

REPRESENTATION OF DRAG IN AIRCRAFT PERFORMANCE CALCULATIONS

Particular care should be taken to distinguish between quantities associated with the aeroplane flight condition for “minimum drag” (for a fixed lift requirement), denoted by the subscript “*md*”, and the point on a graph of drag coefficient against lift coefficient at which the former has its minimum value (denoted $C_{D_{min}}$, $C_{L_{min}}$).

1. NOTATION AND UNITS* (PROPELLER NOTATION IN ADDENDUM F)

		<i>SI</i>	<i>British</i>
A	constant defined in Addendum F*	*	*
<i>A</i>	aspect ratio, b^2/S		
<i>a</i>	speed of sound	km/h, kn	kn
B	constant defined in Table 5.2*	*	*
<i>b</i>	wing span	m	ft
$\bar{c}$	wing geometric mean chord	m	ft
C_D	drag coefficient, $D/q S$		
$C_{D_{min}}$	minimum value of drag coefficient, see Section 3.3		
C_L	lift coefficient, $L/q S$		
$C_{L_{crit}}$	“critical” value of C_L in “dual parabolic” representation of drag polar in Section 3.4		
$C_{L_{min}}$	value of C_L corresponding to $C_{D_{min}}$, see Section 3.3		
C_F	flat plate mean skin friction coefficient		
C_{F_e}	equivalent skin friction coefficient, = (aeroplane drag component independent of lift)/ qS_{wet}		
<i>D</i>	drag	N	lbf
<i>d</i>	maximum diameter of body (or of equivalent axisymmetric body) of aeroplane or of component indicated by subscript	m	ft
G	constant defined in Table 5.2*	N m/kW s	ft lbf/hp s
<i>g</i>	acceleration due to gravity	m/s ²	ft/s ²
H_p	pressure height	m	ft
K_1, K_2	coefficients in “simple parabolic” drag equation in Section 3.2		
K_1', K_2'	coefficients in “dual-parabolic” drag equations in Section 3.4		

* Units quoted are not coherent sets but those most commonly used and in consequence some equations contain numerical constants, denoted **A, B, G**, which may be ignored if coherent units are used. Values of these constants are given in Table 5.2 and Addendum F.

K_3, K_4, K_5	coefficients in “modified-parabolic” drag equations in Section 3.3		
K_3', K_4', K_5'	coefficients in “dual-parabolic” drag equations in Section 3.4		
k_c	(value in compressible flow)/(value in incompressible flow)		
L	lift	N	lbf
l	characteristic length	m	ft
M	Mach number, V/a		
m	aeroplane mass	kg	slug
n	normal load factor		
P	shaft power supplied to propeller	kW	hp
P_r	“thrust power” required for level flight with $n = 1$	kW	hp
p	pressure	N/m ²	lbf/ft ²
q	kinetic pressure, $\mathbf{B}\rho V^2/2$ (identical to dynamic pressure in incompressible flow)	N/m ²	lbf/ft ²
Re	Reynolds number, $\rho V l / \mu$		
$Re_{\bar{c}}$	Reynolds number based on wing geometric mean chord, $\rho V \bar{c} / \mu$		
S	wing area	m ²	ft ²
S_{wet}	wetted area of aeroplane or component indicated by subscript	m ²	ft ²
V	true airspeed	km/h, kn	kn
V_e	equivalent airspeed, $V\sqrt{\sigma}$	km/h, kn	kn
W	aeroplane weight, mg	N	lbf
α	angle of attack	deg	deg
β	angle of sideslip	deg	deg
Δ	denotes an increment in the affixed parameter		
δ	relative pressure, p/p_0		
δ_c	control angles for trimmed flight	deg	deg
$\Lambda_{1/4}$	sweep of wing 1/4-chord line	deg	deg
μ	dynamic viscosity	N s/m ²	lbf s/ft ²
ρ	density of air	kg/m ³	slug/ft ³
σ	relative density, ρ/ρ_0		

Subscripts

cg	denotes value corresponding to a fixed position of the aeroplane centre of gravity
i	denotes lift-dependent components of drag and thrust power in method of Section 3.2
md	denotes conditions of minimum drag force in “1g” level flight
mp	denotes conditions for minimum thrust power in “1g” level flight
0	denotes (i) conditions at sea level in ISA (ii) drag and “thrust power” components independent of lift in method of Section 3.2

2. INTRODUCTION

This Item describes methods used to represent airframe drag for performance calculations for all flight conditions in terms of the general functional relationships between the variables. Several analytical variants of the familiar parabolic relationship between lift and drag are introduced, their limitations pointed out, and some useful derived expressions presented in Tables 5.2 to 5.4 and plotted in Figures 1 and 2. Table 5.5 gives a summary of the aeroplane drag data available elsewhere in the ESDU Performance Series of Data Items. Detailed examples of the drag characteristics of particular aeroplanes are also given in Addenda A, B, C, . . . to this Item to illustrate the methods of representation discussed in Section 3. Each Addendum gives the relationship(s) between lift and drag coefficients for a particular aeroplane and in most cases curves are included to show the variation of drag with speed or Mach number at a typical weight and altitude(s). Brief descriptions of the aeroplane, particular features of the data and/or additional notation are also given.

