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PROCEDURE FOR ESTIMATING ZERO YAW DRAG COEFFICIENT FOR LONG ROD PROJECTILES AT MACH NUMBERS FROM 2 TO 5

William F. Donovan
Bertram B. Grollman

March 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Procedures for estimating the drag coefficient of either finned or flared projectiles are presented for application in the Mach range from 2 to 5. The techniques are based on linearizations of curves and simplifications of analyses as extracted from AMC Pamphlet 706-280.

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LIST OF SYMBOLS

$A_{base\ body}$	Area of body exposed to base pressure $(cal)^2$
$A_{base\ fin}$	Area of fin exposed to base pressure $(cal)^2$
A_{ref}	Reference area (.785 cal^2)
$A_{wetted\ surface}$	Area of particular surface assigned viscous flow drag (cal^2)
C_D	Total drag coefficient (Reference Symbol) = $\frac{2D}{\rho v^2 A_{ref}}$
C_{DBB}	Pressure drag coefficient - base of body
C_{DBF}	Pressure drag coefficient - base of fins
C_{DT}	Total drag coefficient
C_{DTB}	Total body drag coefficient
C_{DTF}	Total fin drag coefficient
C_{DVB}	Viscous drag coefficient - body
$C_{DV(B+F)}$	Viscous drag coefficient - body & flare
C_{DWB}	Wave drag coefficient - body (nose)
C_{DWF}	Wave drag coefficient - flare or fin
Δ_{DB}	Interference drag coefficient
$C_{F'}$	Skin friction factor for flat plate viscous flow
$C_{F''}$	Empirical constant
$C_{F'''}$	Conversion factor between flat plate and cylindrical viscous flow
D	Drag Force
M	Mach number
Re	Reynolds number

c	Chord length of base fin (cal)
d	Representative diameter of cylindrical reference area (1.0 cal)
d_b	Base flare dia. (cal)
h	Span of fin (cal)
j	Length of leading edge of fin (cal)
ℓ_{ab}	Length of after body of projectile (cal)
ℓ_f	Axial length of flare (cal)
ℓ_n	Axial length of projectile nose (cal)
ℓ_{sn}	Slant height of projectile nose (cal)
ℓ_{sf}	Slant height of flare (cal)
n	Number of blades per fin assembly
t	Representative fin thickness (cal)
v	Projectile velocity (length/time)
β	Thermodynamic parameter $(M^2 - 1)^{1/2}$
θ	Flare half angle (rad in calculations and degrees on reference charts)
ρ	Ambient air density (mass/unit volume)

I. INTRODUCTION

The preliminary design of projectiles must include a determination of drag coefficient in order to establish the retardation which is required to estimate the velocity of the projectile at the target. In lieu of range test results defining a particular configuration, the appropriate values are calculated. Predictive calculating schedules include BRLESC computer codes[1] and tabulations[2]; wherein, the retarding forces acting on the projectile are composed as wave drag, viscous drag and base (pressure) drag. Reference 1 is derived in rigorous mathematical expression to model the forward fluid flow but is limited to axisymmetric bodies of revolution. Reference 2 requires extensive use of selected charts which are geometrically restrictive in application.

This report presents a simplified technique for estimating the component drag in algebraic expression. Drag coefficients for both finned and flared projectiles are calculated and the results compared with aerodynamic range test data[3].

II. PROCEDURE

Figure 1-a is a schematic of a long rod projectile with a fin empennage and Figure 1-b a projectile with a flare. Figures 2-a and 2-b define the common nomenclature.

Considering the body drag:

1. The wave drag coefficient is given as

$$C_{DWB} = .7M^{-.28}\ell_n^{-1.73}$$

directly from Figure 8-29 of Reference 2 and reproduced as Figure B-1 of Appendix B. Both conical and ogival noses are described adequately by this equation with divergence occurring only where there is a combination of short nose length and high Mach number. The expression applies to both the finned and the flared projectiles for the Mach range M>.8.

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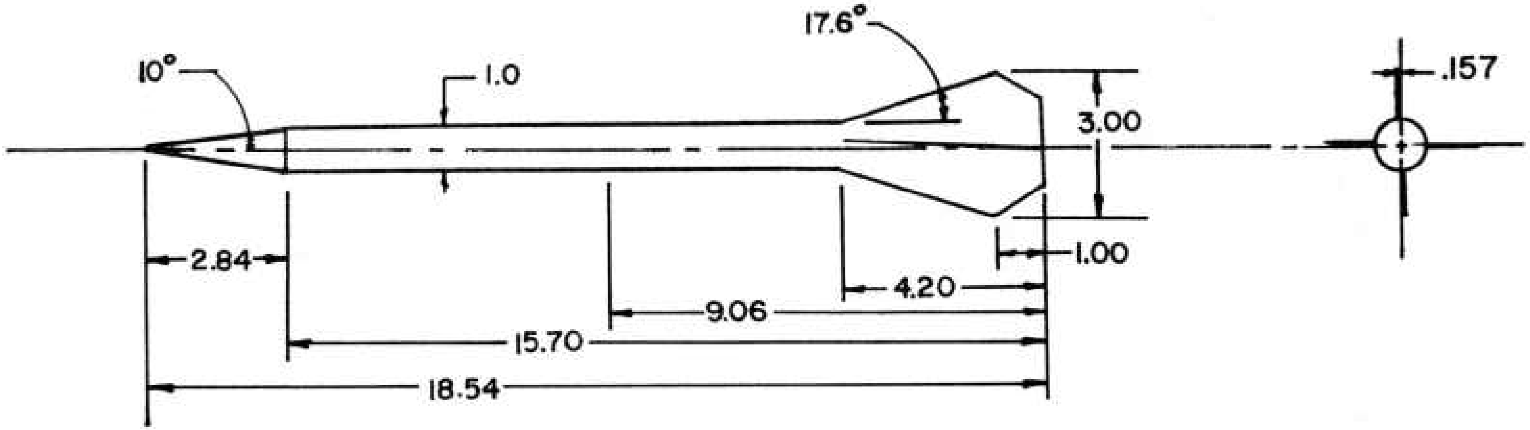
1. *Robert L. McCoy, "MACDRAG" BRLESC computer program.*

