



ESDU 96012

Issued June 1996
With Amendment A
November 2005

Subsonic and transonic base and boat-tail pressure drag of cylindrical bodies with circular-arc boat-tails

Endorsed by
The Royal Aeronautical Society

AVA Documents
Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

Chairman

Mr H.C. Garner — Independent

Members

Mr G.E. Bean*	— Boeing Commercial Airplane Co., Seattle, Wash., USA
Dr M.Z. Bouter*	— Raytheon Aircraft Co., Wichita, Kansas, USA
Dr P.C. Dexter	— British Aerospace plc, Sowerby Research Centre, Bristol
Mr J.R.J. Dovey	— Independent
Dr K.P. Garry	— Cranfield University
Mr D.H. Graham*	— Northrop Grumman Corp., Pico Rivera, Calif., USA
Mr M.J. Green	— Independent
Dr H.P. Horton	— Queen Mary and Westfield College, University of London
Dr D.W. Hurst	— University of Glasgow
Mr M. Jager*	— McDonnell Douglas Aerospace, Long Beach, Calif., USA
Mr P.K. Jones	— Independent
Mr K. Karling*	— Saab-Scania AB, Linköping, Sweden
Dr E.H. Kitchen	— Rolls-Royce plc, Derby
Mr M. Maurel	— Aérospatiale, Toulouse, France
Mr C.M. Newbold	— Aircraft Research Association, Bedford
Mr J.B. Newton	— British Aerospace Defence Ltd, Warton
Mr R. Sanderson	— Daimler-Benz Aerospace Airbus GmbH, Bremen, Germany
Mr J. Tweedie	— Short Brothers plc, Belfast

* Corresponding Member

The technical work in the assessment of the available information and the development and subsequent construction of the Data Item method was carried out under contract to ESDU by

Mr A.J. Clarke

The person with overall responsibility for the work in this subject area is Mr P.D. Chappell, Head of the Aircraft Aerodynamics Group.

SUBSONIC AND TRANSONIC BASE AND BOAT-TAIL PRESSURE DRAG OF CYLINDRICAL BODIES WITH CIRCULAR-ARC BOAT-TAILS

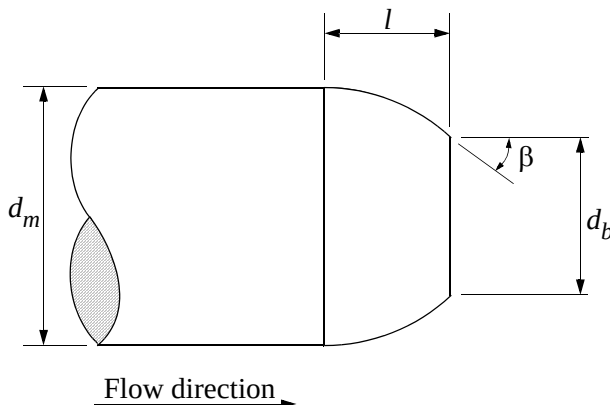
CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	2
3. METHOD	2
3.1 Base Pressure Drag	2
3.2 Boat-tail Pressure Drag	3
3.3 Total Afterbody Pressure Drag	3
4. ACCURACY AND APPLICABILITY	3
4.1 Accuracy	3
4.2 Applicability	3
5. DERIVATION AND REFERENCES	6
5.1 Derivation	6
5.2 References	6
6. EXAMPLE	7
6.1 Base Drag and Mean Base Pressure	7
6.2 Boat-tail Drag	8
6.3 Total Afterbody Pressure Drag	8
FIGURES 1a to 14	10 to 27