2.1 Aerodynamic Definitions

Drag, D , and lift, L , are the force components acting at right angles to one another into which it is customary to resolve the resultant external* airframe aerodynamic force acting on an aeroplane. Drag is considered to be a positive force acting in the opposite direction to the true airspeed vector, V , while lift acts normal to V in the aeroplane's plane of symmetry and is positive in the dorsal sense. While drag and lift forces are required for performance calculations, the presentation of drag and lift characteristics is most effectively achieved by following aerodynamic practice and reducing the number of independent variables by combination into drag and lift coefficients C_D , C_L or other useful drag parameters such as D/q or D/δ . In general, values of C_D are presented as a function of C_L and the flow Mach and Reynolds numbers, M , Re , which take account of compressibility and viscous effects respectively. Additional parameters are used to specify completely the drag characteristics in some cases while simplifications or alternatives may be introduced in others.

Conventional aerodynamic analysis suggests a subdivision of the drag force (or drag parameter) into components related to the basic mechanisms of its production, for example "drag due to viscous effects" plus "inviscid drag" or, alternatively, "friction drag" plus "pressure drag". To estimate drag, for example during airframe design, and for the analysis and "book keeping" of flight and wind-tunnel test data, it is usually necessary to subdivide drag on other bases. A geometric breakdown is often used and drag components are associated with different parts of the airframe such as the wing, flaps, slats, control surfaces and their deflections, the body, undercarriages, excrescences, "interference effects", etc. For components such as nacelles, intakes, nozzles and afterbodies the drag characteristics are of course dependent on the intake, exhaust and/or slipstream flow conditions. In a limited number of cases airframe deformation under load provides a significant source of drag variation.

For an aeroplane in "trimmed" flight, the control angles, δ_c , must be those which produce zero resultant moments about all three axes. For these conditions the drag coefficients can be expressed as,

$$C_D = f [C_L, M, Re, \delta_c] . \quad (2.1)$$

* See Item No. 69006 for definitions of drag and thrust forces associated with the internal-flow stream tube of turbo-jet and turbo-fan engines. There are, however, exceptions to the convention regarding forces associated with the external flow (drag) and internal flow (thrust). Examples are the windmilling drag of a turbo-jet or turbo-fan engine and the cooling drags associated with piston engines and various equipment installations. In the case of propeller-driven aircraft, Reference ¹⁴ gives a guide to methods of thrust and drag accounting, while Addendum F in this Item provides an example for a turbo-prop transport aeroplane. In practice, the whole of the effect in the "V" direction due to slipstream interference with the airframe has often been taken into account as a change in propeller efficiency or thrust.

3. REPRESENTATION OF DRAG IN PERFORMANCE CALCULATIONS

For performance calculations the total drag force for a given aeroplane is required for different aerodynamic configurations, powerplant settings, mass and cg positions, normal accelerations, speeds, and ambient conditions – usually pressure heights and temperatures. Taken together, any one combination of these parameters implies unique values of control-surface settings, airframe deformation and intake and exhaust flow interference effects and so a unique value of drag. As in Section 2.1 the relationship between the drag force and the independent variables can be simplified for the purposes of presentation by the use of dimensionless parameters and, for a defined aerodynamic configuration and powerplant setting(s), data for an aeroplane in trimmed flight are frequently presented as follows,

$$[C_D]_{cg} = f [C_L, M, Re] . \quad (3.1)$$

In this form of presentation (see, for example, Addendum B) speed and ambient conditions are included in each of the dimensionless parameters while the aeroplane mass and normal acceleration are represented by C_L . The following paragraphs offer further comments on the methods indicated by Equations (2.1) and (3.1) under the broad headings “trim”, “powerplant setting” and “compressibility” and “Reynolds number” effects.

Trimmed steady flight requires, in general, deflections of all the aeroplane’s control surfaces and, as indicated by the inclusion of δ_c in Equation (2.1), is accompanied by a “trim-drag” component; see Sections 3.2 and 3.8 of Data Item No. 97016 (Reference 17) for a definition of this term. Favourable adjustments to powerplant settings and aeroplane mass distribution can be used to provide significant reductions in this component of drag.

