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MEMORANDUM REPORT ARBRL-MR-03041

HYPOTHETICAL ZERO YAW DRAG
COEFFICIENT OF KINETIC ENERGY
PROJECTILES BETWEEN $M = 5$ and $M = 10$

William F. Donovan

August 1980



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

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-03041	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HYPOTHETICAL ZERO YAW DRAG COEFFICIENT OF KINETIC ENERGY PROJECTILES BETWEEN $M = 5$ and $M = 10$		5. TYPE OF REPORT & PERIOD COVERED Memorandum Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William F. Donovan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLP Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research & Development Command U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE August 1980
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Drag coefficient Kinetic Energy projectile Hypersonic flow Retardation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) jmk From a review of existing techniques and extrapolation of lower velocity data, the drag characteristics of a typical kinetic energy projectile are proposed for application in the range $5 < M < 10$.		

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I. INTRODUCTION

In the particular kinetic energy branch of the field of tank warfare, various improvements in the kinetic energy projectile; e.g. higher length/diameter ratios, monolithic construction and classified materials, compete with corresponding vehicle defensive improvements such as tipping screens, spaced heavy armor and equally classified materials.

It is obvious that the gun-launched kinetic energy projectile can be most efficiently employed in velocity regimes higher than those currently encountered in practice; but neither empirical data nor rigorous analytical technique is immediately available to exploit such potential. This report examines the free flight drag in the velocity region between Mach 5 and Mach 10 in conventional representation as composed from wave, viscous and base contributions analogous to the treatment of Reference 1. The procedure is essentially algebraic and the results are listed in tabulation. Transcription to desk calculator form is presented as an appendix.

II. PROCEDURE

Figure 1 is a schematic of a long rod, fin stabilized projectile and Figure 2 defines the nomenclature employed in the analysis. Standard sea level air properties are assumed.

A. For the body drag:

1. The wave drag coefficient (C_{DWB}) is given as

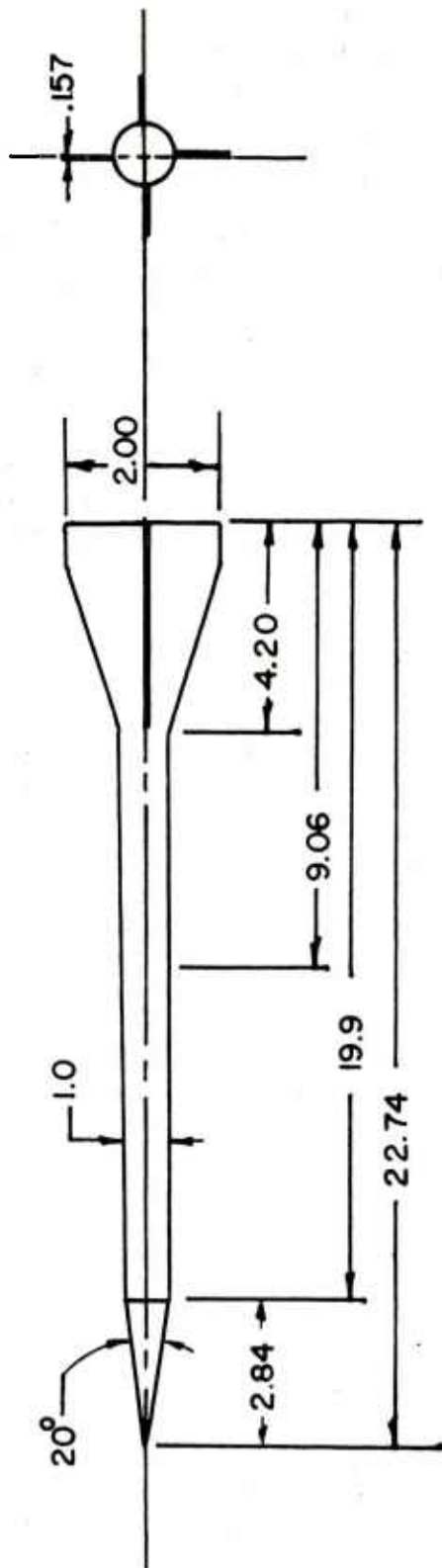
$$C_{DWB} = .7 M^{-.28} \lambda_n^{-1.73}$$

directly from Figure 8-29 of Reference 2 which is reproduced here as Figure 3. The quantity M is the Mach Number, and λ_n is the length of the projectile nose (in calibers). Both conical and ogival noses are described by this equation with restrictions imposed only in the case of a short nose length where $\frac{M}{\lambda_n} < 1.0$ and $2 < M < 10$. A data base exists to $M = 5$.

