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REPORT NO. RD-TM-70-7

ESTIMATED POWER-ON BASE DRAG FOR A ROCKET-ASSISTED PROJECTILE

by

Charles E. Brazzel

July 1970

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by

Charles E. Brazzel

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Advanced Systems Laboratory
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US Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

Power-on base drag values estimated for an existing rocket-assisted projectile (RAP) show that a major portion of the rocket impulse is expended in overcoming drag rather than in extending the range of the projectile. A parametric study of the effects of thrust level, afterbody geometry, and nozzle position on power-on base drag shows that the losses due to drag can be significantly decreased.

CONTENTS

SYMBOLS

A_{REF}	Body reference area, sq ft
C_D	Drag coefficient = drag/qA_{REF}
$C_{D_{AB}}$	Afterbody drag coefficient = $C_{D_b} + C_{D_{BT}}$
$C_{D_{BT}}$	Boattail wave drag coefficient
C_{D_b}	Base drag coefficient
$C_{D_{FB}}$	Forebody drag coefficient = $C_{D_T} - C_{D_b}$ (in this report)
C_{D_T}	Total drag coefficient
C_T	Thrust force coefficient = thrust/qA_{REF}
D_B	Diameter of cylindrical portion of body, ft
D_b	Diameter of body base, ft
D_J	Diameter of rocket nozzle at exit plane, ft
L_b	Boattail length, ft
M_∞	Free-stream Mach number
P_b	Base pressure, psf
P_∞	Free-stream static pressure, psf
q	Free-stream dynamic pressure, psf
X_J	Distance from nozzle exit plane forward to body base
δ	Boattail half angle, deg.

SUBSCRIPTS

BT	Boattailed afterbody
CYL	Cylindrical afterbody
ON	Power-on
OFF	Power-off

1. Introduction

At the request of the Aeroballistics Branch, Engineering Sciences Laboratory, Picatinny Arsenal, power-on base drag values were estimated for an existing rocket-assisted projectile (RAP). A parametric study was also made to investigate the effectiveness of various techniques in reducing power-on base drag. The estimated base drag values, a description of the estimation technique, and results of the parametric study are presented.

2. Configuration and Trajectory

The following configuration and trajectory information was provided by the Aeroballistics Branch.

a. External Configuration

The projectile is a body of revolution with a 3-caliber tangent ogive nose, a 2.04-caliber cylindrical body 8 inches in diameter, and a 0.60-caliber boattailed afterbody with a 0.8425-caliber base diameter. A sketch of the afterbody is presented in Fig. 1.

b. Rocket Configuration

The projectile is powered by a solid propellant rocket with a thrust of 791.3 pounds, a burning time of 3.0 seconds, and a specific impulse of 193.0 seconds. The rocket nozzle has a throat diameter of 0.68 inch, an exit diameter of 1.85 inches, and a conical expansion half-angle of 15 degrees. The nozzle exit plane is 3.75 inches forward of the body base.

c. Trajectory

The projectile is gun launched with a muzzle velocity of 2510 feet per second (Mach number = 2.248 at sea level). Rocket ignition occurs 7 seconds after launch; burning time is 3 seconds. Trajectory data computed by Picatinny Arsenal for a launch quadrant elevation of 52 degrees at sea level are shown below:

Time (sec)	Altitude (ft)	Velocity (ft/sec)	Mach Number
7	11,580	1859	1.735
8	12,979	1917	1.799
9	14,406	1977	1.866
10	15,862	2039	1.935

The following power-off total drag values were also supplied by Picatinny Arsenal:

Mach Number	Total Power-Off Drag ($C_{D_{T_{OFF}}}$)
1.7	0.279
2.0	0.262
2.5	0.227

3. Power-On Base Drag Estimate

A general technique for estimating power-on base drag is described in Ref. 1. A modified version of this technique, described below, was used to estimate the power-on base drag for the RAP.

First, base pressures on an equivalent cylindrical body (no boattail) with the nozzle flush with the base are calculated for the flight conditions. Next, the base pressure values are adjusted for boattail effects. And last, the base pressure values are adjusted for nozzle position and base drag values are calculated.

a. Base Pressure on a Cylindrical Afterbody with the Nozzle Flush with the Base

Reference 1 indicates that the base pressure at various Mach numbers, nozzle diameters, and chamber pressures can be correlated as a function of the thrust force coefficient, C_T. Figure 2 presents a correlation of experimental data for a configuration with:

(1) a cylindrical afterbody

(2) cold air nozzle flow

(3) nozzle flush with base

(4) nozzles of various diameters with a design Mach number of 2.7 and a conical expansion half angle of 20 degrees.

Although the correlation is based on experimental results for cold air nozzle flow, there is close agreement with flight test results for configurations with cylindrical afterbodies, with solid propellant rockets of moderate specific impulse, and with the nozzle flush with the body base. Therefore, Fig. 2 may be used to estimate base pressure for configurations in this category.

To use Fig. 2 for estimates, a thrust force coefficient (C_T) is calculated for conditions at a given free-stream Mach number. The base pressure is taken from the curve for that C_T and free-stream Mach number. For example, for a free-stream Mach number of 1.0, the base pressures for C_T values between 0.01 and about 2.0 are along the broken line (1)-(2). For C_T values between about 2.0 and 15.0, the base pressures fall on the solid line (2)-(3) which is common to all free-stream Mach numbers. For C_T values above 15.0, the base pressures fall on the broken line (3)-(4). (It should be noted that base pressures on the broken line (3)-(4) are sufficient to cause extreme thickening or even separation of the body boundary layer; therefore aerodynamic stability problems will result.)

Using Fig. 2 and the trajectory information in section 2, the base pressures on an equivalent cylindrical body with a flush nozzle are estimated for RAP (Table I).

Table I

Base Pressure Ratio on an Equivalent Cylindrical Afterbody with a Flush Nozzle

Time	M_∞	q	Thrust	C_T	$(P_b/P_\infty)_{CYL}$
7	1.735	2896	781.3	0.783	0.280
8	1.799	2939	781.3	0.771	0.280
9	1.866	2984	781.3	0.760	0.280
10	1.935	3025	781.3	0.749	0.280

b. <u>Base Pressure on a Boattailed Afterbody with a Flush Nozzle</u>

The base pressure values in Table I must be adjusted from cylindrical afterbody to boattailed afterbody base pressures. Figure 8 in Ref. 1 presents a proportionality factor to adjust for boattail effects. This factor is repeated in Fig. 3 for the range of parameters of interest on the RAP. For this configuration, the cylindrical values must be multiplied by a factor of 1.32 to adjust the boattail base pressure. Results are given in Table II.

Table II

Base Pressure Ratio on a Boattailed Afterbody with a Flush Nozzle

Time	M_∞	$(P_b/P_\infty)_{CYL}$	$(P_{b_{BT}}/P_{b_{CYL}})$	$(P_b/P_\infty)'_{BT}$
7	1.735	0.280	1.32	0.370
8	1.799	0.280	1.32	0.370
9	1.866	0.280	1.32	0.370
10	1.935	0.280	1.32	0.370

c. Base Drag on Projectile with Boattailed Afterbody and the Nozzle Forward of the Base

The base pressure values of Table II must now be adjusted for nozzle position.

A positive increment in base pressure ratio for nozzles extended forward of the base of cylindrical afterbodies is presented in Fig. 4 (see Fig. 9 in Ref. 1). It has been determined from previous experiments (Ref. 2) that the base increment in base pressure ratio becomes negative as the nozzle moves forward of the base.

For this estimate, the base pressure increment due to the nozzle's being forward of the base was assumed to be equal (but opposite in sign) to the base pressure increment for a nozzle aft of the base. The effects of nozzle position with boattailed bodies are not known. For this estimate, however, the base pressure increment for cylindrical bodies was multiplied by the inverse of the proportionality factor $(P_{b_{BT}}/P_{b_{CYL}})$ used in section 3b. Results are given in Table III.

Table III

Base Drag for the Projectile

Time	M_∞	$(P_b/P_\infty)'_{CYL}$	$(\Delta P_b/P_\infty)_{CYL}$	$(\Delta P_b/P_\infty)_{BT}$	P_b/P_∞	C_{D_b}
7	1.735	0.370	0.173	-0.131	0.239	0.237
8	1.799	0.370	0.169	-0.128	0.242	0.219
9	1.866	0.370	0.164	-0.124	0.246	0.203
10	1.935	0.370	0.160	-0.121	0.249	0.188

To illustrate the effects of thrust on the projectile, estimated power-on total drag values were compared to the thrust force coefficients. The power-on total drag values were obtained by manipulation of the power-off total drag values of section 2c. Power-off base drag values (estimated by interpolation of experimental data) were subtracted, and power-on base drag values of Table III were added to approximate the total power-on drag values shown in Table IV and Figure 5.