For steady symmetric flight ($\beta = 0$) trim drag arises from the deflection, δ_t , say, of the longitudinal control surfaces. This “longitudinal trim drag” is taken into account in Equation (3.1) by the association of C_D with a particular cg position since for an otherwise fixed aerodynamic configuration, the values of δ_t required for trim and their associated contributions to drag vary with C_L at a rate dependent on cg position. Consequently, the contribution to drag due to changes in δ_t is usually taken into account by the C_L term alone (and δ_t omitted as a variable) provided the particular drag variation is identified with the appropriate cg position. In general, the longitudinal trim drag increases with forward movement of the cg (see, for example, Addendum D) so that it may be advantageous to operate with aft cg . However, on all aeroplanes the minimum performance characteristics needed to comply with airworthiness requirements have to be demonstrated at all cg positions permitted in flight.

For manoeuvring flight, particularly where this represents a significant part of the operating regime of an aircraft, – such as highly-maneuvrable combat types – the drag associated with control surface deflection(s) may need to be considered in detail. It can then be advantageous (even essential) to consider separately the drag and lift characteristics of the control surface(s) (tail or canard) and the rest of the airframe. The two sets of lift and drag data are used in combination with an appropriate model of the flow field in which the control surface operates. Addendum G provides an example of an aircraft’s drag characteristics represented in this form.

Asymmetric flight may be imposed by engine failure on a multi-engined aeroplane and, more generally, by any asymmetry in configuration or thrust settings. Usually, trim is obtained by the deflections of the directional and roll control surfaces and combination of sideslip and bank angles. This aeroplane state, which achieves trim for asymmetric flight, would be considered as part of the defined aerodynamic configuration in Equation (3.1). Data Item No. 88006 (Reference 16) considers this topic (“asymmetric trim drag”) in detail and provides methods of estimation and several examples.

Powerplant settings are included as part of the “defined configuration” associated with Equation (3.1) since powerplant-related drag components are often represented in terms of powerplant settings rather than the corresponding values of intake, exhaust and slipstream flow parameters. Two examples of drag changes arising solely from changes in powerplant settings* are:

Changes in spillage and afterbody drags between the powerplant settings corresponding to steady flight and those corresponding to maximum acceleration or deceleration.

Changes in slipstream and cooling drags with changes in power settings between, say, level flight and maximum climb rate at the same forward speed.

The effect of compressibility on drag at low speeds is negligible in most cases and the influence of M can then be ignored in Equations (2.1) and (3.1). However, high-lift devices provide one example where changes in freestream Mach number cannot be ignored even at the low values of M typical of landing or take-off. At values of $C_L > 3$, say, the flow through a high-lift system can attain local values of M in the transonic range so that changes in freestream conditions can lead to significantly different effects of compressibility on lift and drag characteristics.

Reynolds number effects on drag depend on the range of values of Re involved. Large variations in Re , for example as between model-test and full-scale flight conditions, should always be taken into account and corrected for, as far as possible. On the other hand, the drag characteristics of aeroplanes designed to operate within limited ranges of speed and pressure height can be represented quite well using only the variations in C_L and M . In such cases it may not be necessary (or even possible) to identify effects due explicitly to changes in Reynolds number since, at a given pressure height, Re is directly proportional to M and its variation with temperature is small for typical ranges of temperature. Where the effects of Re can be identified, they are sometimes represented in the form,

$$[C_D]_{cg} = f [C_L, M, H_p] , \quad (3.2)$$

and an example of this form of presentation is provided in Addendum A. Reference to Item No. 77022, Sections 3.1, 6.2 and 7, shows that for any chosen variation of temperature with pressure height as, for example, in the International Standard Atmosphere, relationships (3.1) and (3.2) are equivalent.

3.1 Analytical Methods of Representing Aeroplane Drag

In performance estimation work it is often convenient to use analytical expressions for aeroplane drag characteristics – particularly where detailed estimates of drag are unavailable or where measured data are of limited extent. Three such methods are described in Sections 3.2 to 3.4 based on the sub-division of the total drag into the following two components,

- (i) a drag component that is “independent of lift”,
- (ii) a “lift-dependent drag” component.

This approach, while of practical value, does not constitute a fundamental treatment of drag analysis. For example, the lift-dependent term necessarily includes any part of the total drag which varies with angle of attack although it may not be directly related to the generation of lift.

* i.e. in addition to the obvious case of an inoperative powerplant in which case the effects of β on C_D must also be considered.