SUBSONIC AND TRANSONIC BASE AND BOAT-TAIL PRESSURE DRAG OF CYLINDRICAL BODIES WITH CIRCULAR-ARC BOAT-TAILS

1. NOTATION AND UNITS

		SI	British
C_{Da}	total afterbody pressure-drag coefficient, $C_{Db} + C_{D\beta}$		
C_{Db}	base pressure-drag coefficient based on maximum cross-sectional area of body		
$C_{D\beta}$	boat-tail pressure-drag coefficient based on maximum cross-sectional area of body		
C_{pb}	mean base pressure coefficient		
d_b	diameter of base, see Sketch 1.1	m	ft
d_m	maximum diameter of body, see Sketch 1.1	m	ft
l	length of boat-tail, see Sketch 1.1	m	ft
M	free-stream Mach number		
R_D	Reynolds number based on body maximum diameter		
R_L	Reynolds number based on body length		
β	boat-tail angle, see Sketch 1.1	degree	degree
Subscript			
$()_{cyl}$	denotes value for cylindrical body		



$$\beta = 2 \tan^{-1} \left(\frac{d_m - d_b}{2l} \right)$$

$$\frac{l}{d_m} = \frac{1 - d_b/d_m}{2 \tan(\beta/2)}$$

Sketch 1.1

Issued June 1996
With Amendment A, November 2005 – 27 pages
This page Amendment A

2. INTRODUCTION

This Item provides an empirical means of estimating the base and boat-tail pressure-drag coefficients of axisymmetric cylindrical bodies with circular-arc boat-tailing for Mach numbers up to 1.3. The method applies to bodies which are at zero angle of attack with cylindrical midbodies immediately in front of the boat-tailing. The method assumes that the overall pressure drag of an axisymmetric body can be sub-divided into forebody, boat-tail and base pressure drags. Experience suggests that the boat-tail and base pressure drags can be regarded as independent of the forebody drag provided that the cylindrical midbody between the forebody and boat-tail is more than about three body diameters in length. It is further assumed that the boundary layer is turbulent and that there is no jet flow through the base. The data used in deriving the method in this Item were obtained from the wind-tunnel tests reported in Derivations 1 to 3.

A worked example is given in Section 6.

Base and boat-tail drag data for conical afterbodies may be obtained from Item Nos 76033 and 77020 (References 7 and 9) at subsonic speeds, Item No. 78041 (Reference 10) at transonic speeds and Item Nos 79022 and Aero B.S. 02.03.04 (References 11 and 4) at supersonic speeds.

3. METHOD

3.1 Base Pressure Drag

Figures 1 to 6 show families of curves for C_{Db} plotted against $(d_b/d_m)^2$ for Mach numbers of $\leq 0.8, 0.9, 1.0, 1.1, 1.2$ and 1.3 . Data are given for each Mach number at various values of β for $2^\circ \leq \beta \leq 45^\circ$, with the lower values of β in Figures 1a to 6a and the higher values in Figures 1b to 6b.

Estimates of C_{Db} at intermediate values of β and M may be obtained by cross-plotting.

If required, the mean base pressure coefficient may be obtained from the equation

$$C_{pb} = -C_{Db} \left(\frac{d_m}{d_b} \right)^2. \quad (3.1)$$

In deriving the curves of Figures 1 to 6 cross-plots were made of C_{Db} versus β for fixed values of d_b/d_m . In order to provide an end point for these plots, to enable estimates of C_{Db} to be made for small values of β , it was assumed that as β approaches zero (and l becomes large), the base pressure coefficient will approach that of the cylindrical body, *i.e.*

$$(C_{pb})_{\beta \rightarrow 0} = (C_{pb})_{cyl}. \quad (3.2)$$

With application of Equation (3.1), the limiting value of C_{Db} as β tends to zero is given by

$$(C_{Db})_{\beta \rightarrow 0} = (C_{Db})_{cyl} \left(\frac{d_b}{d_m} \right)^2, \quad (3.3)$$

where $(C_{Db})_{cyl}$ is given in Figure 7 and has been taken from Item No. 78041.

3.2 Boat-tail Pressure Drag

Figures 8 to 14 show families of curves for $C_{D\beta}$ plotted against $(d_b/d_m)^2$ for Mach numbers of ≤ 0.6 , 0.8, 0.9, 1.0, 1.1, 1.2 and 1.3. Data are given at various values of β .