Table IV

Total Power-On Drag for the Projectile

Time	M_∞	$C_{D_{TOTAL_{OFF}}}$	$C_{D_{b_{OFF}}}$	$C_{D_{FB}}$	$C_{D_{b_{ON}}}$	$C_{D_{TOTAL_{ON}}}$	C_T
7	1.735	0.277	0.040	0.237	0.237	0.474	0.783
8	1.799	0.272	0.044	0.228	0.219	0.447	0.771
9	1.866	0.268	0.048	0.220	0.203	0.423	0.760
10	1.935	0.264	0.051	0.213	0.188	0.401	0.749

By comparing the total power-on drag coefficient with the thrust force coefficient, it can be seen that as much as 60 percent of the thrust impulse is used to overcome the drag. Thus the projectile will not achieve the anticipated range due to drag penalty.

4. Generalized Effects of Thrust on Projectile Drag

Some of the problems of adding thrust to a projectile can be illustrated with a generalized configuration. This was done in Ref. 3 for a 155mm (Type 1) configuration at a Mach number of 2.0 at sea level and shown in Fig. 6. With no thrust, the total drag force is about 360 pounds. However, adding 360 pounds of thrust does not cancel the drag, since the influence of thrust boosts the total drag to about 540 pounds. In fact, it can be seen that over 520 pounds of thrust must be applied before the projectile begins to accelerate. At about 15,000 pounds thrust the base drag becomes base thrust; and at some value over 15,000 pounds thrust, the base pressure is sufficiently high to significantly influence the body boundary layer leading to aerodynamic stability problems.

5. Parametric Study of Factors Influencing Power-On Base Drag

A parametric study of factors influencing power-on base drag was performed to investigate methods for reducing projectile drag. The effects of boattail length and base diameter, nozzle position, and thrust level were investigated at a Mach number of 1.8.

In an optimization study the total afterbody pressure drag (boattail wave drag plus base drag) must be considered. Figures 7, 8, and 9 present boattail wave drag as a function of length and base diameter for Mach numbers 1.6, 1.8, and 2.0 respectively.

Using the base drag estimation technique described in section 3 and the wave drag of Figs. 7, 8, and 9, afterbody drag values for boattail lengths of 0.13 to 0.60 body diameters, and boattail base diameters of 0.7 to 1.0 body diameters were estimated for two nozzle positions and for thrust levels of 800, 1600, and 2400 pounds. The results are presented in Figs. 10, 11, and 12, and are tabulated in the Appendix. It is apparent that there is an optimum base diameter (minimum drag) for each boattail length which varies with nozzle position and thrust level.

The estimated afterbody drag values for the optimum boattail base diameter are shown in Fig. 13.

6. Conclusions

The following conclusions may be drawn from the results of this study:

a. Due to the influence of thrust on base drag, the high level of total drag on the projectile will seriously degrade its performance.

b. The performance can be improved by (1) increasing the thrust level; (2) moving nozzle aft; or (3) optimizing boattail configuration.

c. Adding thrust to a projectile to achieve a greater range must be done with careful consideration of the effects of thrust on projectile aerodynamic characteristics.