2. *AMCP 706-280, "Design of Aerodynamically Stabilized Free Rockets", 1968.*

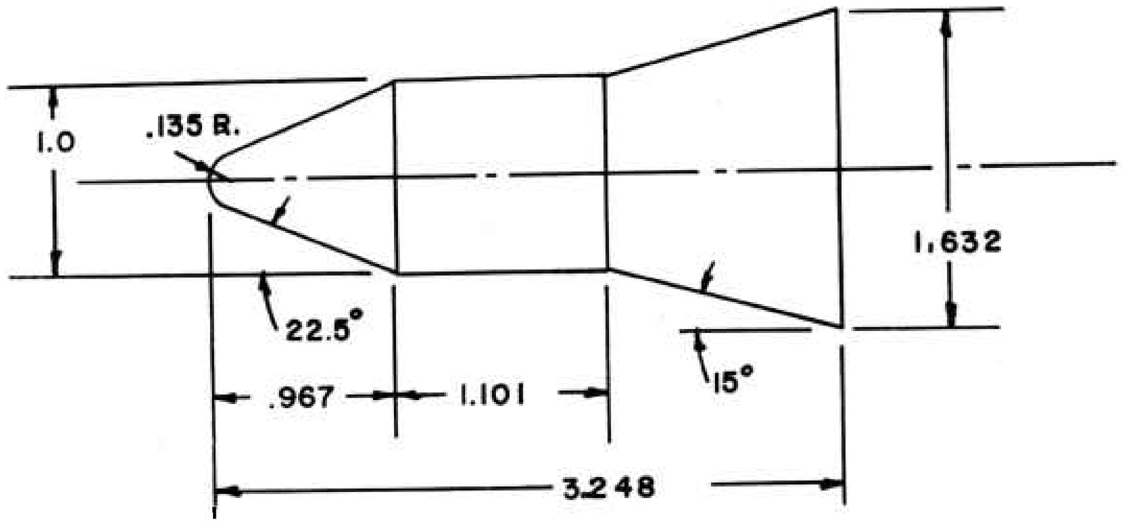
3. *Walter F. Braun, "Aerodynamic Data for Small Arms Projectiles," BRL Report 1630, January 1973, p. 187-188. (AD #909757L)*



— DIMENSIONS IN CALIBERS

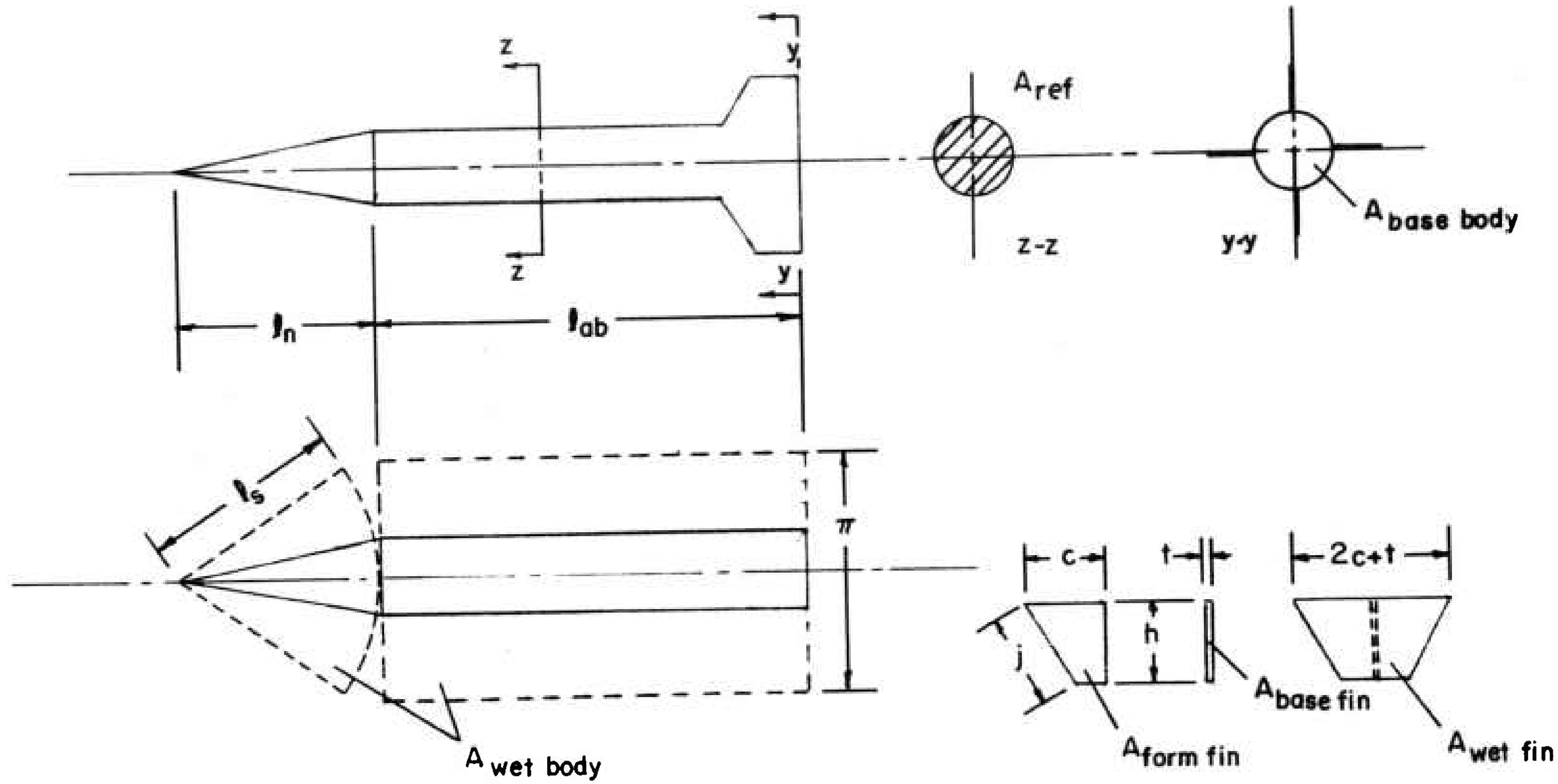
— FLIGHT MODEL FIN HAS REFLEX CURVED
LEADING EDGE AND ROUNDED CORNERS

Figure 1-a APFSDS Projectile



DIMENSIONS IN CALIBERS

Figure 1-b Outline Sketch of Flared Projectile



C_{DT} ~ Total drag coefficient

C_{DXX}
- Location: B Body, F Fin
- Type: W Wave, V Viscous, B Base
- Drag Coefficient