The figures for $C_{D\beta}$ are limited to maximum values of β of 25 degrees for $M < 1$, 30 degrees for $M = 1$ and 35 degrees for $M > 1$, above which the test data indicate a reversal in the trend of increasing $C_{D\beta}$ with β , which is associated with flow separation, see Section 4.

3.3 Total Afterbody Pressure Drag

When estimating drag at Mach numbers between those for which data have been given, a cross-plot of drag coefficient should be made against Mach number. Any minor irregularities occurring in the cross-plot should be smoothed out. The total afterbody pressure drag coefficient is simply obtained as the sum of the base and boat-tail components, *i.e.*

$$C_{Da} = C_{Db} + C_{D\beta} \quad (3.4)$$

4. ACCURACY AND APPLICABILITY

4.1 Accuracy

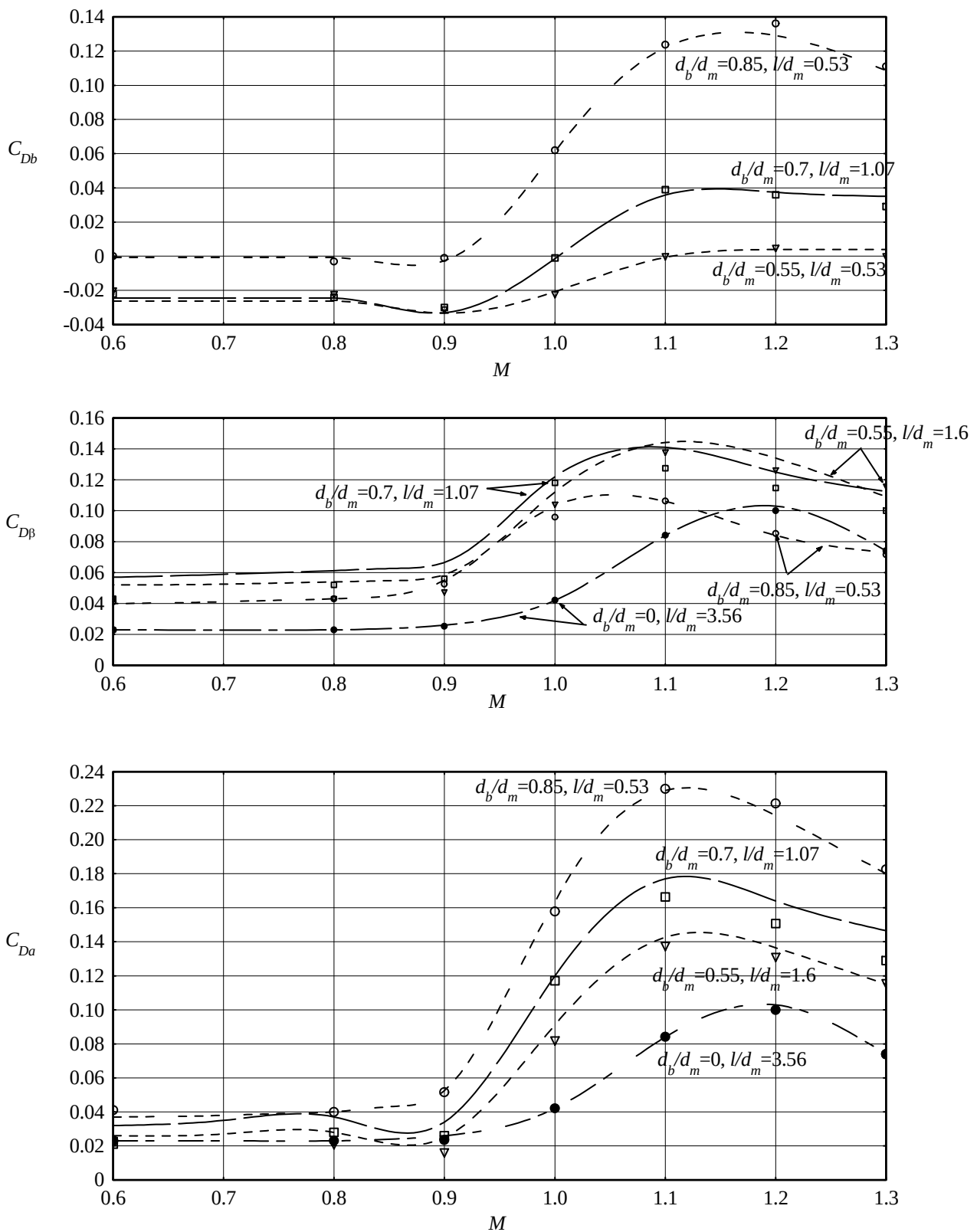
The curves of Figures 1 to 6 for C_{Db} and Figures 8 to 14 for $C_{D\beta}$ reproduce the test data of Derivations 1 to 3 to within about ± 0.01 . The total afterbody pressure drag coefficient C_{Da} is predicted to within about ± 0.015 . However, owing to the limited nature of the data base (nineteen boat-tail configurations from just three studies), and in the absence of suitable test data from independent sources to assess the quality of prediction, it is not possible to quote an absolute accuracy. Sketch 4.1 shows a comparison of prediction with the test data of Derivation 1 for boat-tails of differing base diameter with $\beta = 16$ degrees. It is worth noting, however, that the corresponding accuracies of Item No. 78041 for conical boat-tails, which were based on a larger and more widely sourced body of data, are ± 0.025 for C_{Db} , ± 0.02 for $C_{D\beta}$ and ± 0.03 for C_{Da} . These might be considered to be more realistic guides to expected accuracy with the greatest uncertainty in the Mach number range $0.9 < M < 1.1$.