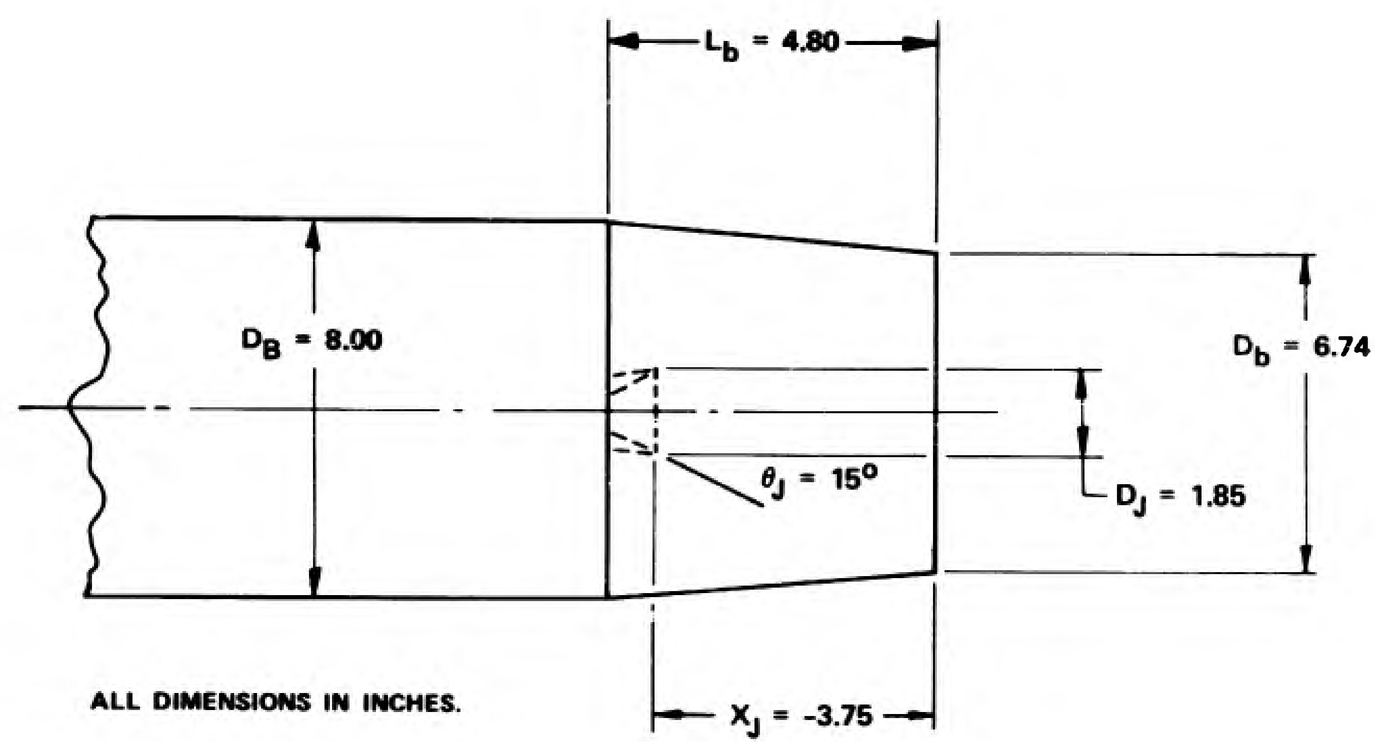

Fig. 1. Afterbody Configuration

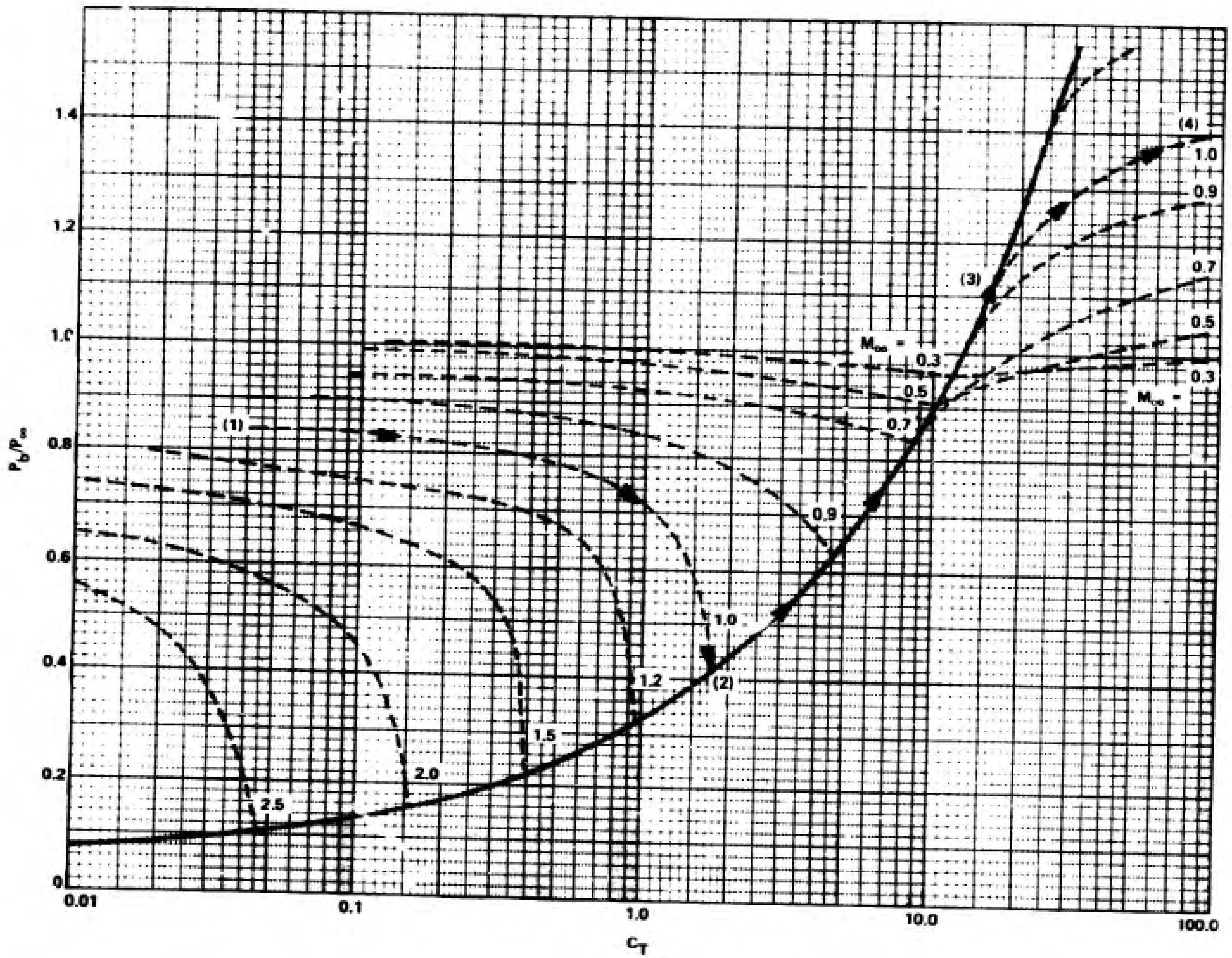

Fig. 2. Base Pressure Variation with Thrust for a Cylindrical Afterbody with a Nozzle Flush with Base