2. The hypersonic base drag (C_{DDB}) is specified from pragmatic considerations. It is assumed that the extreme decrement from the lower velocity flow is bounded by the value at $M = 5$ and zero. A patch

¹W. F. Donovan and B. B. Grollman, "Procedure for Estimating Zero Yaw Drag Coefficient for Long Rod Projectiles at Mach Numbers from 2 to 5", ARBRL-MR-02819, March 1978. (AD#A054326)

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



DIMENSIONS IN CALIBERS

Figure 1. Typical Kinetic Energy Projectile

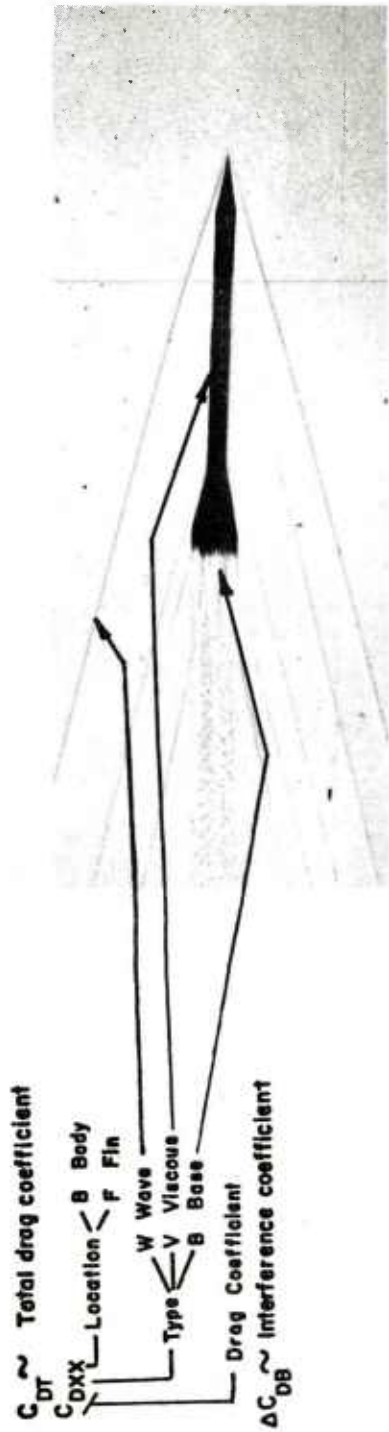
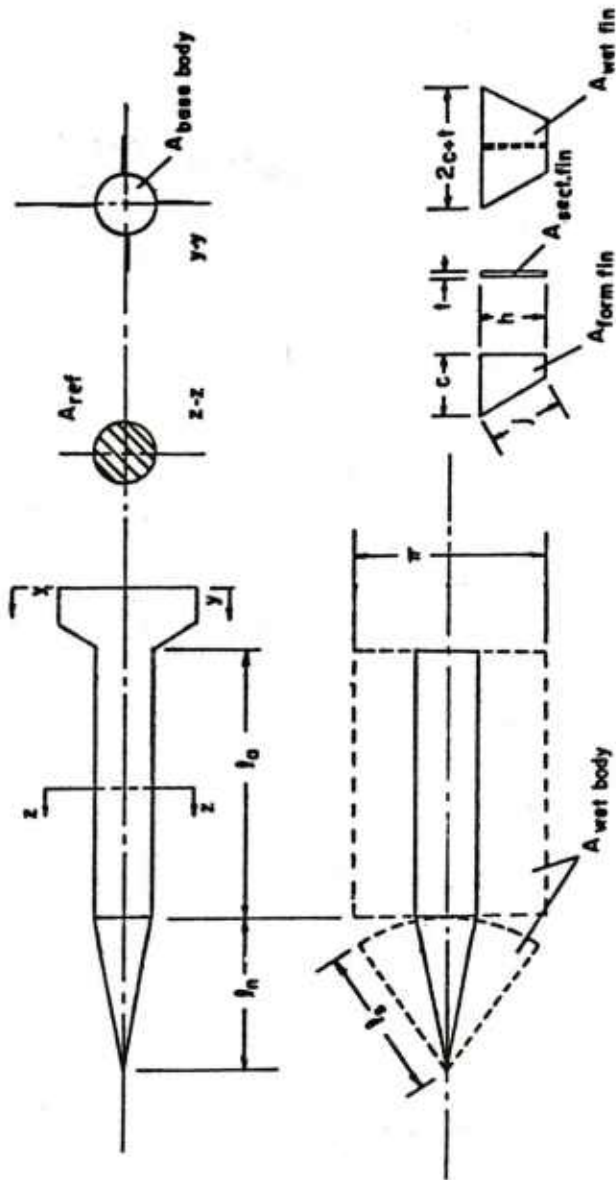