As indicated in Section 2.1, it is more convenient to express the drag components* (i) and (ii) in coefficient form and each component of the drag coefficient can then be expected to vary with both M and Re . The analytical methods of representing drag given in Sections 3.2 to 3.4 employ a system of dimensionless coefficients* $K_1, K_2, K_3 \dots$ instead of several more familiar terms (such as $C_{D_0}, C_{D_{min}}$) so as to associate each method with its own system of coefficients and to avoid the confusion that can occur when the more traditional quantities are used with more than one analytical method.

A brief discussion of some of the limitations associated with the analytical methods of representing drag data is contained in Section 3.5.

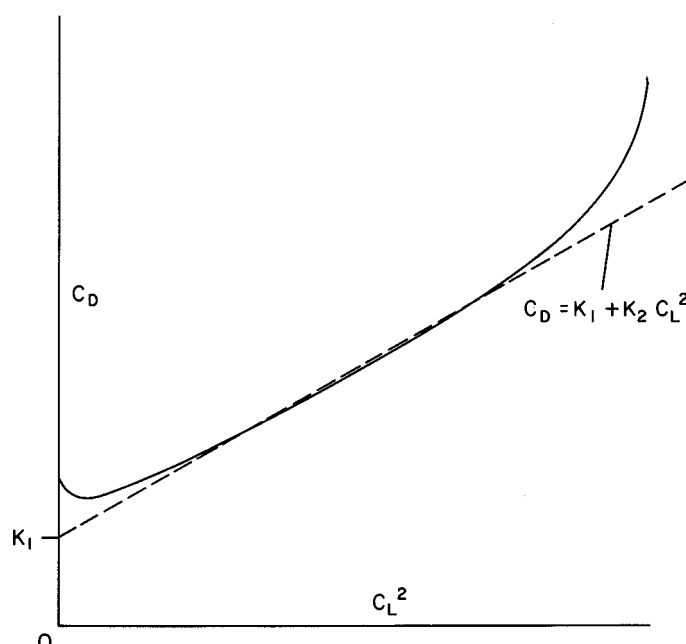
3.2 Simple Parabolic Drag Law

The simplest and most widely used form of analytical expression for the total drag coefficient of an aeroplane is the parabolic relationship

$$C_D = K_1 + K_2 C_L^2. \quad (3.3)$$

The relationships between K_1, K_2 and the numerous alternatives to these quantities that appear in other Data Items and elsewhere are given in Table 5.1.

Equation (3.3), with K_1 and K_2 taken as constants as in Sketch 3.1, is usually adequate to represent the drag characteristics up to C_L values where significant flow separation occurs and provided either that the Mach and Reynolds numbers are constant or that the effects of changes in them can be ignored. Effects of these parameters can be taken into account if further values of K_1 and K_2 are defined either for each value of M and Re of interest or to apply over limited ranges of values of M and Re .



Sketch 3.1 Simple parabolic drag law (Equation (3.3))

* To avoid confusion, a different set of notation is required to identify drag components (i) and (ii) for each analytical method of representing drag. However, in this Item most emphasis is given to the use of non-dimensional coefficients ($C_D, K_1, K_2, K_3 \dots$) so that the drag components (i) and (ii) are rarely used. The exception is in Section 3.2 where the traditional terms D_0 and D_i are used in Tables 5.1, 5.2 and 5.3 (together with corresponding thrust-power components, P_{r_0} and P_{r_i}).

Table 5.2 summarises results derived from Equation (3.3) corresponding to the flight conditions for “minimum drag” (maximum lift to drag ratio) and “minimum thrust power” denoted here by the subscripts “ md ” and “ mp ” respectively. Table 5.3 gives the further relationships between flight speed and the variations in lift to drag ratio and (for level flight) drag, thrust power and their components. These relationships are presented graphically in Figure 1 as a function of V/V_{md} and in Figure 2 as a function of V/V_{mp} . For aeroplanes where K_1 and K_2 can be regarded as independent of Mach number, the influence of the lift-dependent drag term at low C_L is small and can, to a first approximation, be neglected in the expressions in Table 5.3. This effect is demonstrated by the proximity of the curves of D/D_{md} and D_0/D_{md} at high values of V/V_{md} in Figure 1 and the proximity of the curves of $P_r/P_{r_{mp}}$ and $P_{r_0}/P_{r_{mp}}$ at high values of V/V_{mp} in Figure 2.