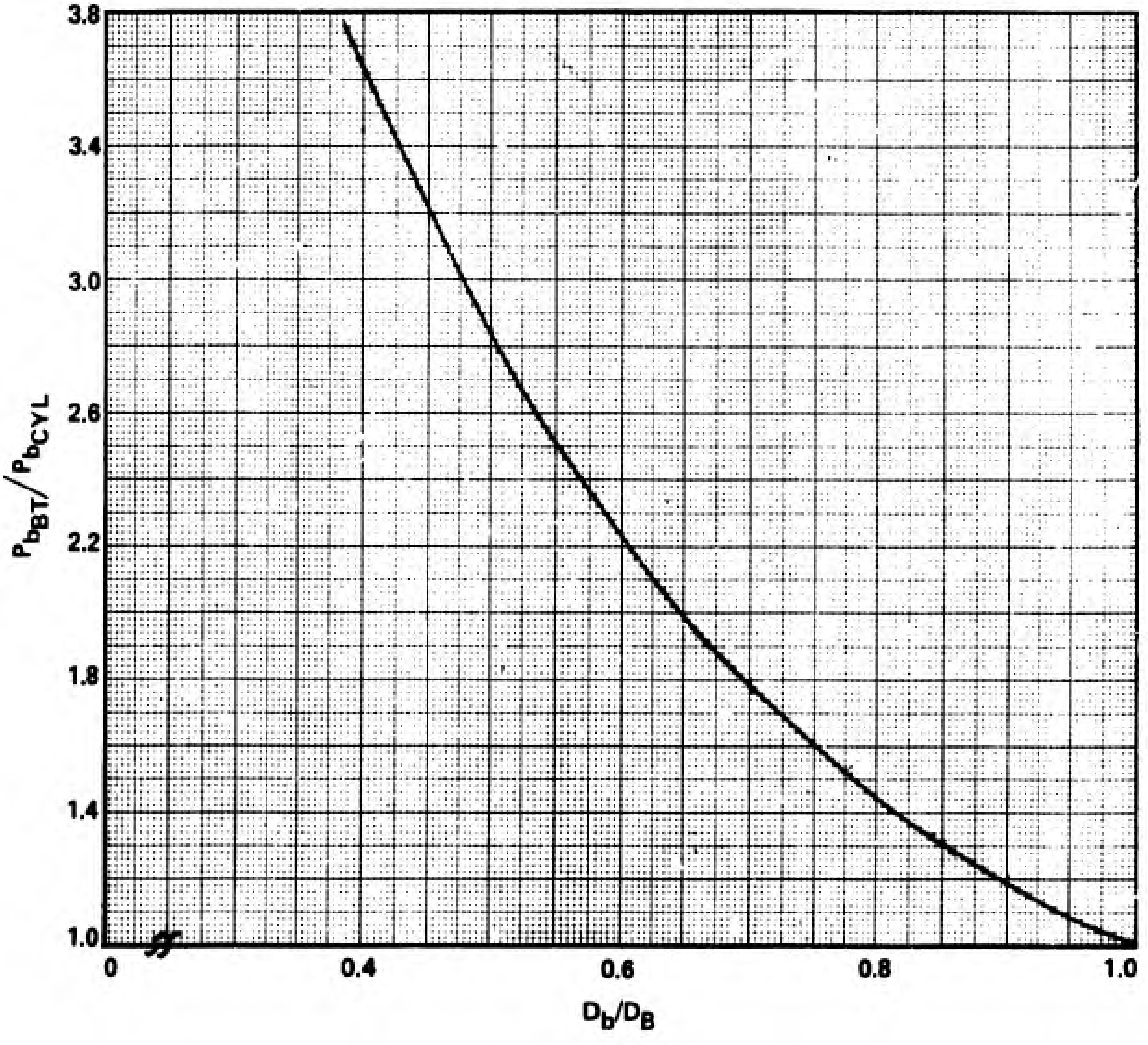

Fig. 3. Ratio of Base Pressure on a Boattail to Base Pressure on a Cylinder

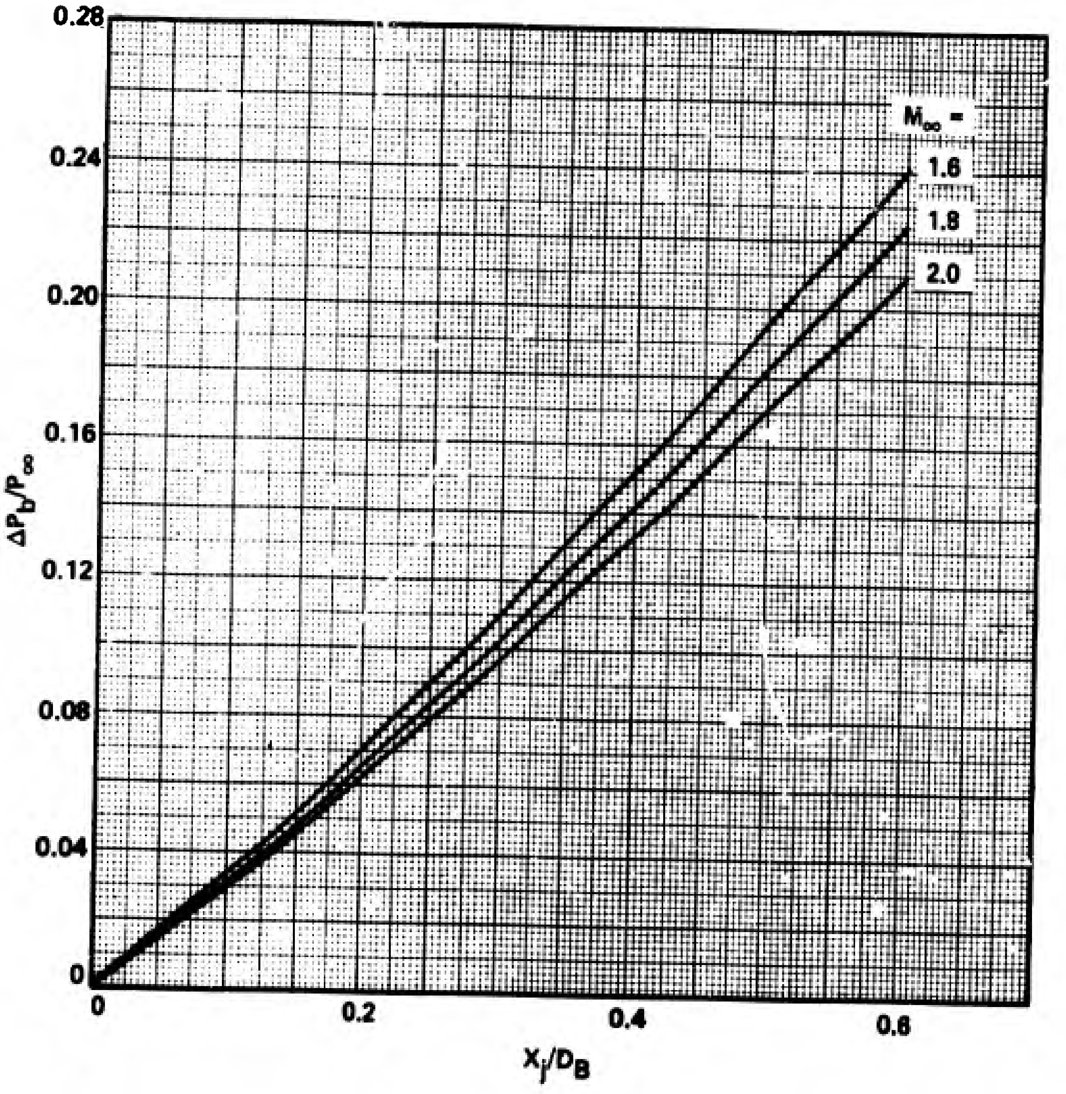

Fig. 4. Incremental Change in Base Pressure Due to Nozzle Aft of Base

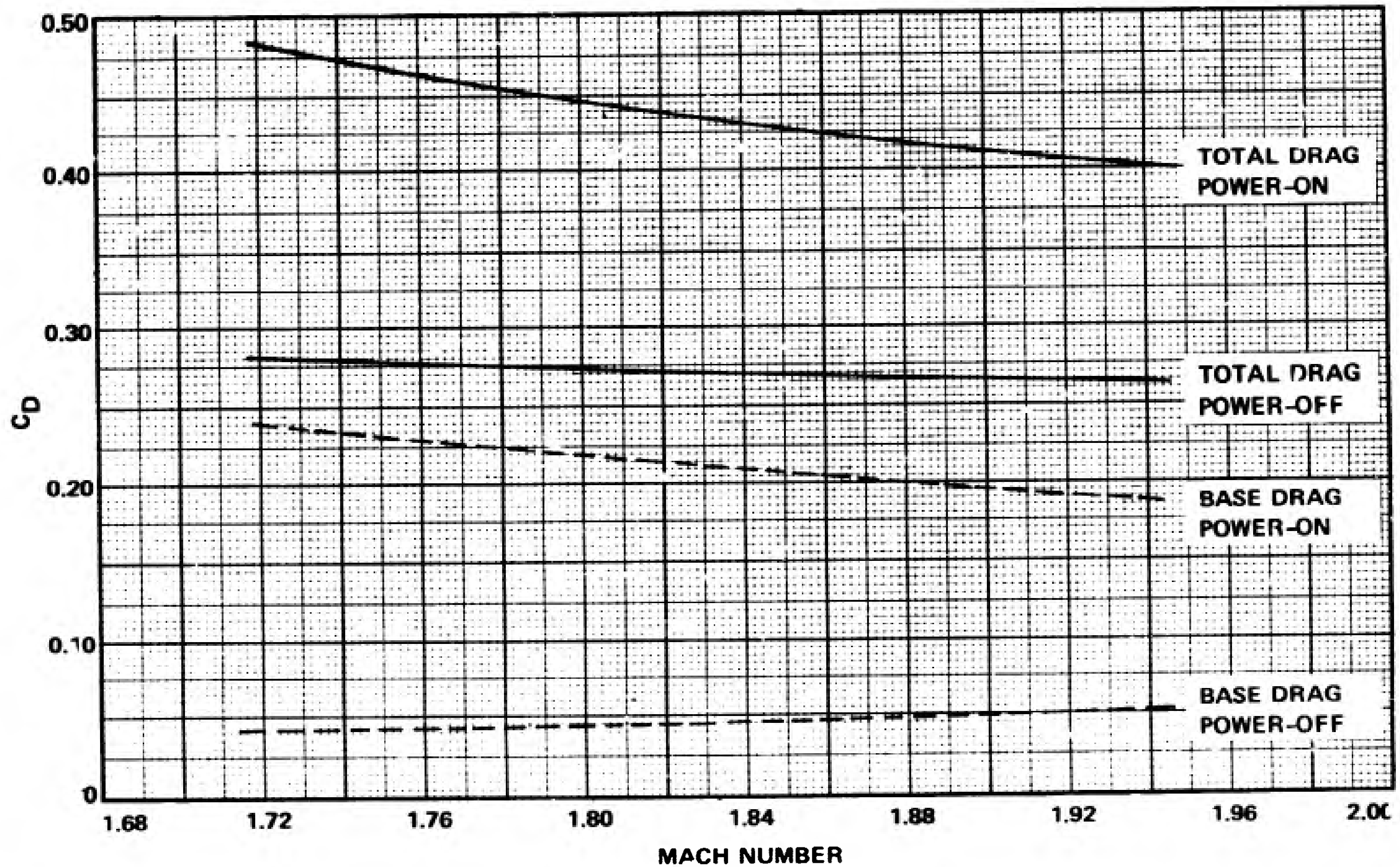