Figure 2. General Nomenclature Specification for Typical Projectile

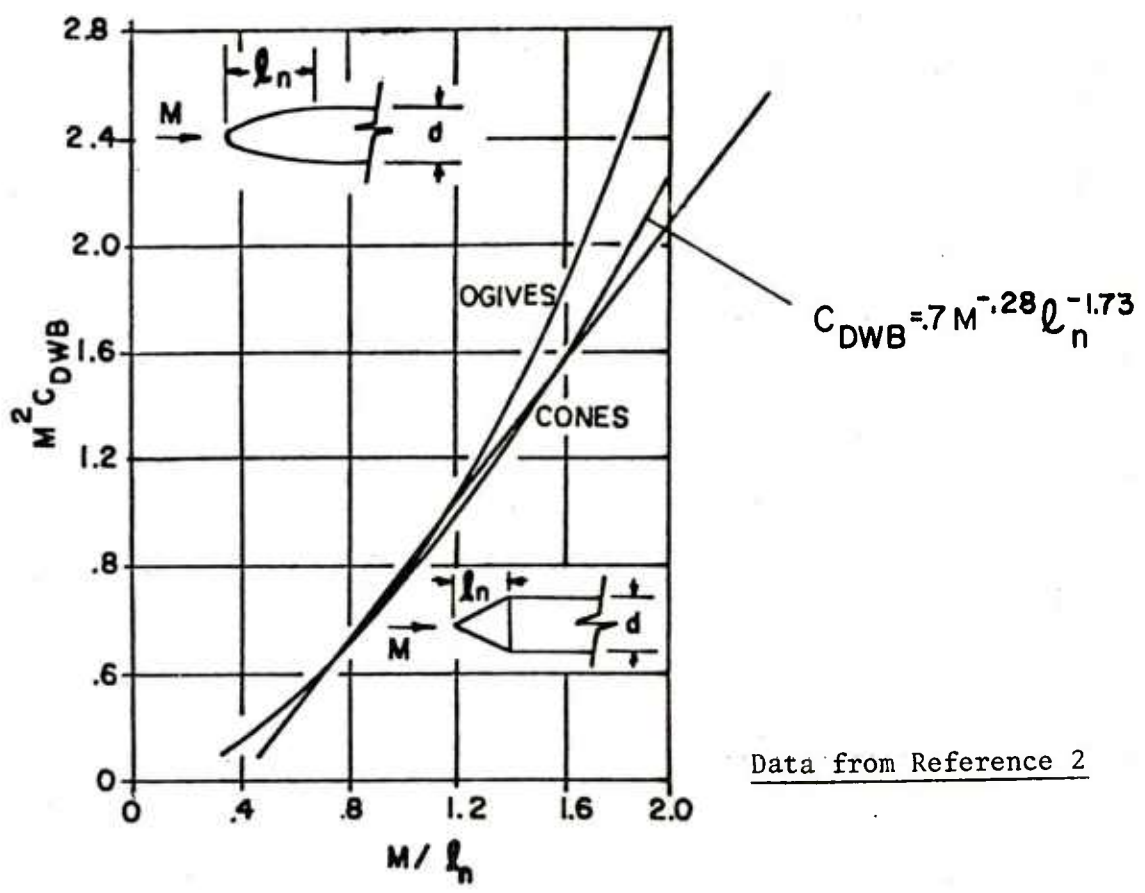


Figure 3. Nose Wave Drag Coefficient Correlation

procedure, which is described in Appendix A, is imposed and the result is a bilinear characteristic from $M = 2$ to $M = 10$ with the knee at $M = 5$. Available references offer little insight into the aerodynamics of hypersonic flow in the wake of cylindrical bodies. The wake flow behind cones has been investigated, however, and a survey of the results of these open literature studies is included in Appendix B. Thus

$$C_{DBB} = .040 - .003 M ,$$

proposed for use in the range $5 < M < 10$.

