendix B), these equations must be expressed in terms of the notation used in the Aerodynamics Series for stability derivatives to give

$$(Y_v \times v) \frac{\rho VS}{2} + (Y_{\zeta} \times \zeta)qS + (Y_{\xi} \times \xi)qS + mg \sin \Phi \cos \Theta + Y_{asym} = 0, \quad (4.12)$$

$$(L_v \times v) \frac{\rho VS b}{2} + (L_{\zeta} \times \zeta)qSb + (L_{\xi} \times \xi)qSb + L_{asym} = 0, \quad (4.13)$$

$$(N_v \times v) \frac{\rho VS b}{2} + (N_{\zeta} \times \zeta)qSb + (N_{\xi} \times \xi)qSb + N_{asym} = 0. \quad (4.14)$$

Further alternative forms of these equations can be written if force or moment data are likely to be available in coefficient form, for example, for the yawing moment due to sideslip the term,

$$(N_v \times v) \frac{\rho VS b}{2} = \left(\frac{\partial N}{\partial v} \times v \right) \frac{\rho VS b}{2} = \left(\frac{\partial C_n}{\partial \beta} \times \beta \right) qSb. \quad (4.15)$$

In such cases, however, it is more likely that the approach of Equations (4.3) to (4.8) will be used.

* As quoted, the coefficients C_Y , C_l , C_n accord with those used in the ESDU Aerodynamics Series. Other methods of rendering these quantities non-dimensional are in use, for example wing chord may be used in place of span, b .

4.2 Solution of Equations for Equilibrium Flight Conditions

Equations (4.3) to (4.5), (4.9) to (4.11) or (4.12) to (4.14) must be solved to determine the values of sideslip and bank angles and rudder and aileron (or spoiler) deflections that correspond to trimmed steady straight flight. However, various simplifying assumptions can be made regarding the representation of the imposed asymmetric force and moments and the solution of the equations for particular cases. These are considered in Sections 4.2.1 and 4.2.2 respectively.

4.2.1 Representation of imposed asymmetric force and moment

In Section 4.1 the terms representing the imposed asymmetric sideforce and moments in Equations (4.3) to (4.5), (4.9) to (4.11) and (4.12) to (4.14) allow all forms of asymmetry to be considered, for example, asymmetries in thrust, drag, lift and mass.

For asymmetry in thrust, the full expressions for body-axis components of forces and moments due to engine gross thrust, momentum drag, propeller thrust and propeller in-plane force are given in Tables 6.3 and 6.4 of Item No. 85030 (Reference 8). In practice, many of the terms involved (particularly those involving more than one small angle) can be ignored.

The simplest expression for N_{asym} , for a symmetrically located pair of powerplants, is

$$N_{asym} = (\text{thrust difference between powerplants}) l_p,$$

so that where one of a symmetric pair of powerplants is inoperative,

$$N_{asym} = (F_N + D_{wm})l_p \text{ for jet and fan engines,} \quad (4.16)$$

$$N_{asym} = (T + D_{feathered})l_p \text{ or } (T + D_{wm})l_p \text{ for propellers.} \quad (4.17)$$

Equations (4.16) and (4.17) take no account of different lines of action of the forces but, if differences exist, the moment arm, l_p , should be selected to take account of any “toe-in” or “toe-out” of the engine gross thrust or propeller thrust vectors. The term representing the drag of the inoperative powerplant (D_{wm} or $D_{feathered}$ here) should strictly include all drag changes due to the inoperative engine, *i.e.* in spillage drag, and in slipstream drag behind a propeller or jet or fan engine (“scrubbing drag”). However for the purposes of calculating N_{asym} (but not for drag calculations) it is permissible to omit many of the smaller terms, such as the drag of a feathered propeller.

For asymmetry in airframe lift and/or drag, Item No. 85030 (Reference 8) gives definitions of both the air-path-axis (Table 6.5) and body-axis (Table 6.6) components of airframe and control aerodynamic forces and moments. Note that Equations given in Section 4.1 here are expressed in terms of body-axis components of forces and moments but that the customary methods of presenting aerodynamic data* provide values of rolling and yawing moment coefficients about the “aerodynamic-body axes” (or “wind axes” or “stability axes”). For small angles of attack and sideslip the differences can be overlooked but, if large angles are likely, the appropriate body-axis components should be derived (see Table 6.2 of Reference 8 for axis-transformation formulae).

* Most wind-tunnel data are presented in terms of these axes and the practice is adhered to in the ESDU Aerodynamics Series.