



Supersonic pressure drag of conical, circular-arc and parabolic boat-tails

Endorsed by
The Royal Aeronautical Society

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 The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants.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	
Dr M.Z. Bouter*	— Raytheon Aircraft Co., Wichita, Kansas, USA
Mr P.D. Chappell	— Independent
Dr P.C. Dexter	— BAE SYSTEMS, Advanced Technology Centre, Sowerby
Mr J.R.J. Dovey	— Independent
Dr K.P. Garry	— Cranfield University
Mr D.H. Graham*	— Northrop Grumman Corp., El Segundo, CA, USA
Mr M.J. Green	— Independent
Dr H.P. Horton	— Queen Mary and Westfield College, University of London
Mr M. Jager*	— Boeing, Long Beach, CA, USA
Dr E.H. Kitchen	— Rolls-Royce Commercial Aero Engines Ltd, Derby
Miss M. Maina	— Aircraft Research Association Ltd
Mr M. Maurel	— Aérospatiale, Toulouse, France
Mr C.M. Newbold	— Defence Evaluation and Research Agency, Farnborough
Mr J.B. Newton	— BAE SYSTEMS, Military Aircraft and Aerostructures, Warton
Mr M.J. Pow	— BAE SYSTEMS, Airbus, Filton
Mr R. Sanderson	— Daimler-Benz Aerospace Airbus, GmbH, Bremen, Germany
Mr E. Totland	— Saab AB, Linköping, Sweden
Mr J. Tweedie	— Short Brothers plc, Belfast
Mr A.J. Wells	— BAE SYSTEMS, Regional Aircraft, Woodford.

* Corresponding Member.

The technical work involved 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 R.W. Gilbey, Head of Aircraft Aerodynamics Group.

SUPERSONIC PRESSURE DRAG OF CONICAL, CIRCULAR-ARC AND PARABOLIC BOAT-TAILS

CONTENTS

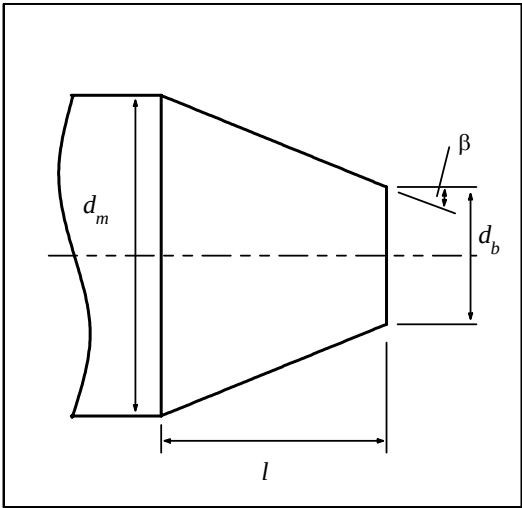
	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	2
3. METHOD	2
3.1 Presentation of Theoretical Data	2
3.2 Empirical Modifications	3
4. ACCURACY AND APPLICABILITY	3
5. REFERENCES	4
6. EXAMPLE	5
FIGURES 1a to 2e	7-13

ESDU Copyright material. For current status contact ESDU.

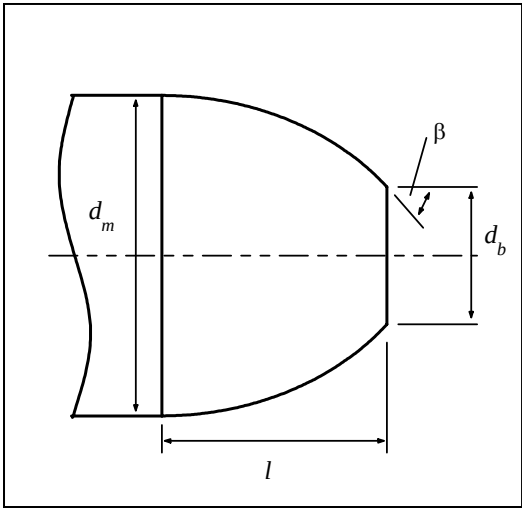
SUPERSONIC PRESSURE DRAG OF CONICAL, CIRCULAR-ARC AND PARABOLIC BOAT-TAILS

1. NOTATION AND UNITS (see Sketch 1.1)

		SI	British
$C_{D\beta}$	boat-tail pressure-drag coefficient based on S		
$(C_{D\beta})_{Th}$	theoretical boat-tail wave drag coefficient based on S		
d_b	base diameter	m	ft
d_m	maximum body diameter	m	ft
l	boat-tail length	m	ft
M_∞	freestream Mach number	m	ft
S	reference area, $\pi d_m^2/4$	m ²	ft ²
β	boat-tail angle	deg	deg



Cone



Circular arc or paraboloid

Sketch 1.1 Boat-tail geometry

2. INTRODUCTION

This Item presents data for the pressure-drag coefficient of conical, circular-arc and parabolic boat-tails at zero angle of attack over the Mach number range 1.5 to 4. The method, given in Section 3, is based on theoretical estimates of wave drag obtained from the Method of Characteristics, which are then modified empirically to achieve better comparison with wind-tunnel test results. It should be noted that theoretical data for boat-tail wave drag are also available in Item No. Aero B.S.02.03.02 (Reference 1), but the presentation therein employs similarity laws to correlate computed results and is appropriate only for boat-tails of fairly large length to maximum body diameter ratio. The present Item applies to shorter boat-tails and is restricted to a maximum value of l/d_m of 2.5. The user is referred to Item No. Aero B.S.02.03.02 when l/d_m is greater than 2.5. A guide to the accuracy and applicability of the Item is given in Section 4, the references are given in Section 5 and the method is illustrated by a worked example in Section 6.