3. The viscous drag component (C_{DVB}) is obtained by Mach extrapolation of Figures 8-39 and 8-40 of Reference 2, which is presented in Figure 4. Here, C_F is the flat plate friction factor, which is a function of M , $C_{F'}$ is an empirical constant equal to 1.51, as employed in Reference 1, and $C_{F''}$ transposes the classical flat plate coefficients to cylindrical applications³ and is taken as a constant equal to 1.15.

Whereby:

$$\begin{aligned} C_{DVB} &= C_F C_{F'} C_{F''} \left(\frac{A_{\text{wetted surface}}}{A_{\text{ref}}} \right) \\ &= 10^{-4} (13.84 - 1.184 M) (1.51) (1.15) \left(\frac{A_{\text{wetted surface}}}{A_{\text{ref}}} \right) \\ &= .000173 (13.84 - 1.184 M) \left(\frac{A_{\text{wetted surface}}}{A_{\text{ref}}} \right), \end{aligned}$$

proposed for the range $5 < M < 10$.

Any superposed drag due to aerodynamic disturbances from the driving grooves is assumed as part of the empirical constant $C_{F''}$. As in 2, the bilinear characteristic is retained. The viscous flow mechanics in hypersonic flow have been examined from divergent assumptions (refer to Appendix B) and are considered here from the conservative premise.

³L. M. Freeman and R. H. Korkegi, "Projectile Aft-Body Drag Reduction by Combined Boat-Tailing and Base Blowing", AFAP-TR-75-111, February 1976.

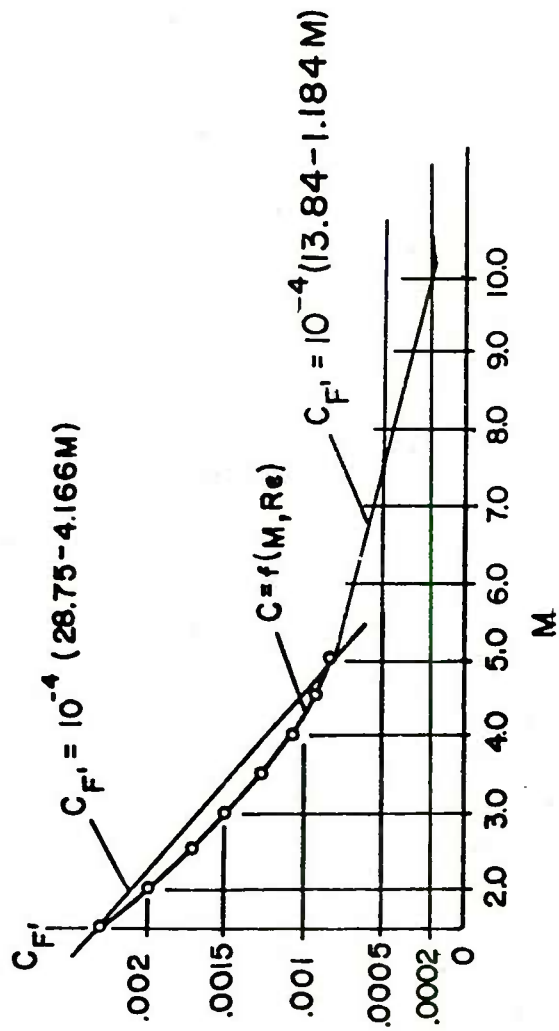


Figure 4. Conversion of Mach Number to C_{F1}

B. For the empennage:

1. The wave drag coefficient for the fins (C_{DWF}) is suggested by Reference 4 and is recommended for fins with a single bevel leading edge, where

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

proposed for the range of $2 < M < 10$. Reference 5 presents a similar form for biconvex profiles.

2. The fin base drag (C_{DBF}) is determined by an area ratio with the body base, or

$$C_{DBF} = n \left(\frac{A_{\text{sect fin}}}{A_{\text{base body}}}\right) C_{DBB},$$

where n is the number of fin blades per fin assembly. This report considers that the full thickness fin area represents the active drag cross section, which is a conservative assumption. The effects of fin-body interference may be neglected on the basis of magnitude (refer to Appendix C). Since the fin base area is considered as the extension of the body base area, the same Mach limitations are assumed.