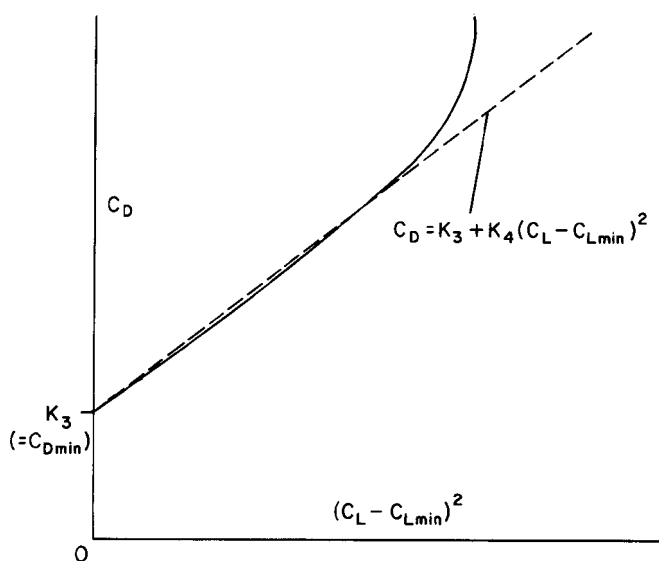
3.3 Modified Parabolic Drag Law

One effect of wing camber, twist and/or flap deflection is that the drag coefficient can have a minimum value, denoted $C_{D_{min}}$, at some positive value of lift coefficient, denoted $C_{L_{min}}$. If $C_{L_{min}}$ is outside the range of practical flight conditions, it may be acceptable still to use Equation (3.3) to represent aeroplane drag data. However, if necessary, a “modified parabolic drag law” can be used which provides a closer approximation to the actual C_D , C_L values. Two equivalent forms of this modified law are

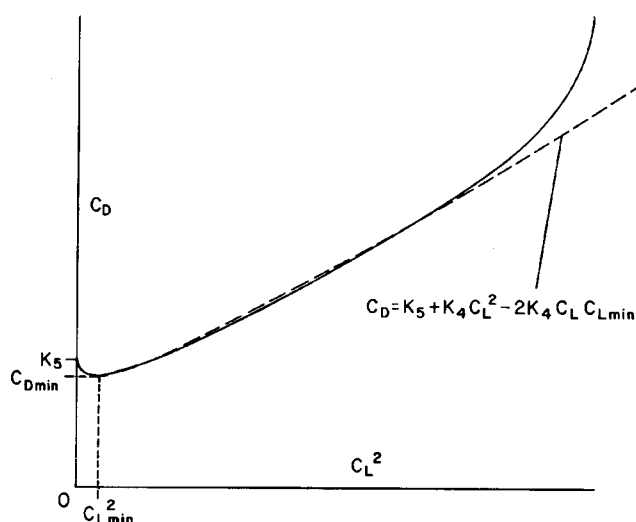
$$C_D = K_3 + K_4(C_L - C_{L_{min}})^2 \quad (3.4)$$

and
$$C_D = K_5 + K_4 C_L^2 - 2K_4 C_L C_{L_{min}} \quad (3.5)$$

where $K_5 = K_3 + K_4 C_{L_{min}}^2$, and, as in Section 3.2, single values of the coefficients K_3, K_4, K_5 are, strictly speaking, associated with fixed values of M and Re . Sketches 3.2 and 3.3 illustrate the graphical presentations associated with Equations (3.4) and (3.5) respectively. While Equation (3.4) provides the simpler presentation, Equation (3.5) leads to simpler analytical results and so it is used as the basis for the expressions given in Table 5.4 for the flight conditions for minimum drag (maximum lift to drag ratio). The corresponding expressions based on Equation (3.4) can be obtained by substituting $K_3 = K_5 - K_4 C_{L_{min}}^2$ in the expressions in Table 5.4.



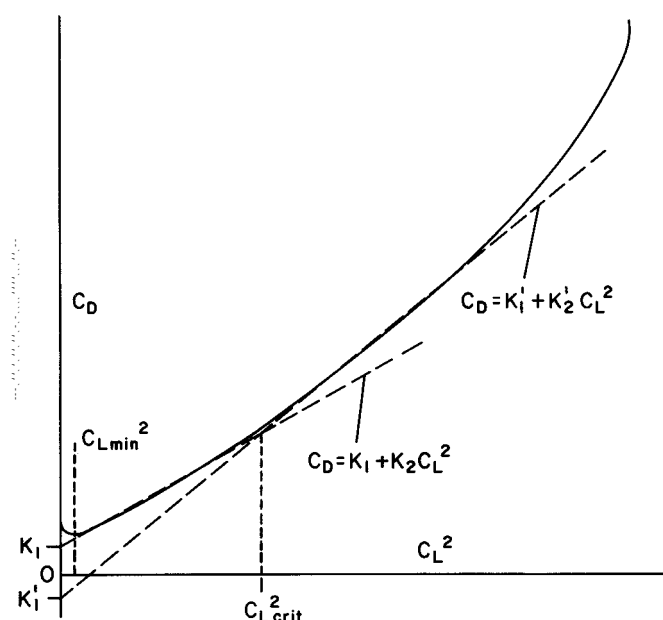
Sketch 3.2 Modified parabolic drag law
(Equation (3.4))