ΔC_{DB} ~ Interference coefficient

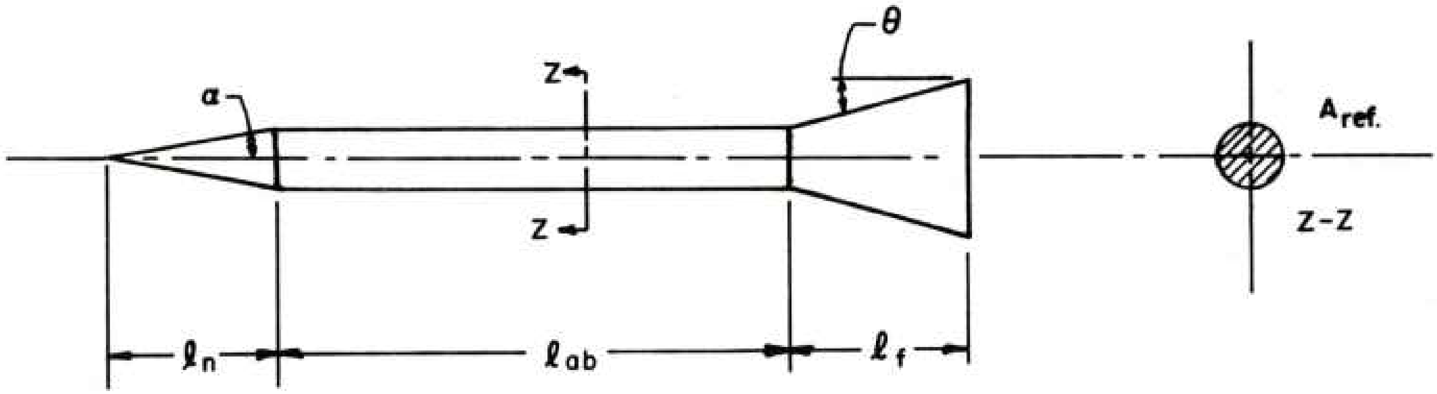
n = number of fins

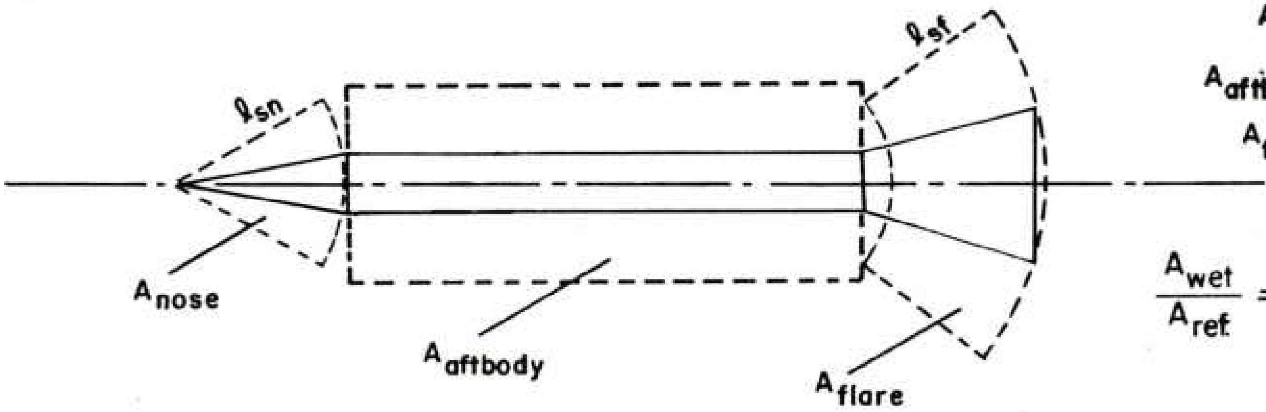
Re ~ Reynolds number

M ~ Mach number

$\beta = (M^2-1)^{1/2}$

Figure 2-a Nomenclature Specification for Finned Projectile





$$A_{nose} = .5\pi \, \ell_n \sec \alpha$$

$$A_{aftbody} = \pi \, \ell_{ab}$$

$$A_{flare} = \pi \, \ell_f \sec \theta (1 + \ell_f \tan \theta)$$

$$\frac{A_{wet}}{A_{ref}} = 2\ell_n \sec \alpha + 4\ell_{ab} + 4\ell_f \sec \theta (1 + \ell_f \tan \theta)$$

Wetted Areas

Figure 2-b. Nomenclature Specification for Flared Projectile

2. The base drag is deduced from a linearization of Figure 8-41, Reference 2, modified to Figure B-2 of Appendix B. This takes the form

$$C_{DBB} = (-.048M + .265)\ e^{.6\Theta}\ d_b^2$$

where the factor $e^{.6\Theta}$ converts the flare half-angle data to an approximation of the linearized characteristic.

Note that a tapered afterbody on finned projectile presents special difficulties in estimating base drag and Reference 2 does consider such projectiles. However, this requires an assumption that the expanding flow from a fenced channel (a cornered lattice) is equivalent to flow around an unbounded two dimensional corner. Efforts to validate this assumption by either calculation or by aerodynamic range data have been unavailing. In this report the maximum fin hub diameter is taken to identify the base drag area for the finned application.