Fig. 5. Estimated Drag for the Projectile

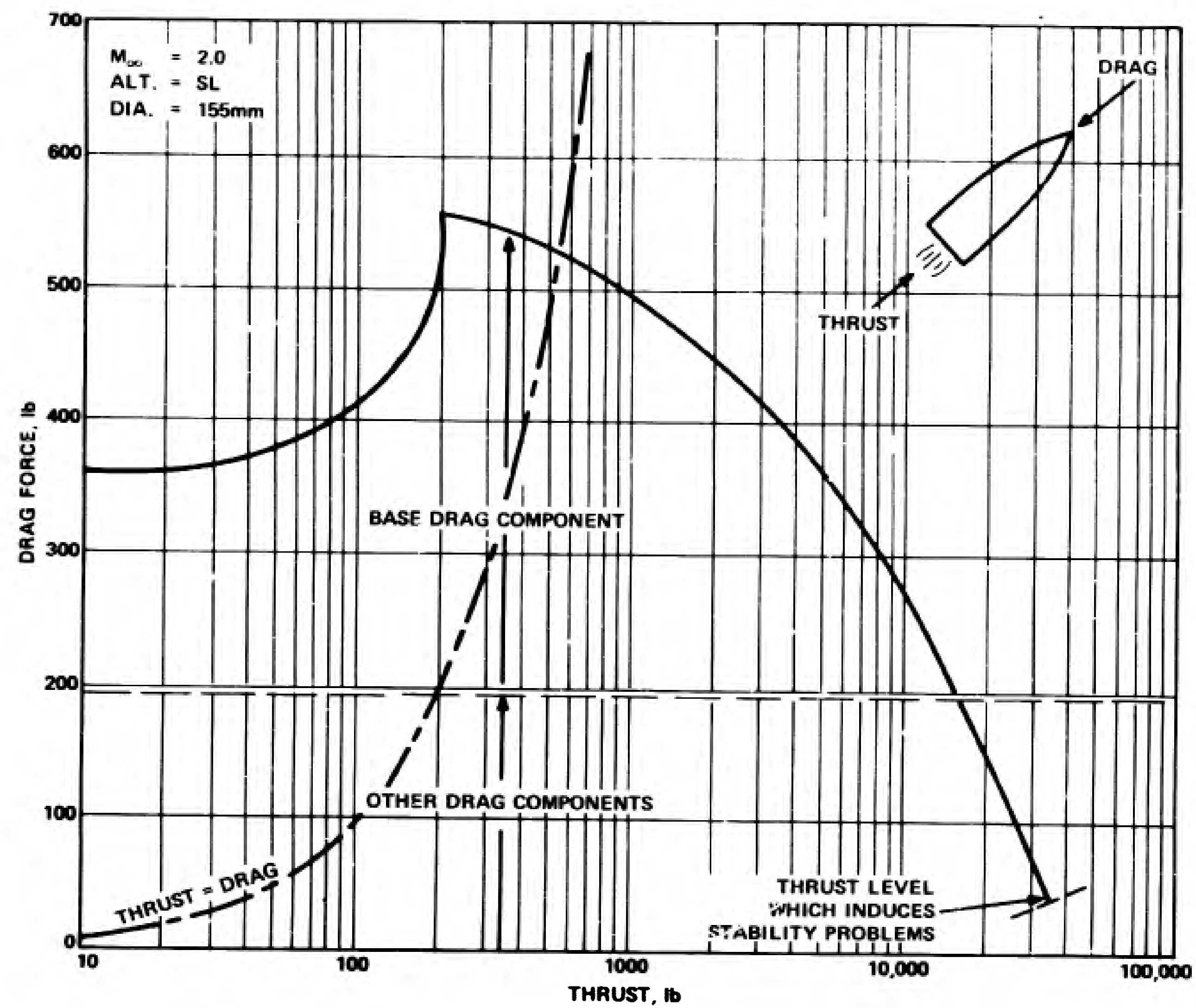

Fig. 6. Generalized Drag as a Function of Thrust

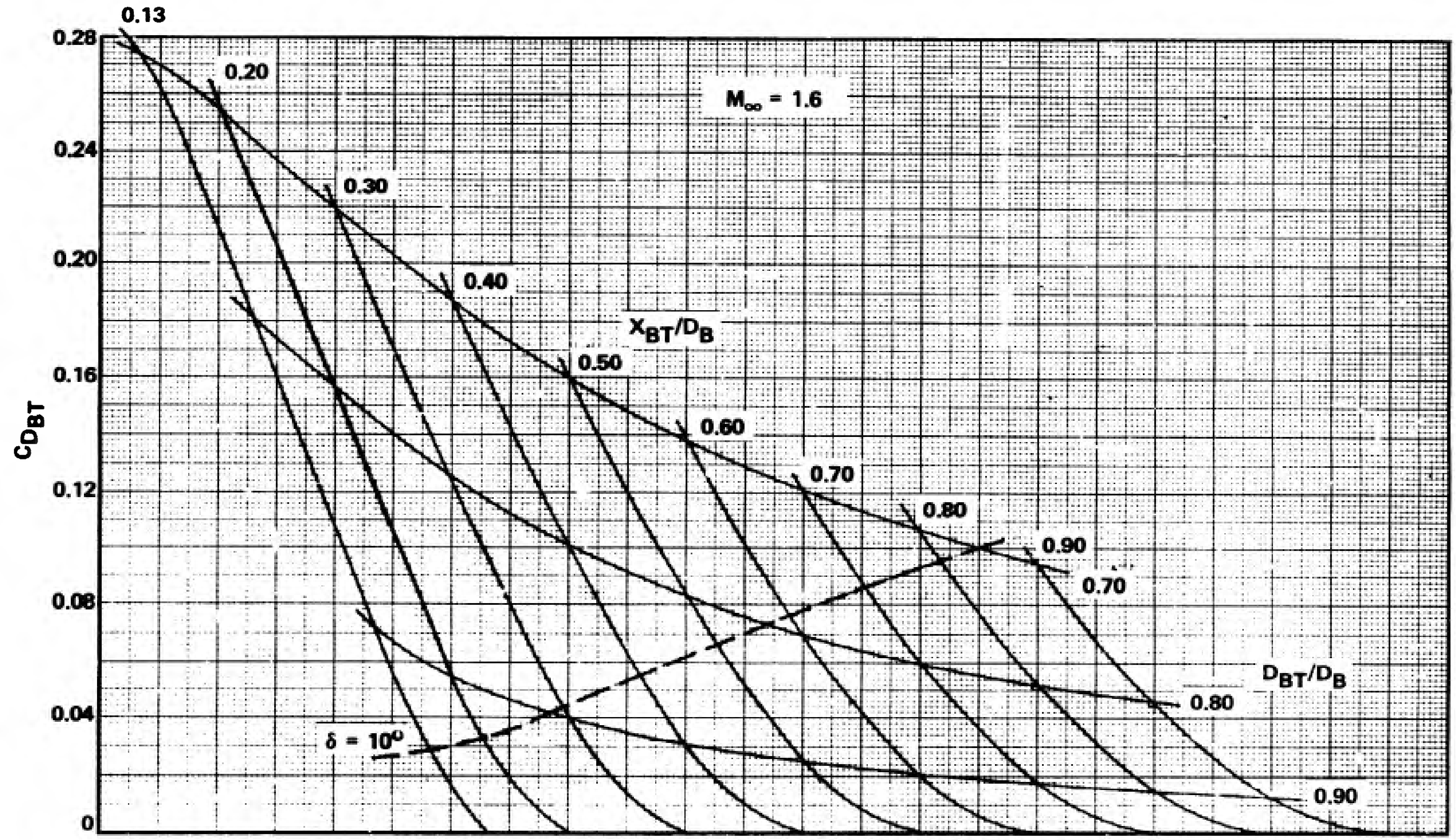

Fig. 7. Boattail Wave Drag ($M_\infty = 1.6$)

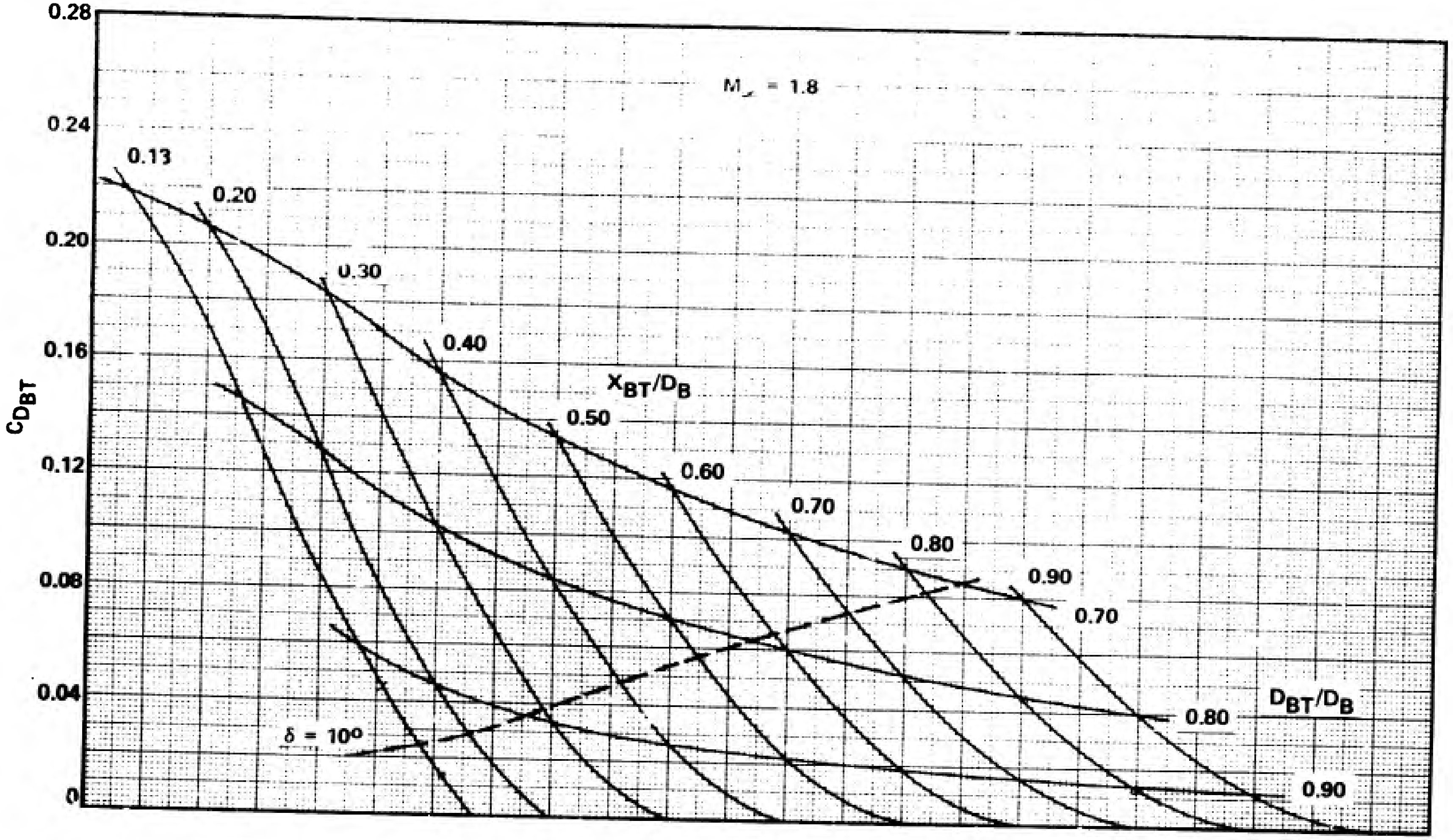

Fig. 8. Boattail Wave Drag (M_∞ = 1.8)