3. The fin viscous drag (C_{DVF}) 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, leading to

$$C_{DVF} = n \frac{1}{1.15} \left(\frac{A_{\text{wetted fin}}}{A_{\text{wetted body}}}\right) C_{DVB}.$$

In viscous behavior, the fin is also an extension of the body.

C. The total zero-yaw drag coefficient is then equal to the sum of the individual contributions.

III. RESULTS

Figure 5 presents the graphical form of the analysis of the projectile drag coefficient for the Mach number range from $M = 5$ to $M = 10$. The discrete contributions of the individual components are available from Tables 1 and 2 and from the Hewlett Packard calculator printout of the calculator program list given in Appendix D.

⁴S. F. Hoerner, "Fluid Dynamic Drag", Published by the author, 1958.

⁵H. Schlichting, *Boundary Layer Theory*, McGraw-Hill Book Company, Inc., New York, 1960.

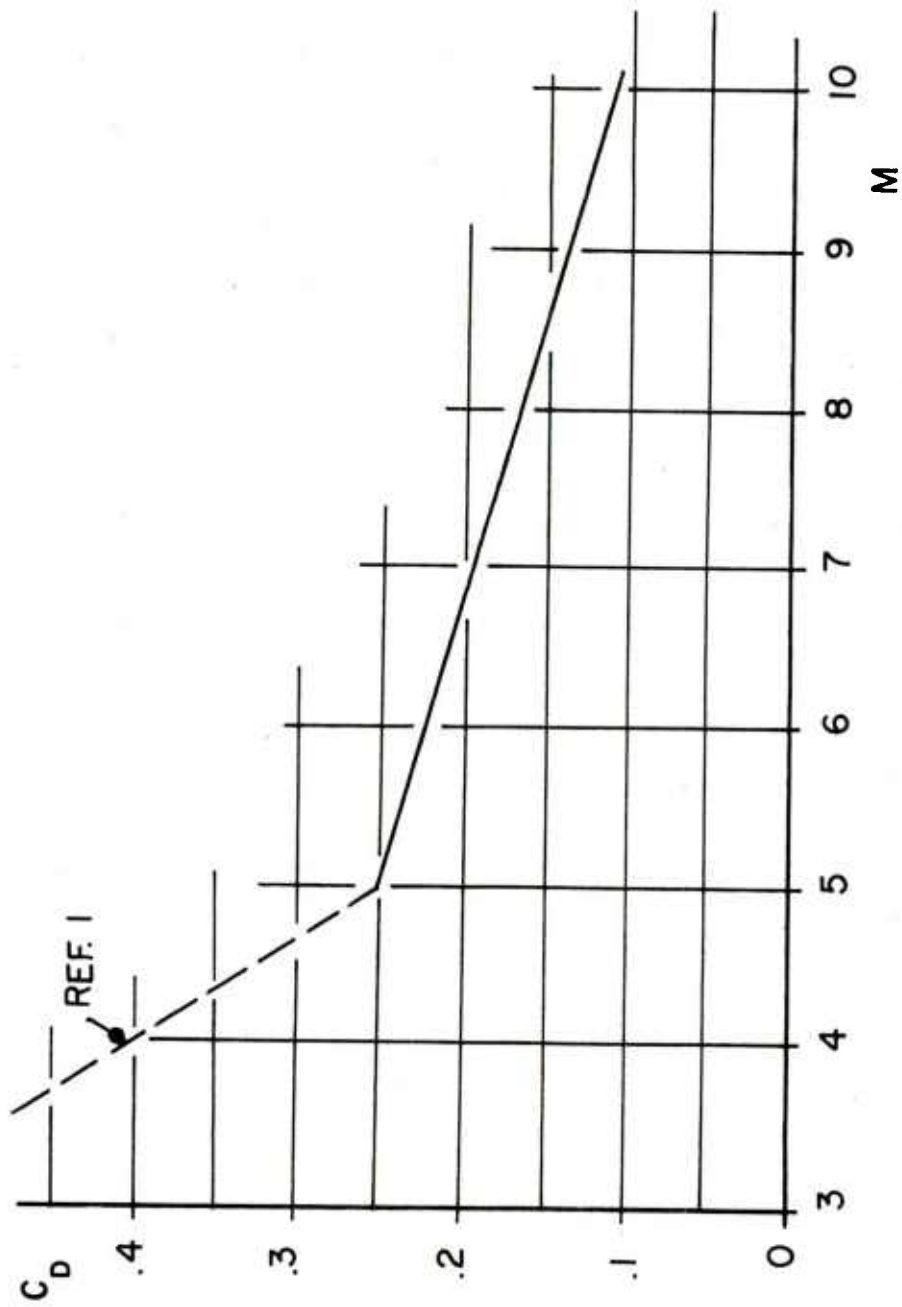


Figure 5. Drag Coefficient for Typical Kinetic Energy Projectile

TABLE 1. INPUT PARAMETERS FOR CALCULATING PROCEDURE

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}		d			c	t	j	h	n	A_{form}	A_{wet}	A_{sect}	
UNITS	cal	cal	rad	cal	cal ²	cal ²		cal			cal	cal	cal	cal		cal ²	cal ²	cal ²	