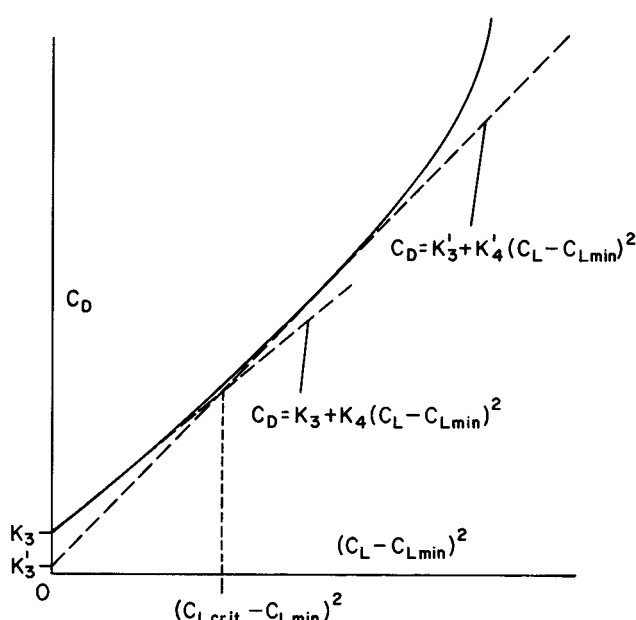
Sketch 3.3 Modified parabolic drag law
(Equation (3.5))

3.4 Dual-Parabolic Drag Law

For some purposes, such as in estimating manoeuvring performance, it is convenient to represent analytically a wider range of values of C_D and C_L than can be handled using Equations (3.3) or (3.4) and (3.5). One method demonstrated in References 7 and 8 adds a term in C_L^4 to Equations (3.3) or (3.4) and (3.5). A more widely-used technique is to approximate the continuous curves of C_D against C_L^2 by two straight-line segments which intersect at, say, C_{Lcrit} . This approach can be developed with each segment represented either as in Equation (3.3), see Sketch 3.4, or as in Equations (3.4) and (3.5), see Sketch 3.5. The relationships presented in Tables 5.2 and 5.4 are still valid although this is not the case with Table 5.3. Note that the minimum drag condition for this “dual-parabolic” drag curve occurs in the left hand segment i.e. $C_{Lmd} < C_{Lcrit}$ and that, as in Section 3.2, single values of the coefficients in the equations relating C_D and C_L are, strictly speaking, valid only at fixed values of M and Re . An example of the application of the “dual-parabolic” method is given in Addendum D.



Sketch 3.4 Dual-parabolic drag law
(Equation (3.3))



Sketch 3.5 Dual-parabolic drag law
(Equation (3.4))

3.5 Limitations of Analytical Methods of Representing Drag Coefficient Data

The use of expressions such as Equations (3.3) to (3.5) to represent C_D , C_L data is a long-established practice which owes much to the simplicity of the analytical results that can be derived. These expressions are clearly inappropriate for representing data of the type shown in Addendum B, while the use of computers has reduced the emphasis once placed on the analytical results given in Tables 5.2 to 5.4 and Figures 1 and 2 for the estimation of performance.

When Equations (3.3) to (3.5) are used, care should be taken both in the fitting of the chosen equation(s) to the data and in the subsequent interpretation of the coefficients K_1 , K_2 , K_3 ... Consider, for example, the use of Equation (3.3) to represent a single C_D , C_L curve as in Sketch 3.1. The values of K_1 and K_2 depend on the range of values of C_L used for the “curve-fit” so that while one pair of values may give the best “fit” over a specified range of C_L , a different pair may be preferred if the greatest possible range of

C_L is to be considered. Finally, given the possibility of multiple values of K_1 and K_2 arising from a single C_D , C_L curve, it is clear that comparisons between values of K_1 and K_2 (or their equivalents in Table 5.1) for different aeroplanes must be treated with caution.

Misleading comparisons of drag characteristics can arise from numerous sources, for example, minor differences in thrust/drag accounting or even from different interpretations of notation. In the latter case one of the most persistent differences is the use of the term C_{D_0} to mean both:

- (i) the intersection of a straight line with the C_D axis on a graph of C_D against C_L^2 (i.e. K_1 in Equation (3.3) and Sketch 3.1), and
- (ii) the actual value of C_D at $C_L = 0$ (i.e. K_5 in Equation (3.5) and Sketch 3.3).