Item No. 77020 (Reference 3) and 78041 (Reference 4) provide data for pressure drag of conical boat-tails at subsonic and transonic speeds, respectively. Data for pressure drag of circular-arc and parabolic boat-tails at both subsonic and transonic speeds are given in Item No. 96012 (Reference 6). The method of this Item excludes situations where there are jet interference effects, see Section 4. However, a method that caters for jet interference effects on pressure drag of conical boat-tails is available in Item No. 00017 (Reference 7).

In order to estimate total afterbody pressure-drag coefficient the pressure (base) drag contribution of any rearward facing base and/or nozzle area must be accounted for. Such data are available for conical afterbodies in Item No. 79022 (Reference 5) for the 'jet-off' case and Item No. 00017 (Reference 7) for the 'jet-on' situation.

3. METHOD

3.1 Presentation of Theoretical Data

The data for boat-tail wave drag coefficient, $(C_{D\beta})_{Th}$, are presented in carpet form as functions of boat-tail length and Mach number at given values of boat-tail angle, β . Figures 1a to 1e present the data for conical boat-tails for values of β of 2, 4, 6, 8, and 10 degrees. Figures 2a to 2e present the data for circular-arc boat-tails for values of β of 5, 10, 15, 20 and 25 degrees, respectively. To the order of accuracy of the theory of Figure 2 may also be applied to boat-tails of parabolic profile. Note that for the circular-arc and parabolic profiles the boat-tail angle refers to the local angle at the boat-tail/base junction, see Sketch 1.1.

The geometrical relationships between boat-tail angle, body maximum diameter, base diameter and the boat-tail length are

$$\beta = \tan^{-1} \left[\frac{(d_m - d_b)}{2l} \right] \quad \text{for a conical boat-tail,} \quad (3.1)$$

$$\beta = 2 \tan^{-1} \left[\frac{(d_m - d_b)}{2l} \right] \quad \text{for a circular-arc boat-tail,} \quad (3.2)$$

$$\beta = \tan^{-1} \left[\frac{(d_m - d_b)}{l} \right] \quad \text{for a parabolic boat-tail.} \quad (3.3)$$

3.2 Empirical Modifications

To improve the correlation of the theoretical data with experiment for conical boat-tails, Item No. 00017 uses the equation,

$$C_{D\beta} = 0.85(C_{D\beta})_{Th}, \quad (3.4)$$

where 0.85 is an empirical correction factor

Reference 2 provides an empirical correction for boat-tails without discontinuity at the cylindrical body/boat-tail junction including circular-arc and parabolic profiles. A modified* form of that correlation is given by

$$C_{D\beta} = (C_{D\beta})_{Th} - 0.00019\beta^{3/2}. \quad (3.5)$$

4. ACCURACY AND APPLICABILITY

The method of this Item is applicable to boat-tails of conical, circular-arc and parabolic profile for Mach numbers from 1.5 to 4 at zero angle of attack. The boat-tail angles considered are limited to a maximum of 10 degrees for the case of the conical boat-tails and 25 degrees for the circular-arc and parabolic boat-tails, which should cover most practical applications. The maximum boat-tail length for which data are presented in this Item is $2.5d_m$. Theoretical data for longer boat-tails and closed afterbodies may be obtained from Item No. B.S.02.03.02.

The method does not allow for any interference effects that may arise as a result of a propulsive jet issuing from the base of the body. However, such interference only occurs when the nozzle operating conditions and geometry result in a base pressure, which acts on the annular area bounded between the nozzle exit and the base circumferences, exceeding that on the end of the boat-tail. (Data for pressure distributions and local Mach numbers along conical, circular-arc and parabolic boat-tails are given in Item No. 00028 (Reference 8)). Under these circumstances the higher base pressure feeds onto the boat-tail via the subsonic portion of the boundary layer and causes a reduction in drag. For a highly under-expanded jet producing a high base pressure and a large jet plume a shock wave may form of sufficient strength to separate the flow on the boat-tail at, or even upstream of, the base causing a large reduction in drag, see Item No. 00017.

The method assumes that the flow ahead of the boat-tail is undisturbed by the presence of the forebody. In practice this is realised providing there are three or more body diameters of cylindrical mid-body between the forebody/cylinder and boat-tail/cylinder junctions. The presence of fins fitted for the purposes of aerodynamic stability or control will also affect the pressure drag of the boat-tail, but this effect is expected to be relatively minor providing the fins are thin compared with the body diameter and radially mounted.

Item No. 00017 gives the accuracy of the method for pressure drag coefficient of conical boat-tails as ± 0.003 . Reference 2 gives the accuracy of the correlation for circular-arc and parabolic boat-tails as ± 0.005 .

* The actual formula given in Reference 2 is $C_{D\beta} = (C_{D\beta})_{Th} + 0.0075(1 - \beta/6)$. Equation (3.5) follows this function closely over the range of β for which data are presented in the original correlation, but avoids predicting a drag coefficient greater than the theoretical value for $\beta < 6$ degrees.