3. The viscous drag coefficient is obtained from a combination of Figures 8-39 and 8-40 of Reference 2, converted to Figure B-3 of Appendix B. $C_F'=f(M)$ is the flat plate friction factor, an empirical constant, ($C_F''=1.51$) is established by comparison with Reference 1, and a multiplier ($C_F''' = 1.15$) transposes the classical flat plate coefficients[4] to cylindrical application.

$$C_{DV(B+F)} = C_F'\ C_F''\ C_F'''\ \frac{A_{\text{wetted surface}}}{A_{\text{ref}}}$$

$$= 10^{-4}\ (28.75 - 4.166\ M)(1.51)(1.15)\ \frac{A_{\text{wetted surface}}}{A_{\text{ref}}}$$

$$= 0.000173\ (28.75 - 4.166\ M)\ \frac{A_{\text{wetted surface}}}{A_{\text{ref}}}$$

The drag effect of the driving grooves is assumed as part of the empirical constant C_F''.

The $A_{\text{wetted surface}}$ includes the conical flare surface, Figure 2-b, for the flared projectile. For the finned projectile, the fin viscous drag is separately determined.

4. *L. Michael Freeman, Robert H. Korkegi, "Projectile Aft-Body Drag Reduction by Combined Boat-Tailing and Base Blowing," AFAPI-TR-75-111, February 1976.*

4. A wave drag contribution, emanating from a shock at the body-flare junction, is given in Reference 2 as Figure 8-33, and as Figure B-4 in Appendix B, whereby

$$C_{DWF} = \frac{3\Theta}{M}\left(.75 - \frac{.6}{d_b}\right)$$

The $\frac{.6}{d_b}$ term approximates the compressed curves.

5. Considering the fin drag:

A. The wave drag coefficient for the fins is suggested by Reference 5 and is recommended for fins with a single bevel leading edge.

$$C_{DWF} = \frac{n}{\beta}\left(\frac{t}{j}\right)^2 \frac{A_{wetted\ fin}}{A_{ref}}$$

B. The fin base drag refers to the axial drag at the fin trailing edge. An area ratio with the body base area determines this quantity.

$$C_{DBF} = \frac{A_{base\ fin}}{A_{base\ body}} C_{DBB}$$

This report considers that the full thickness fin area represents the drag cross section. This is a conservative assumption. Also, some effects on drag coefficient may result from fin-body interference flow in the base region. This is given[5] by

$$\Delta C_{DB} = \frac{t}{c}\left(\frac{.825}{M^2} - \frac{.05}{M}\right)(n)\frac{A_{base\ fin}}{A_{base\ body}}$$

C. The fin viscous drag is taken as the area ratio of the respective wetted surfaces of the fin and body as modified by the flat plate cylinder correlation coefficient.

$$C_{DVF} = \frac{1}{1.15}\frac{A_{wetted\ fin}}{A_{wetted\ body}} C_{DVB}$$

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5. *Sighard F. Hoerner, Dr. Ing, Fluid Dynamic Drag, Published by the author, 1958.*

6. The total zero yaw drag coefficient is then equal to that of the sum of the parts.

III. RESULTS

Figures 3-a and 3-b show the results of the calculating procedures for a typical finned and an atypical flared projectile. Correspondence with range test data appears satisfactory.

IV. CONCLUSIONS

The modifications of the calculating scheme and the reference data of AMC Pamphlet 706-280 to predict zero yaw drag coefficient in the Mach range from 2 to 5 is demonstrated. The technique is to simply linearize the region of interest. Agreement with available test data[3,6] indicates that the procedure warrants employment in preliminary estimating or in screening analyses.

6. *Eugene D. Boyer, "Free Flight Range Tests of a MINUTEMAN Re-Entry Stage Model", BRL MR 1346, May 1961 (AD 326744).*