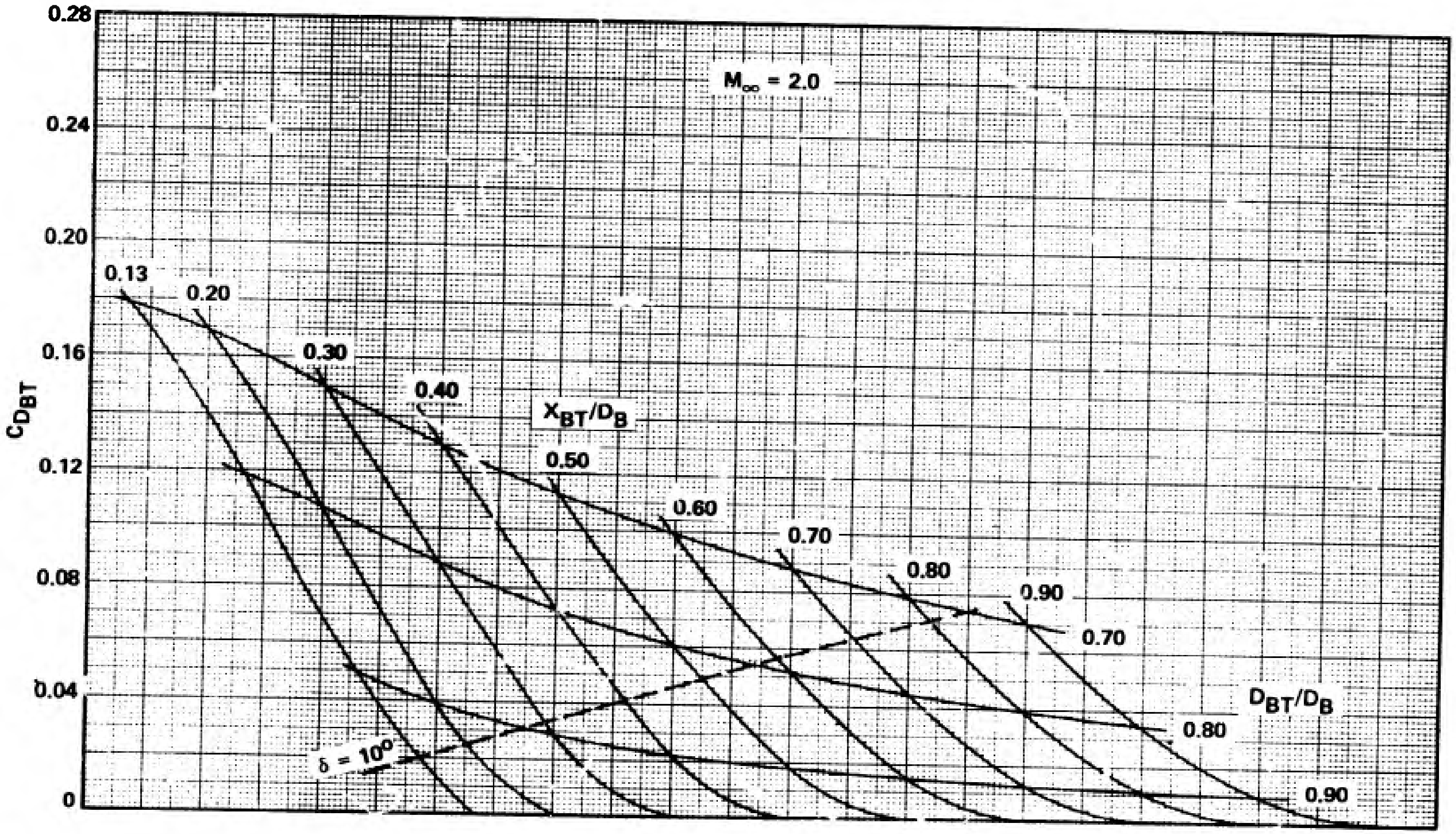

Fig. 9. Boattail Wave Drag ($M_{\infty} = 2.0$)

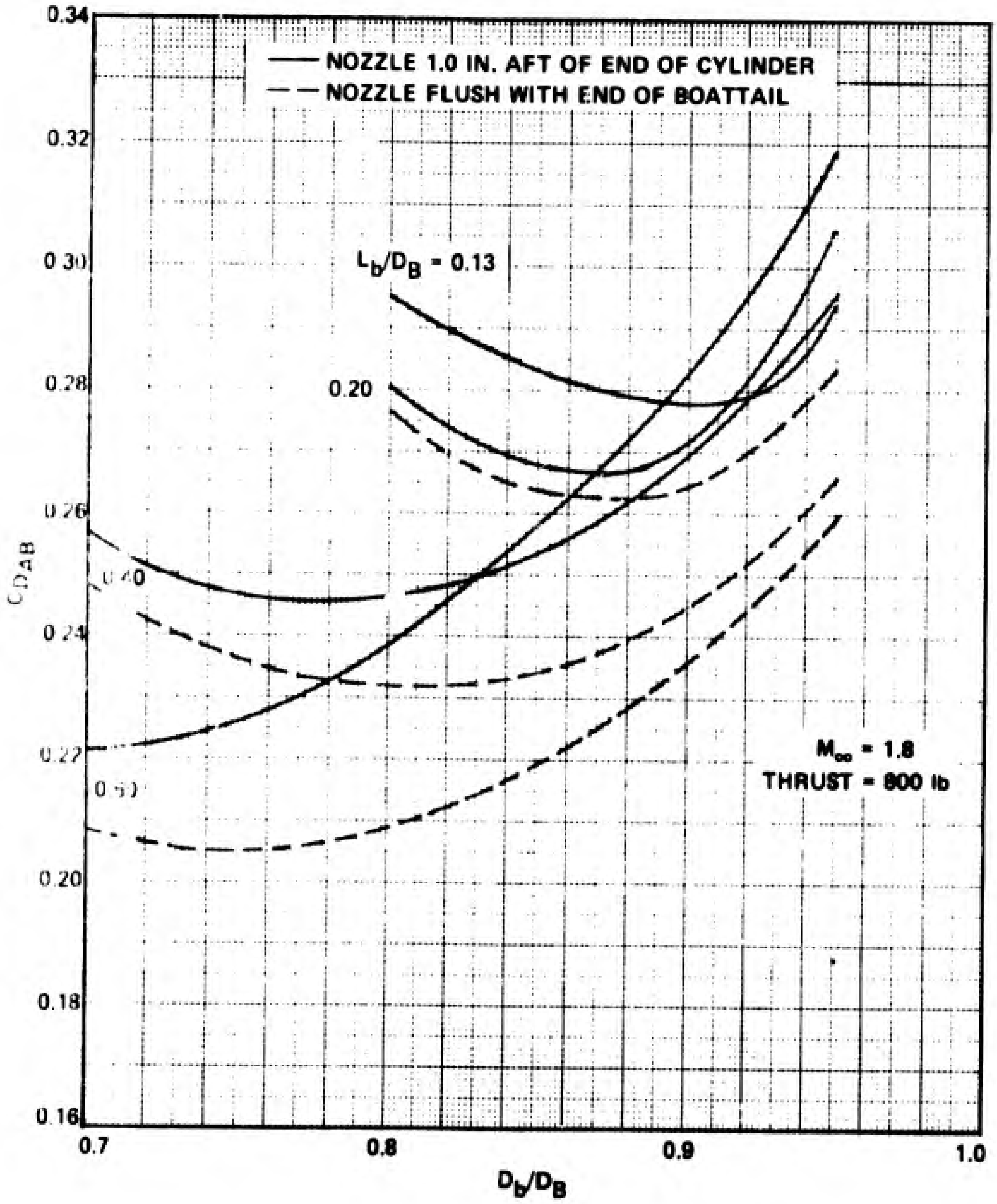

Fig. 10. Afterbody Drag for Parametric Variations
(M_∞ = 1.8; Thrust = 800 lb)