4.2 Applicability

Table 4.1 gives the ranges of experimental data used in the preparation of this Item.

TABLE 4.1 Ranges of experimental data

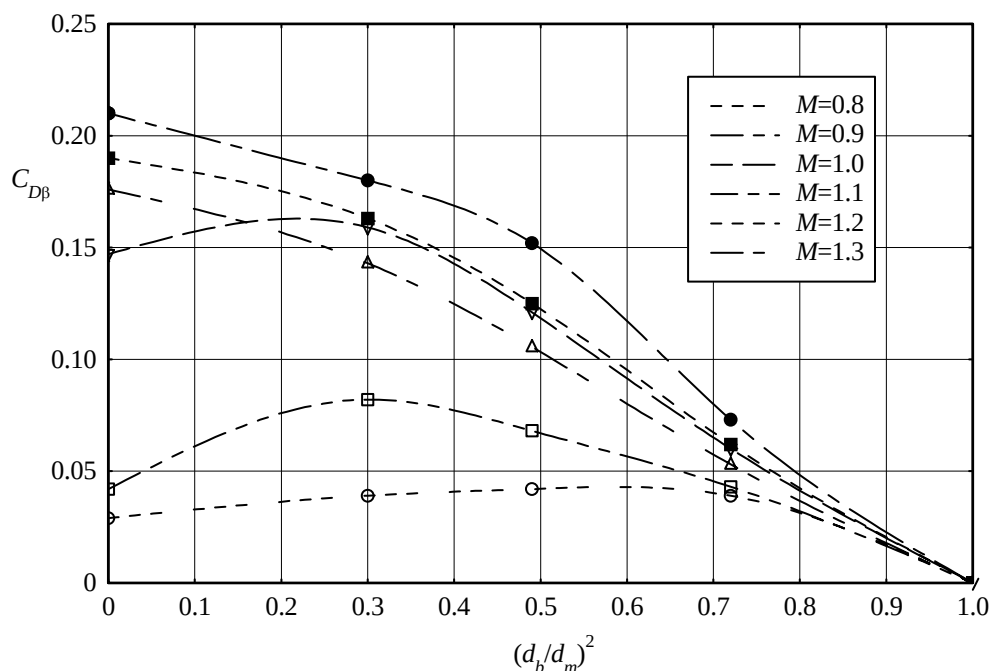
Parameter	Range
M	0.4 to 1.3
β	3° to 45°
d_b/d_m	$\begin{cases} 0.5 \text{ to } 1 \text{ for } C_{Db} \\ 0 \text{ to } 1 \text{ for } C_{D\beta} \end{cases}$
R_L	1.09×10^7 to 2.18×10^7
R_D	2.75×10^5 to 2.18×10^6