	nose length	afterbody length	nose half angle	nose slant height, $l_n \sec \alpha$	reference area, $\pi/4$	wetted surface area, $\pi(.5l_n + l_{ab})$		diameter of of body			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	sectional area of fin blade	
PROJECTILE	2.84	15.7	.176	2.88	.785	53.9		1.0			4.2	.157	3.38	1.0	4	2.6	5.2	.167	

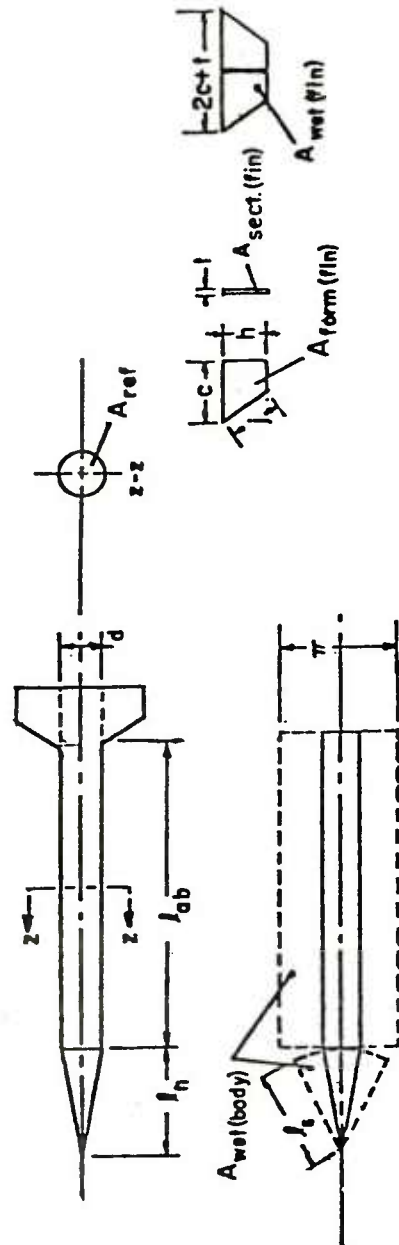


TABLE 2. OPERATING SCHEDULE FOR KINETIC ENERGY PROJECTILE

COLUMN	21	22	23	24	25	26	27	28	29	30	31
SYMBOL	M	β	C_{DWB}	C_{DBB}	C_{DVB}	C_{DTB}	C_{DWF}	C_{DBF}	C_{DVF}	C_{DTF}	C_{DT}
DESCRIPTION	Moeh		Wave - Body	Base-Body	Viscous - Body	Total-Body	Wave - Fin	Base - Fin	Viscous - Fin	Total - Fin	Total-Projectile
TEST NOTATION		$(M^2-1)^{1/2}$	$.7M^{-.28} L_n^{-1.73}$	$-.003M+.040$	$.000173(13.84-1.184M)(A_{wet}/A_{ref})$		$(n/B)(r/l)^2(A_{form}/A_{ref})$	$n(A_{secc}/A_{ref})C_{DBB}$	$n(A_{wet-fin}/A_{wet-body})C_{DVB}$		
CALCULATION			$.7(21)^{-.28}(1)^{-1.73}$	$-.003(21)+.040$	$.000173(13.84-1.184(21))(6/5)$	$(23)+(24)+(25)$	$(15)(22)(12)(13)^2(19/5)$	$(15)(18/5)(24)$	$(15)(17/6)(25)(.897)$	$(27)+(28)+(29)$	$(25)+(30)$
	5.0	4.899	.074	.025	.094	.193	.006	.020	.032	.058	.251
	6.0	5.916	.070	.022	.080	.172	.005	.018	.027	.050	.222
	7.0	6.928	.067	.019	.066	.152	.004	.015	.022	.041	.199
	8.0	7.937	.064	.016	.052	.132	.004	.013	.017	.034	.165
	9.0	8.944	.062	.013	.038	.113	.003	.010	.013	.026	.139
	10.0	9.950	.060	.010	.024	.094	.003	.008	.008	.019	.113