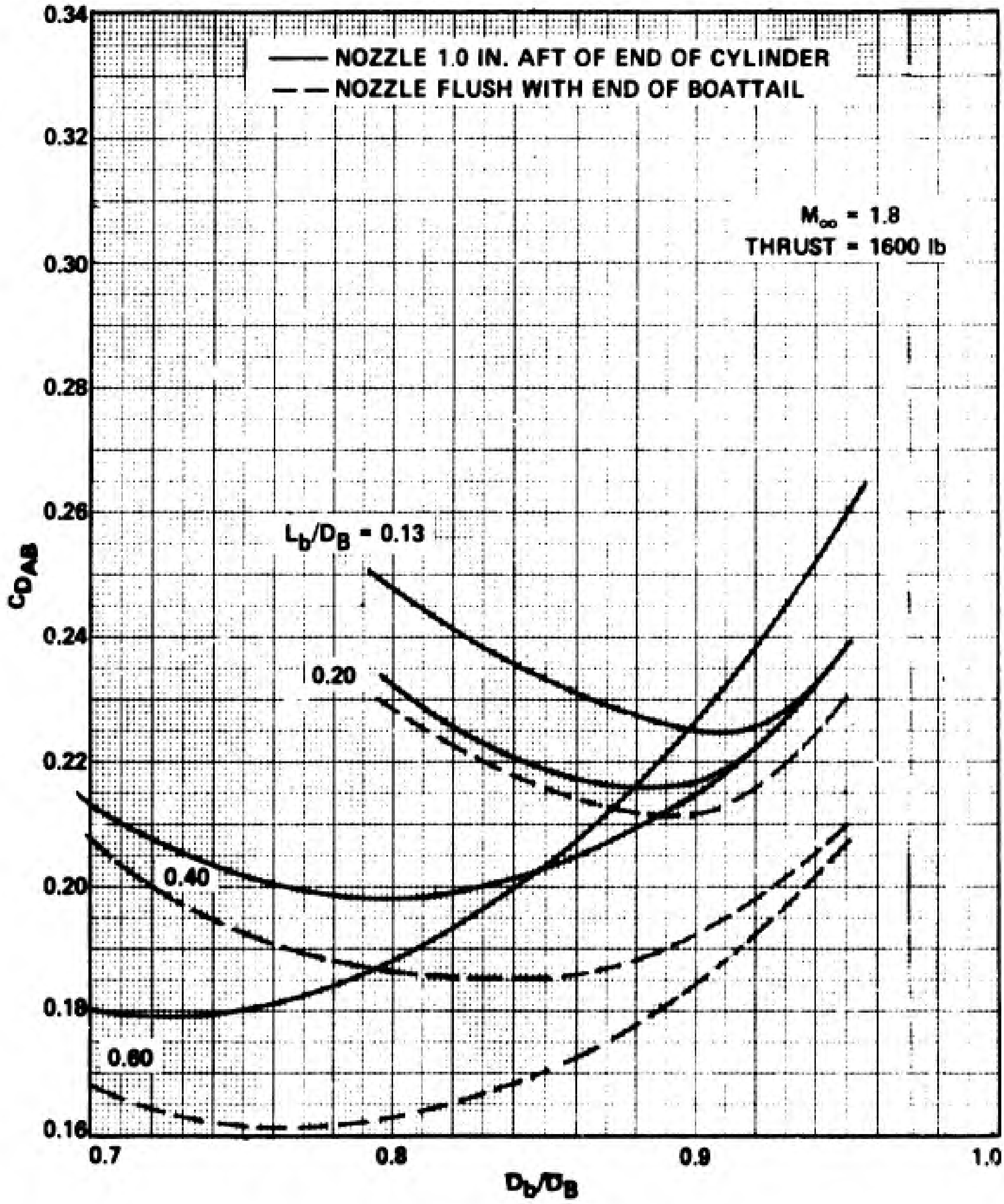

Fig. 11. Afterbody Drag for Parametric Variations
(M_∞ = 1.8; Thrust = 1600 lb)

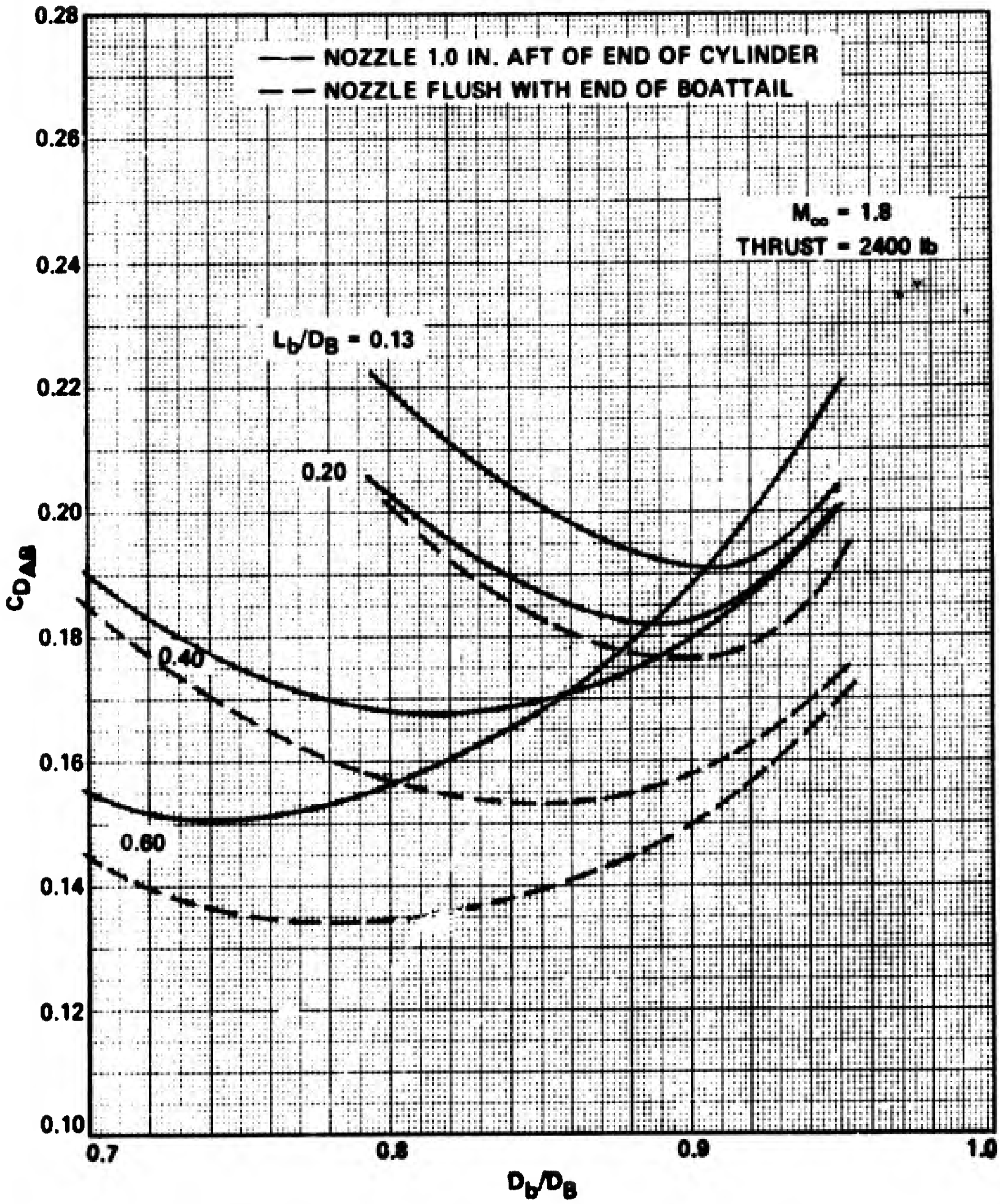

Fig. 12. Afterbody Drag for Parametric Variations (M_∞ = 1.8; Thrust = 2400 lb)