Sketch 4.1 Comparison of prediction with experiment for boat-tails with $\beta = 16$ degrees

The curves for $C_{D\beta}$ for $\beta > 22$ degrees are based on data for just two configurations (from Derivation 3) with boat-tail angles of 27.5 degrees and 34 degrees. Both have closure ratio $d_b/d_m = 0.51$. The pressure distributions over these afterbodies indicate significant areas of flow separation and thus imply a Reynolds number dependence. For Mach numbers below unity a consequence of flow separation is a reversal of the trend of increasing $C_{D\beta}$ with β , and the prediction of $C_{D\beta}$ under such circumstances is beyond the scope of this Item. However, for Mach numbers greater than unity, the presence of separation does not result in a reversal of the $C_{D\beta}$ versus β curve, perhaps as a result of the shock-induced separation occurring significantly further aft. Curves for $\beta = 30$ and 35 degrees have been included in Figures 12 to 14 for use with due caution. Derivation 1 provides data for four boat-tails with $\beta = 45$ degrees. At all Mach numbers the flow separates just aft of the mid-body/boat-tail junction. These data are shown in Sketch 4.2 for information and interpolation between Figures 8 to 14 and the data of Sketch 4.2 is not recommended.

Compared to the overall scatter in the experimental data Reynolds number is considered to have only a slight effect on C_{Db} , and also on $C_{D\beta}$, provided the flow remains attached (see Reference 8).



Sketch 4.2 Test data for $C_{D\beta}$ for boat-tails with $\beta = 45^\circ$ (Derivation 1)

The data apply to bodies with a plain base. However, on the basis of Reference 5, which only considers the case of conical boat-tails, the data should still provide reasonable estimates for bodies with jet orifices so long as the depth of jet cavity is greater than $0.25d_b$ and the diameter of the jet orifice is less than $0.8d_b$. The data are not applicable to bodies with even small amounts of base bleed or jet flow as these are known to have a significant effect on afterbody drag, see Reference 6.

With the same restrictions on β , the method of this Item should also provide reasonable estimates for afterbodies of parabolic profile.

5. DERIVATION AND REFERENCES

5.1 Derivation

The Derivation lists selected sources that have assisted in the preparation of this Item.

1. SILHAN, F.S.
CUBBAGE, J.M. Drag of conical and circular arc boat-tail afterbodies at Mach numbers from 0.6 to 1.3.
NACA RM L56K22 (TIL 5414), 1957.
2. REUBUSH, D.E. Effects of fineness and closure ratios on boattail drag of circular-arc afterbody models with jet exhaust at Mach numbers up to 1.3.
NASA tech. Note D-7163, 1973.
3. REUBUSH, D.E.
RUNCKEL, J.F. Effect of fineness ratio on the boat-tail drag of circular-arc afterbodies having closure ratios of 0.5 with jet exhaust at Mach numbers up to 1.3.
NASA tech. Note D-7192, 1973.

5.2 References

The References given are recommended sources of information supplementary to that in this Item.