4. REFERENCES

1. TAMBOR, R. Flight investigation of the lift and drag characteristics of a swept-wing, multijet transport-type airplane. NASA tech. Note D-30, September 1960.
2. – Summary and substantiation of aerodynamic data. McDonnell Douglas Corp. Douglas Aircraft Division, Rep. DAC 67124, June 1968.
3. NEAL, R.D. Correlation of small-scale and full-scale wind tunnel data with flight-test data on the Lear Jet Model 23. S.A.E. paper No. 700237, March 1970.
4. MARSHALL, R.T.
SCHWEIKHARD, W.G. Modelling of airplane performance from flight-test results and validation with an F-104G airplane. NASA tech. Note D-7137, February 1973.
5. AGARD *Aerodynamic drag*. AGARD CP-124, October 1973.
6. NEAL, R.D.
ROSS, R. Learjet model 25 drag analysis. Paper No. 8.2 in, Proceedings of the NASA, industry, university, general aviation drag reduction workshop held in July 1975 at University of Kansas, Lawrence, Kansas. N76-10997 to N76-11029 (NASA-CR-145627), 1975.
7. YAJNIK, K.S.
MALLADI, V.S. Representation of the drag polar of a fighter aircraft. *J. of Aircraft*, Vol. 13, No. 2, February 1976.
8. YAJNIK, K.S. Energy turn rate characteristics and turn performance of an aircraft. *J. of Aircraft*, Vol. 14, No. 5, May 1977.
9. DANFORTH, E.C.B.
HOPPS, R.H. Correlation of wind-tunnel and flight-test data for the Lockheed L-1011 Tristar. Paper No. 21 presented at AGARD specialists meeting, Paris, October 1977. In, *Performance Prediction Methods*, AGARD CP 242, May 1978.
10. GRELLMAN, H.W. YF-17 Full scale minimum drag prediction. *Ibid*, paper No. 18.
11. KENT, D.R.
WEBB, J.B.
WEBB, T.S. Correlation of F-16 aerodynamics and performance predictions with early flight-test results. *Ibid*, paper No. 19.
12. SODERMAN, P.T
AIKEN, T.N. Full scale wind-tunnel tests of a small unpowered jet aircraft with a T-tail. Ames Research Centre and U.S. Army Air Mobility R and D Laboratory, Moffett Field, Calif. NASA tech. Note D-6573, November 1971.
13. SBAC SBAC standard method of propeller performance estimation. Society of British Aircraft Constructors, 1954.
14. ESDU Thrust and drag accounting for propeller/airframe interaction. ESDU **Aerodynamics** Data Item No. 85017, November 1985.
15. ESDU Propeller/body interaction for thrust and drag. ESDU **Aerodynamics** Data Item No. 86017, August 1986
16. ESDU Estimation of drag arising from asymmetry in thrust or airframe configuration. ESDU Data Item No. 88006, December 1988 (with Amendment A, September 1989).
17. ESDU Estimation of airframe drag by summation of components: principles and examples. ESDU Data Item No. 97016, to be issued.

5. TABLES

TABLE 5.1

Alternative Drag Parameters* to Coefficients K_1 and K_2 in the Simple Parabolic Drag Law: $C_D = K_1 + K_2 C_L^2$

Parameters representing drag component, D_0 , independent of lift	Relationship of K_1 to alternative parameter	Comments
C_{D_0} “zero-lift drag coefficient” or “profile drag coefficient” = D_0/qS	$K_1 = C_{D_0}$	The term C_{D_0} should only be used in conjunction with the simple parabolic drag law of Section 3.2 (and not with the method of Section 3.3).
D_0/q “parasite drag area”	$K_1 = \frac{D_0}{q} \frac{1}{S}$	The parameters D_0/q , D_0/p and D_0/δ are particularly useful when considering and summing the drag due to a number of miscellaneous components, such as undercarriage, excrescences, etc. when no useful purpose is served by dividing by wing area to obtain a coefficient form.
D_0/p	$K_1 = \frac{D_0}{p} \frac{1}{(0.7M^2S)}$	
D_0/δ	$K_1 = \frac{D_0}{\delta} \frac{1}{(0.7p_0M^2S)}$	
D_{100} value of D_0 at 100 ft/s in ISA, sea-level conditions (defined for British units only)	$K_1 = D_{100} \frac{1}{11.88S}$ British units only	This term, which originated in the UK, is included because it still appears in some of the older Performance Data Sheets. It is not in current use.