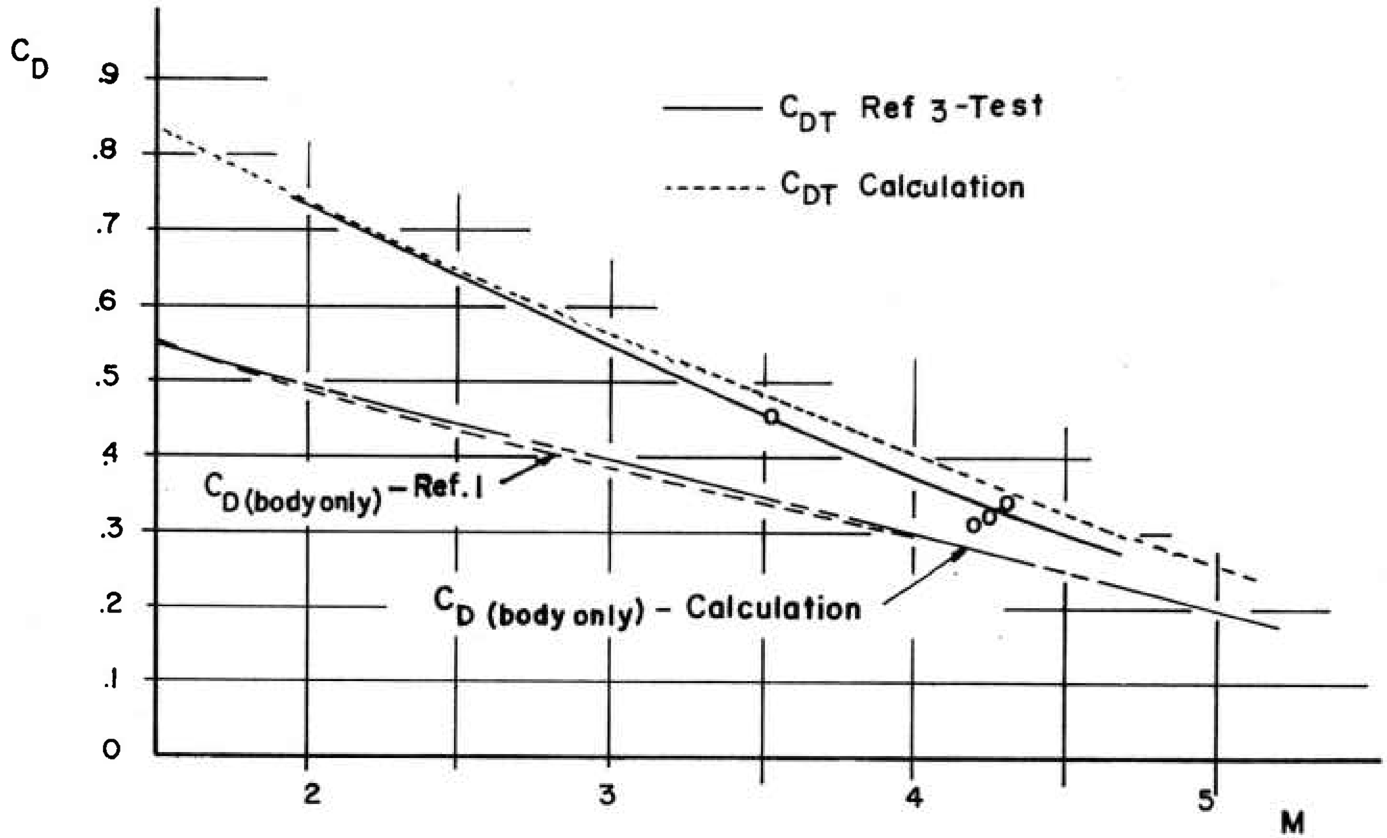

Figure 3-a Drag Coefficient Comparison, Finned Projectile

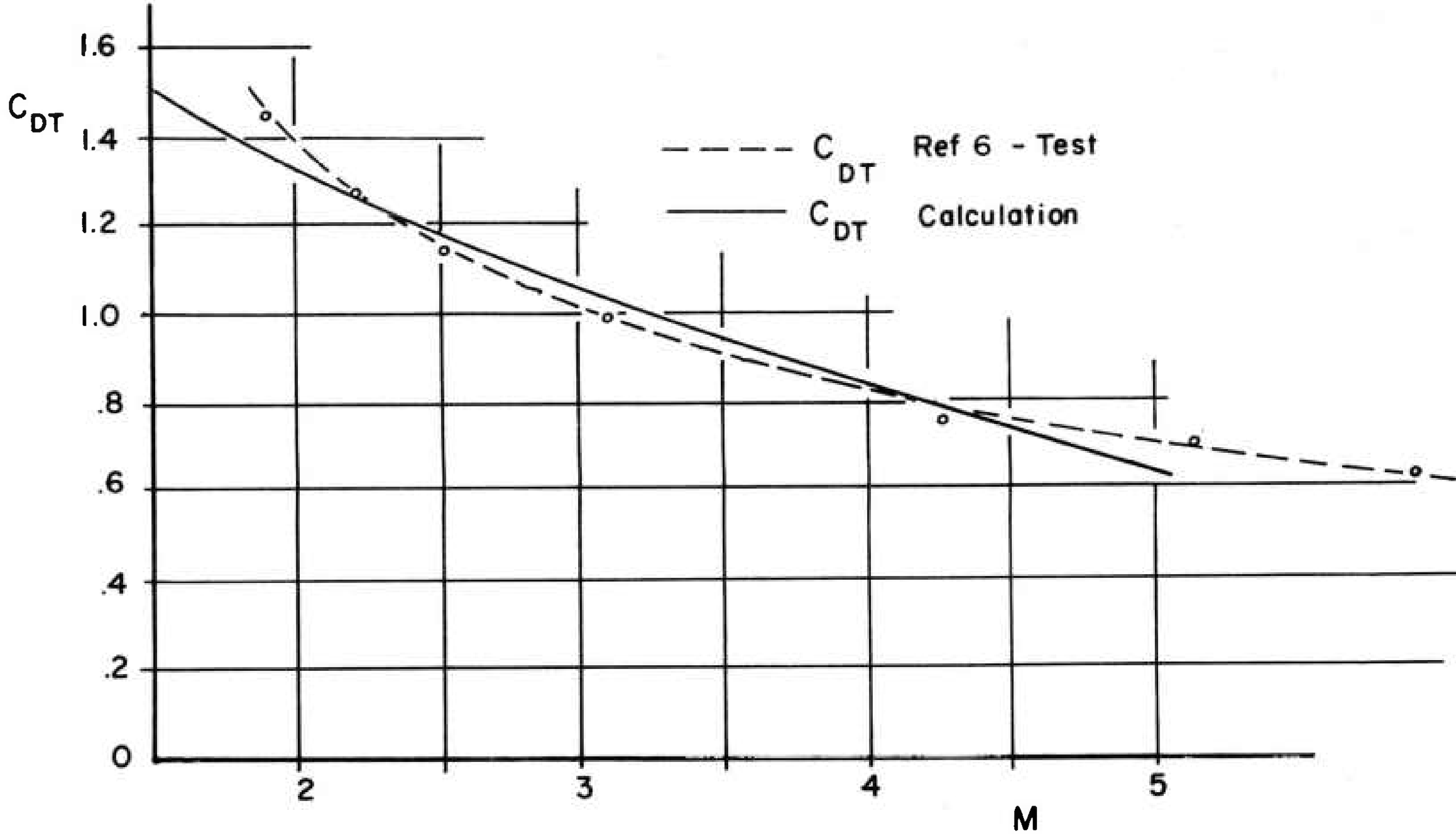

Figure 3-b Drag Coefficient Comparison - Flared Projectile

REFERENCES

1. Robert L. McCoy, "MACDRAG" BRLESC computer program.

2. AMCP 706-280, "Design of Aerodynamically Stabilized Free Rockets", 1968.

3. Walter F. Braun, "Aerodynamic Data for Small Arms Projectiles," BRL Report 1630, January 1973, p. 187-188. (AD #909757L)

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6. Eugene D. Boyer, "Free Flight Range Tests of a MINUTEMAN Re-Entry Stage Model", BRL MR 1346, May 1961 (AD 326744).