4. ESDU External wave drag of bodies.
ESDU International, Data Item No. Aero B.S.02.03.04, 1954.
5. COMPTON, W.B. Effect on base drag of recessing the bases of conical afterbodies at subsonic and transonic speeds.
NASA tech. Note D-4821, 1968.
6. SYKES, D.M. Experimental investigation of low flow rate base bleed at transonic speeds.
City University, Res. Rep. Aero. 69-2, 1969.
7. ESDU Subsonic base drag of cylindrical bodies with conical boat-tails.
ESDU International, Data Item No. 76033, 1976.
8. REUBUSH, D.E. Effects of Reynolds number on boat-tail drag.
J. Aircraft, Vol. 13, No. 5, 1976.
9. ESDU Subsonic pressure drag of conical boat-tails.
ESDU International, Data Item No. 77020, 1977.
10. ESDU Transonic base and boat-tail pressure drag of cylindrical bodies with conical boat-tails.
ESDU International, Data Item No. 78041, 1978.
11. ESDU Supersonic base drag of cylindrical bodies with conical boat-tails.
ESDU International, Data Item No. 79022, 1979.

6. EXAMPLE

Calculate the variation of base drag and associated mean base pressure, boat-tail drag and total afterbody drag over the subsonic and transonic Mach number range for a circular-arc afterbody of length 2m, maximum body diameter 1m and base diameter 0.65 m.

From the equation in Sketch 1.1

$$\beta = 2 \tan^{-1} \left(\frac{d_m - d_b}{2l} \right) = 2 \tan^{-1} \left(\frac{1 - 0.65}{2 \times 2} \right) = 10.0 \text{ degrees.}$$

Also,

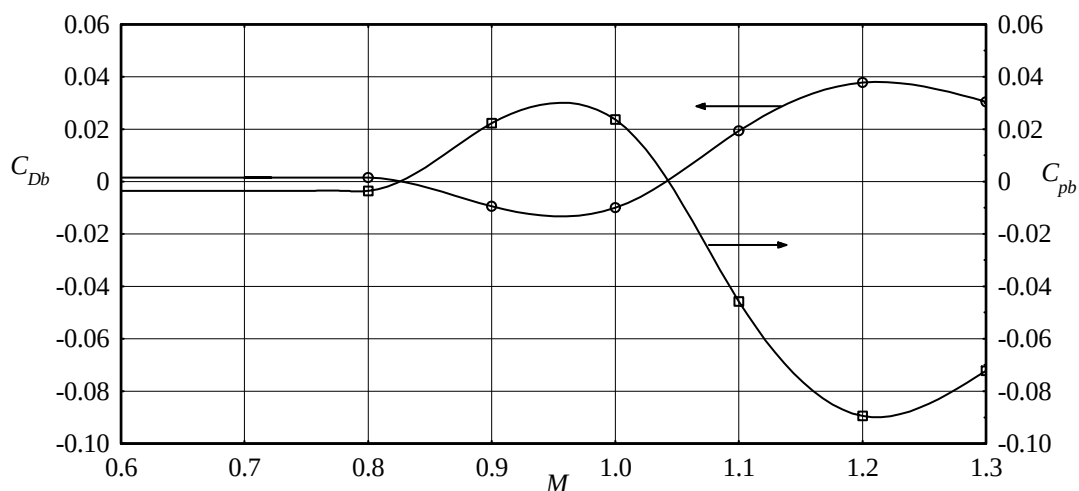
$$(d_b/d_m)^2 = (0.65/1.0)^2 = 0.4225 .$$

6.1 Base Drag and Mean Base Pressure

From Figures 1 to 6 values for C_{Db} are taken for $\beta = 10$ degrees and $(d_b/d_m)^2 = 0.4225$ at each Mach number. In each case the corresponding value of C_{pb} may then be calculated using Equation (3.1). The results are set out in Table 6.1 and illustrated in Sketch 6.1 with a smooth curve being drawn through the points.

TABLE 6.1

M	≤ 0.8	0.9	1.0	1.1	1.2	1.3
C_{Db}	0.0015	-0.0094	-0.0100	0.0193	0.0378	0.0305
C_{pb}	-0.0036	0.0222	0.0237	-0.0457	-0.0895	-0.0722



Sketch 6.1 Variations of C_{Db} and C_{pb} with Mach number

This page Amendment A