Parameters representing lift-dependent drag component, D_i	Relationship of K_2 to alternative parameter	Comments
C_{D_i} “induced drag coefficient” (= D_i/qS)	$K_2 = C_{D_i} \frac{1}{C_L^2}$	The term “induced” and the subscript “i” derived from it, are widely used to denote the lift-dependent drag component and the corresponding term in the simple parabolic drag law of Section 3.2. In strict aerodynamic usage it usually implies only the “vortex-induced” contribution to drag and as such is only one of the possible contributions to the overall lift-dependent drag.
k “induced drag factor”	$K_2 = k \frac{1}{\pi A}$	
e “efficiency factor”	$K_2 = \frac{1}{e} \frac{1}{\pi A}$	This term is the American equivalent of the factor k (see above). It is sometimes referred to as “Oswald’s efficient factor” while the product eA is sometimes referred to as an “effective aspect ratio”.
$\frac{D_i}{q}$	$K_2 = \frac{D_i}{q} \frac{1}{S C_L^2}$	
$\frac{D_i}{p}$	$K_2 = \frac{D_i}{p} \frac{1}{(0.7M^2S) C_L^2}$	
$\frac{D_i}{\delta}$	$K_2 = \frac{D_i}{\delta} \frac{1}{(0.7p_0M^2S) C_L^2}$	

* With the exception of D_0 and D_i , the terms defined in the left-hand column of this Table do not appear in the main Notation of the Item.

TABLE 5.2

Minimum Drag, Minimum Thrust Power and Associated Conditions for the Simple Parabolic Drag Law: $C_D = K_1 + K_2 C_L^2$

Quantity	Expressions derived from parabolic drag law for:	
	Minimum drag condition	Minimum thrust-power condition
Drag in 1g level flight	$D_{md} = \frac{W}{(L/D)_{md}} = 2W(K_1 K_2)^{1/2}$	$D_{mp} = \frac{W}{(L/D)_{mp}} = 4W\left(\frac{K_1 K_2}{3}\right)^{1/2}$
Thrust power* in 1g level flight	$P_{r_{md}} = \frac{1}{G} \frac{(2WK_2^{1/2})^{3/2} K_1^{1/4}}{(\rho S)^{1/2}}$	$P_{r_{mp}} = \frac{1}{G} \frac{4}{3^{3/4}} \left(\frac{2W^3}{\rho S}\right)^{1/2} K_2^{3/4} K_1^{1/4}$
Drag coefficient	$C_{D_{md}} = 2K_1$	$C_{D_{mp}} = 4K_1$
Lift coefficient	$C_{L_{md}} = \left(\frac{K_1}{K_2}\right)^{1/2}$	$C_{L_{mp}} = \left(\frac{3K_1}{K_2}\right)^{1/2}$
Lift to drag ratio	$\left(\frac{L}{D}\right)_{md} = \frac{1}{2(K_1 K_2)^{1/2}} = \left(\frac{L}{D}\right)_{max}$	$\left(\frac{L}{D}\right)_{mp} = \left(\frac{3}{16K_1 K_2}\right)^{1/2}$
True airspeed* in 1g level flight	$V_{md} = \frac{1}{B} \left(\frac{2W}{\rho S}\right)^{1/2} \left(\frac{K_2}{K_1}\right)^{1/4}$	$V_{mp} = \frac{1}{B} \left(\frac{2W}{\rho S}\right)^{1/2} \left(\frac{K_2}{3K_1}\right)^{1/4} = \frac{V_{md}}{3^{1/4}}$
Equivalent airspeed* in 1g level flight	$V_{e_{md}} = \frac{1}{B} \left(\frac{2W}{\rho_0 S}\right)^{1/2} \left(\frac{K_2}{K_1}\right)^{1/4}$	$V_{e_{mp}} = \frac{1}{B} \left(\frac{2W}{\rho_0 S}\right)^{1/2} \left(\frac{K_2}{3K_1}\right)^{1/4} = \frac{V_{e_{mp}}}{3^{1/4}}$
Mach number in 1g level flight	$M_{md} = \left(\frac{W}{0.7pS}\right)^{1/2} \left(\frac{K_2}{K_1}\right)^{1/4}$	$M_{mp} = \left(\frac{W}{0.7pS}\right)^{1/2} \left(\frac{K_2}{3K_1}\right)^{1/4} = \frac{M_{mp}}{3^{1/4}}$

* In Table 5.2 the conversion factors **B**, **G**, are as follows.

Quantity	SI units		British units
	V in kn	V in km/h	
B	$0.5144 \frac{\text{m/n.mile}}{\text{s/h}}$	$0.2778 \frac{\text{m/km}}{\text{s/h}}$	$1.688 \frac{\text{ft/n.mile}}{\text{s/h}}$
G	$1000 \frac{\text{Nm/s}}{\text{kW}}$		$550 \frac{\text{ft lbf/s}}{\text{hp}}$