APPENDIX A

	BODY GEOMETRY										FIN GEOMETRY							
COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SYMBOL	ℓ_n	ℓ_{ab}	α	ℓ_s	A_{ref}	A_{wet}	θ		d	A_{wet}	c	t	j	h	n	A_{form}	A_{wet}	A_{base}
UNITS	cal	cal	rad	cal	cal^2	cal^2	rad		cal	cal^2	cal	cal	cal	cal		cal^2	cal^2	cal^2
	nose length	afterbody length	nose half angle	nose slant height, $\ell_n \sec \alpha$	reference area, $\pi/4$	wetted surface area, $\pi(.5\ell_s + \ell_{ab})$	half angle of flare		diameter of base of body	wetted surface area, $\pi(.5\ell_s + \ell_{ab})$	length of fin chord at root	trailing edge fin thickness	length of fin leading edge	length of fin half span	number of blades per fin assembly	planform area of fin blade	wetted surface area of fin blade	base area of fin blade
FLECHETTE	2.84	15.7	.175	2.88	.785	53.9				53.9	4.2	.157	3.38	1.0	4	2.6	5.2	.157

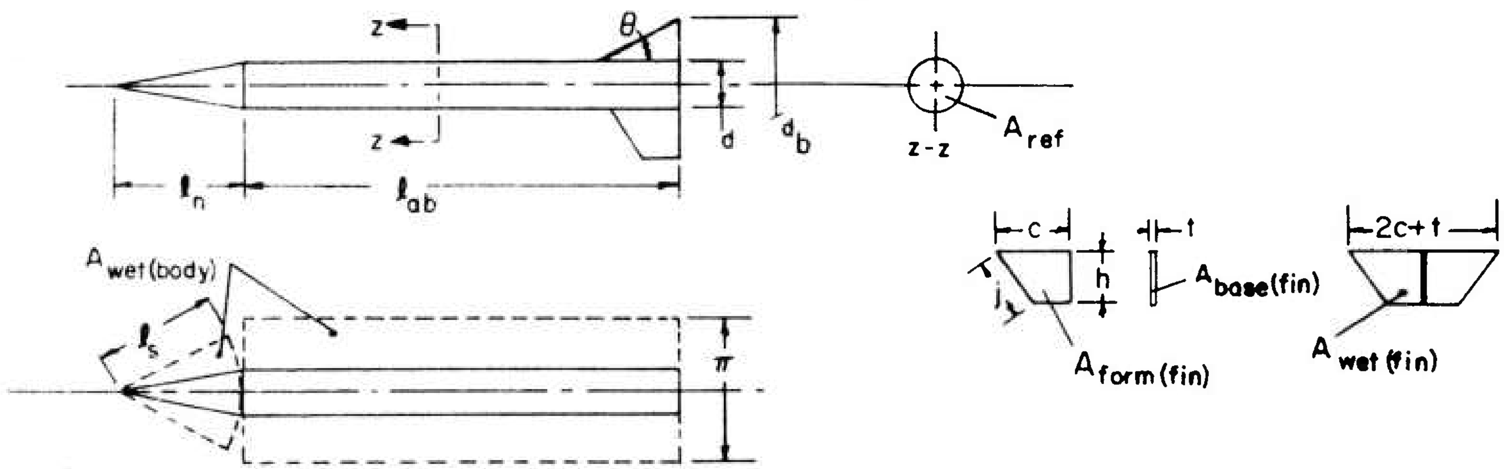

Figure A-1. Calculating Table for Flechette - Input Parameters

BODY/FLARE GEOMETRY										
COLUMN	1	2	3	4	5	6	7	8	9	10
SYMBOL	ℓ_n	ℓ_{ab}	α	ℓ_{sn}	$A_{ref.}$	ℓ_f	θ	ℓ_{sf}	d_b	A_{wet}
UNITS	cal	cal	rad	cal	cal^2	cal	rad	cal	cal	cal^2
	nose length	afterbody length	nose half angle	nose slant height, $\ell_n \sec\alpha$	reference area, $\pi/4$	flare length	flare half angle	flare slant height $\ell_f \sec\theta$	diameter of base of flare	wetted surface area $\pi(.5\ell_n \sec\alpha + \ell_{ab} + \ell_f \sec\theta(1+\ell_f \tan\theta))$
MINUTEMAN	.967	1.101	.393	1.047	.785	1.180	.262	1.220	1.632	10.156