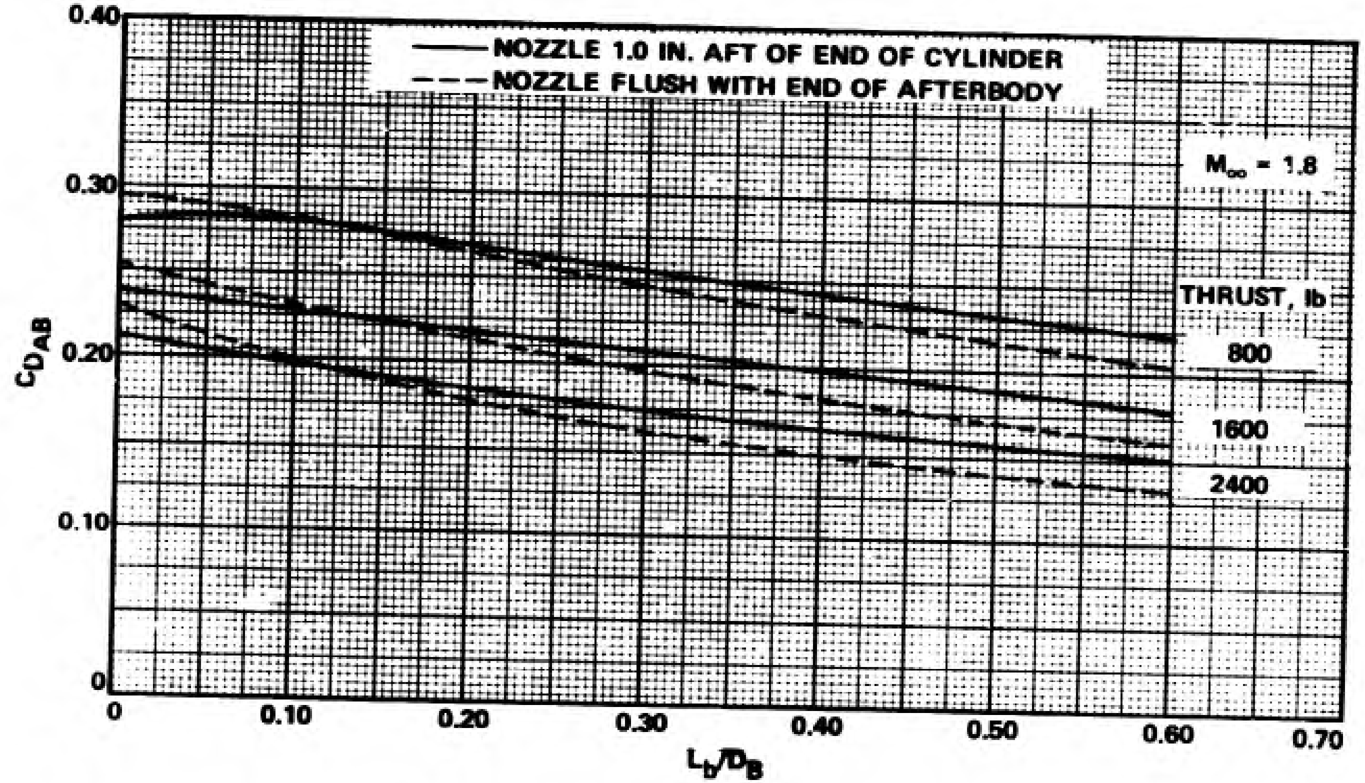

Fig. 13. Optimum Afterbody Drag

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Appendix

AFTERBODY DRAG CALCULATIONS FOR PARAMETRIC VARIATIONS

M_∞ = 1.8
Thrust = 791.3 lb
X_J = 1.0 in. and L_b from end of cylinder

L_b/D_B	D_b/D_B	$C_{D_{BT}}$	Flush P_b/P_∞	X_J $\Delta P_b/P_\infty$	P_b/P_∞	A_b/A_B	C_{D_b}	X_J = 1.0 $C_{D_{AB}}$	$X_J = L_b$ $C_{D_{AB}}$
0.1313	0.80	0.146	0.421	0	0.421	0.5815	0.149	0.295	0.295
	0.85	0.101	0.380	0	0.380	0.6640	0.182	0.283	0.283
	0.90	0.059	0.342	0	0.342	0.7515	0.218	0.277	0.277
	0.95	0.039	0.316	0	0.316	0.8440	0.255	0.294	0.294
0.2000	0.80	0.128	0.421	0.013	0.408	0.5815	0.152	0.280	0.277
	0.85	0.082	0.380	0.015	0.365	0.6640	0.186	0.268	0.264
	0.90	0.046	0.342	0.019	0.323	0.7515	0.224	0.270	0.264
	0.95	0.029	0.316	0.022	0.294	0.8440	0.278	0.307	0.284
0.4000	0.70	0.156	0.516	0.040	0.476	0.4315	0.0997	0.256	0.248
	0.75	0.117	0.467	0.046	0.421	0.5040	0.129	0.246	0.235
	0.80	0.084	0.421	0.053	0.368	0.5815	0.162	0.246	0.233
	0.85	0.052	0.380	0.068	0.312	0.6640	0.201	0.253	0.233
	0.90	0.026	0.342	0.076	0.266	0.7515	0.243	0.269	0.244
	0.95	0.009	0.316	0.085	0.231	0.8440	0.286	0.295	0.264
0.6000	0.70	0.116	0.516	0.074	0.442	0.4315	0.106	0.222	0.208
	0.75	0.086	0.467	0.087	0.380	0.5040	0.138	0.224	0.204
	0.80	0.063	0.421	0.110	0.311	0.5815	0.177	0.240	0.211
	0.85	0.037	0.380	0.124	0.256	0.6640	0.218	0.255	0.219
	0.90	0.018	0.342	0.139	0.203	0.7515	0.264	0.282	0.236
	0.95	0.005	0.316	0.155	0.161	0.8440	0.312	0.317	0.260

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M_∞ = 1.8
Thrust = 1600 lb
X_J = 1.0 in. and L_b from end of cylinder

L_b/D_B	D_b/D_B	$C_{D_{BT}}$	Flush P_b/P_∞	X_J $\Delta P_b/P_\infty$	P_b/P_∞	A_b/A_B	C_{D_b}	$X_J = 1.0$ $C_{D_{AB}}$	$X_J = L_b$ $C_{D_{AB}}$
0.1313	0.80	0.146	0.558	0	0.558	0.5230	0.102	0.248	0.248
	0.85	0.101	0.501	0	0.501	0.6055	0.133	0.234	0.234
	0.90	0.059	0.458	0	0.458	0.6930	0.166	0.225	0.225
	0.95	0.039	0.420	0	0.420	0.7855	0.201	0.240	0.240
0.2000	0.80	0.128	0.558	0.013		0.5230	0.105	0.233	0.230
	0.85	0.082	0.501	0.015		0.6055	0.137	0.219	0.215
	0.90	0.046	0.458	0.019		0.6930	0.171	0.217	0.212
	0.95	0.029	0.420	0.022		0.7855	0.209	0.238	0.230
0.4000	0.70	0.156	0.685	0.040		0.3730	0.058	0.214	0.208
	0.75	0.117	0.616	0.046		0.4455	0.085	0.202	0.192
	0.80	0.084	0.558	0.053		0.5230	0.114	0.198	0.186
	0.85	0.052	0.501	0.068		0.6055	0.151	0.203	0.185
	0.90	0.026	0.458	0.076		0.6930	0.189	0.215	0.192
	0.95	0.009	0.420	0.085		0.7855	0.230	0.239	0.210
0.6000	0.70	0.116	0.685	0.074		0.3730	0.064	0.180	0.168
	0.75	0.086	0.616	0.087		0.4455	0.093	0.179	0.161
	0.80	0.063	0.558	0.110		0.5230	0.127	0.190	0.165
	0.85	0.037	0.501	0.124		0.6055	0.166	0.203	0.170
	0.90	0.018	0.458	0.139		0.6930	0.208	0.226	0.184
	0.95	0.005	0.420	0.155		0.7855	0.255	0.260	0.206

M_∞ = 1.8

Thrust = 2400 lb

X_J = 1.0 in. and L_b from end of cylinder

L_b/D_B	D_b/D_B	$C_{D_{BT}}$	Flush P_b/P_∞	X_J $\Delta P_b/P_\infty$	P_b/P_∞	A_b/A_B	C_{D_b}	X_J = 1.0 $C_{D_{AB}}$	$X_J = L_b$ $C_{D_{AB}}$
0.1313	0.80	0.146	0.645	0	0.645	0.4645	0.073	0.219	0.219
	0.85	0.101	0.579	0	0.579	0.5470	0.102	0.203	0.203
	0.90	0.059	0.530	0	0.530	0.6345	0.132	0.190	0.190
	0.95	0.039	0.485	0	0.485	0.7270	0.165	0.204	0.204
0.2000	0.80	0.128	0.645	0.013		0.4645	0.075	0.203	0.201
	0.85	0.082	0.579	0.015		0.5470	0.105	0.187	0.184
	0.90	0.046	0.530	0.019		0.6345	0.137	0.183	0.177
	0.95	0.029	0.485	0.022		0.7270	0.172	0.201	0.194
0.4000	0.70	0.156	0.792	0.040		0.3145	0.034	0.190	0.185
	0.75	0.117	0.712	0.046		0.3870	0.057	0.174	0.166
	0.80	0.084	0.645	0.053		0.4645	0.084	0.168	0.157
	0.85	0.052	0.579	0.068		0.5470	0.118	0.170	0.154
	0.90	0.026	0.530	0.076		0.6345	0.153	0.179	0.157
	0.95	0.009	0.485	0.085		0.7270	0.192	0.201	0.174
0.6000	0.70	0.116	0.792	0.07		0.3145	0.039	0.155	0.145
	0.75	0.086	0.712	0.087		0.3870	0.064	0.150	0.135
	0.80	0.063	0.645	0.110		0.4645	0.095	0.158	0.136
	0.85	0.037	0.579	0.124		0.5470	0.131	0.168	0.139
	0.90	0.018	0.530	0.139		0.6345	0.170	0.188	0.149
	0.95	0.005	0.485	0.155		0.7270	0.215	0.220	0.170

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13. ABSTRACT

Power-on base drag values estimated for an existing rocket-assisted projectile (RAP) show that a major portion of the rocket impulse is expended in overcoming drag rather than in extending the range of the projectile. A parametric study of the effects of thrust level, afterbody geometry, and nozzle position on power-on base drag shows that the losses due to drag can be significantly decreased.

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