Figure A-2 Calculating Table for Minuteman - Input Parameters

APPENDIX B

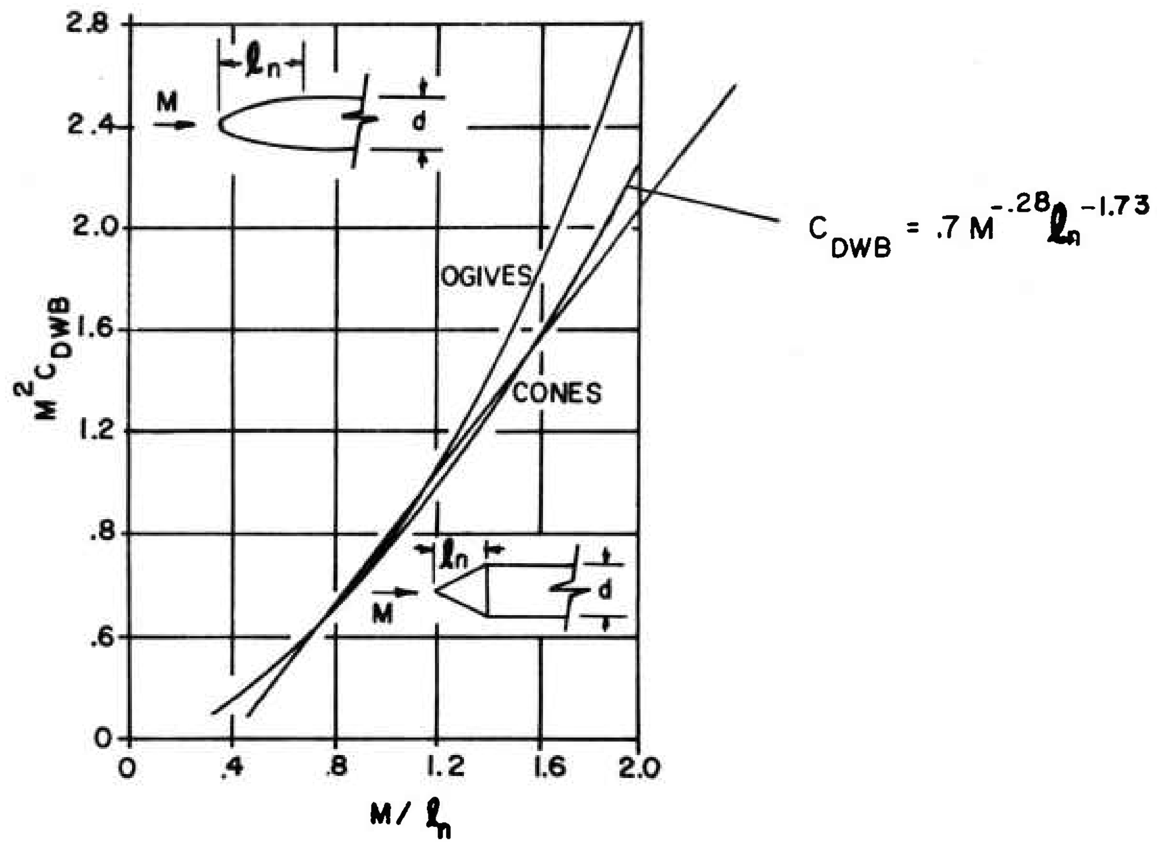

Figure B-1. Nose Wave Drag Coefficient

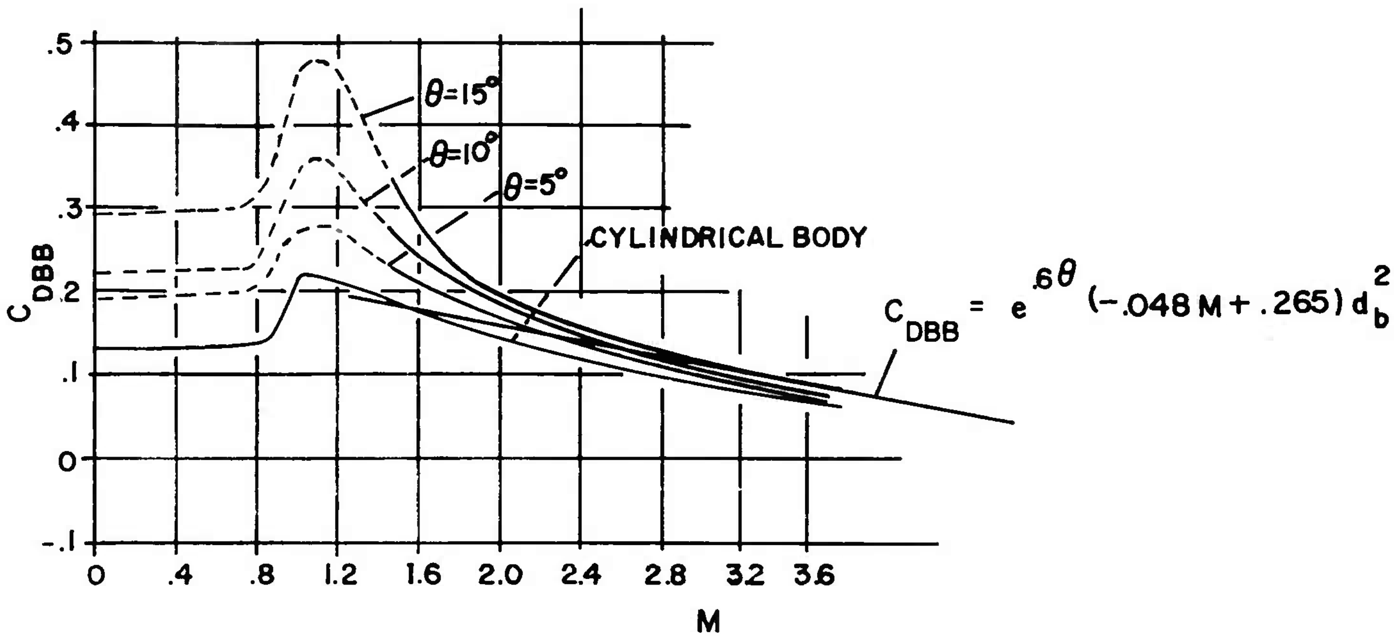

Figure B-2. Base Drag Coefficient

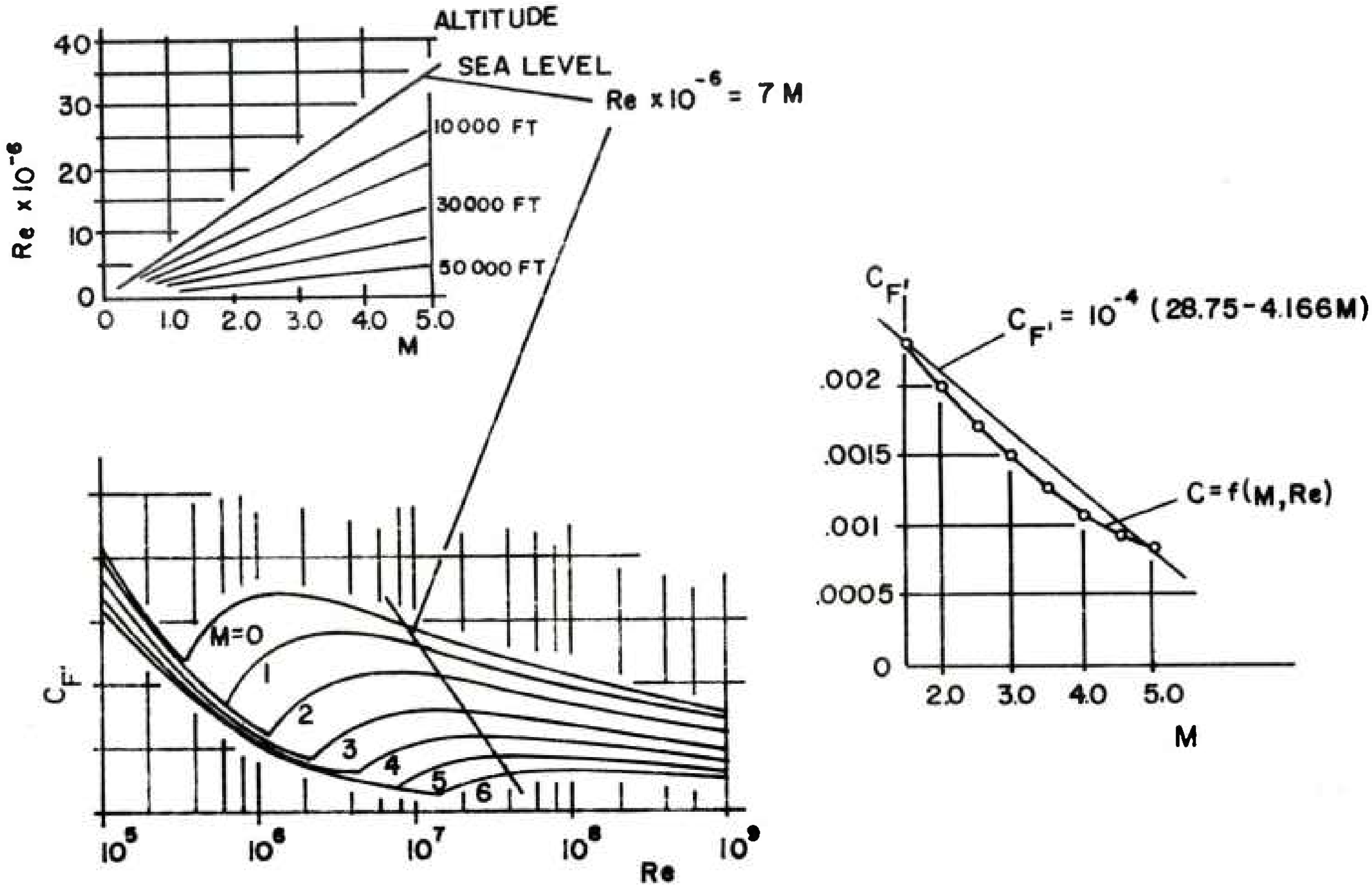

Figure B-3. Conversion of M-$C_{F'}$

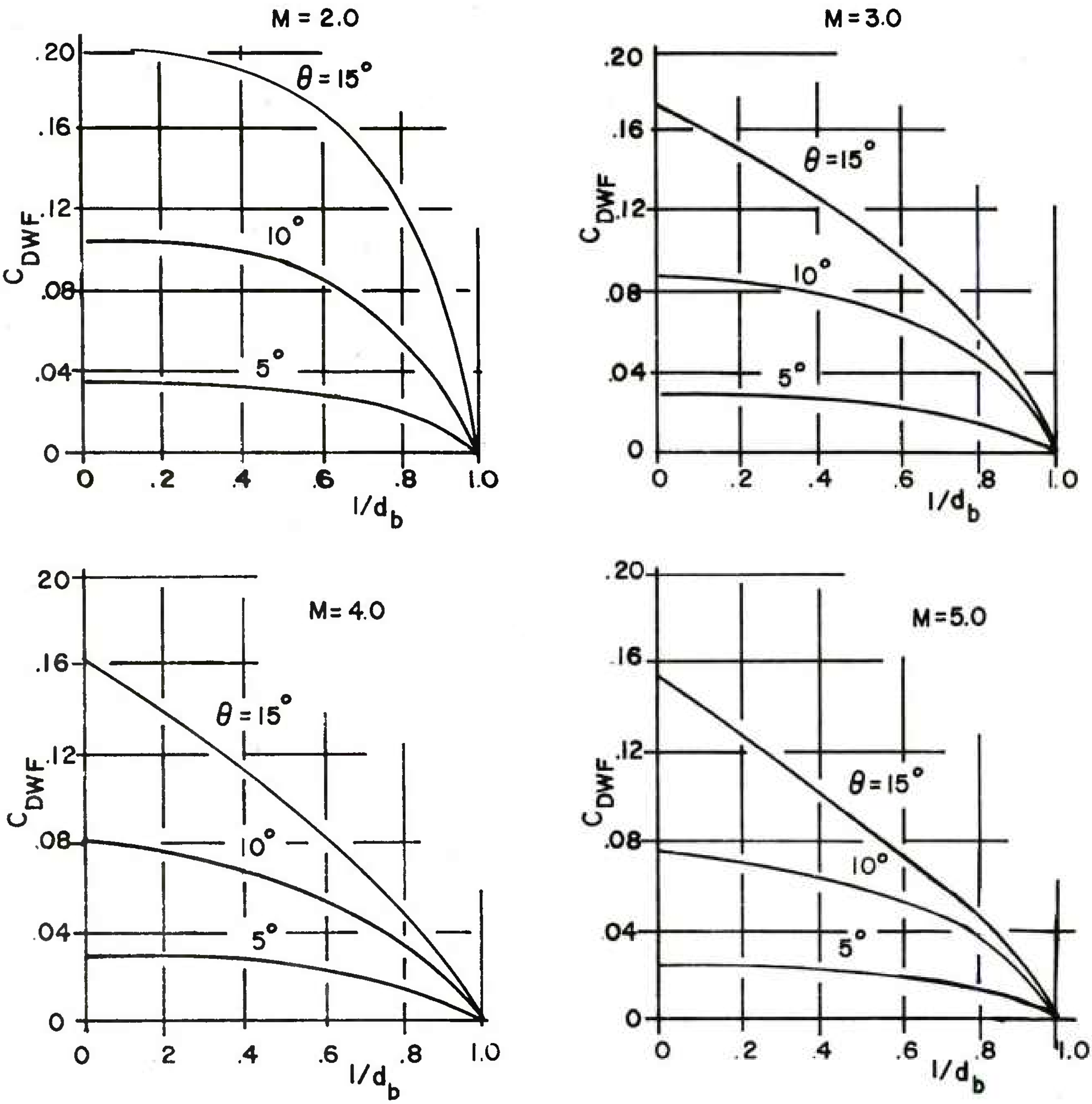

Figure B-4. Flare Wave Drag Coefficient

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