TABLE 2. OPERATING SCHEDULE FOR KINETIC ENERGY PROJECTILE (continued)

Printed Output

Mach number	M	10.00000000	***
Body wave	CDWB	0.060375023	***
Body base	CDBB	0.010000000	***
Body viscoous	CDVB	0.023724305	***
Body total	CDTB	0.094099329	***
Fin wave	CDWF	0.002855548	***
Fin sectional	CDBF	0.007995944	***
Fin viscous	CDVF	0.007924091	***
Fin total	CDTF	0.018775584	***
Projectile	CD	0.112874912	***

10.00000000	***	7.00000000	***
0.060375023	***	0.066715979	***
0.010000000	***	0.019000000	***
0.023724305	***	0.065858672	***
0.094099329	***	0.151574650	***
0.002855548	***	0.004100969	***
0.007995944	***	0.015192294	***
0.007924091	***	0.021997276	***
0.018775584	***	0.041290540	***
0.112874912	***	0.192865196	***

9.00000000	***	6.00000000	***
0.062182676	***	0.069658635	***
0.013000000	***	0.022000000	***
0.037769094	***	0.079903460	***
0.112951770	***	0.171562096	***
0.003176597	***	0.004802563	***
0.010394728	***	0.017591078	***
0.012615153	***	0.026688338	***
0.026186477	***	0.049081979	***
0.139138248	***	0.220644075	***

8.00000000	***	5.00000000	***
0.064267605	***	0.073307045	***
0.016000000	***	0.025000000	***
0.051813883	***	0.093948249	***
0.132081488	***	0.192255294	***
0.003579619	***	0.005799646	***
0.012793511	***	0.019989861	***
0.017306215	***	0.031379400	***
0.033679345	***	0.057168907	***
0.165760833	***	0.249424200	***

REFERENCES

1. W. F. Donovan and B. B. Grollman, "Procedure for Estimating Zero Yaw Drag Coefficient for Long Rod Projectiles at Mach Numbers from 2 to 5", ARBRL-MR-02819, March 1978. (AD#A054326)
2. "Design of Aerodynamically Stabilized Free Rockets", AMC Pamphlet 706-280, 1968.
3. L. M. Freeman and R. H. Korkegi, "Projectile Aft-Body Drag Reduction by Combined Boat-Tailing and Base Blowing", AFAP1-TR-75-111, February 1976.
4. S. F. Hoerner, "Fluid Dynamic Drag", Published by the author, 1958.
5. H. Schlichting, "Boundary Layer Theory", McGraw-Hill Book Company, Inc., New York, 1960.

PARTIAL BIBLIOGRAPHY

- Hayes, W.D., Probst, R.F., "Hypersonic Flow Theory", Academic Press, New York, 1966, pp 9, 64; Definition of flow regime, Drag of slender bodies, pp 545 - 574; List of references.
- Kuethe, A.M., Schetzer, J.D., "Foundations of Aerodynamics", John Wiley and Sons, Inc., New York, 1967, p 381; Examination of continuum vs slip flow.
- Liepman, H.W., Roshko, A., "Elements of Gasdynamics", John Wiley and Sons, Inc., New York, 1957, pp 122, 218 - 269, 343; Mach nose effects, Hypersonic similarity. Slender body theory. Skin friction to $M = 10$.
- Murphy, C.H. "Free Flight Motion of Symmetric Missiles", Ballistic Research Laboratories Report No. 1216, July, 1963 (AD 442757), pp 9-17, 29, 131 - 135; Aerodynamic drag. Skin friction parameters as affected by heat transfer. (AD#442757)
- Shapiro, A.H., "The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. II". The Ronald Press Company, New York, 1953, pp 1109 - 1125; Discussion of Mach number, skin friction, etc., on cones and cylinders in hypersonic flow.
- Stivers, L.S. Jr. "Calculated Pressure Distributions and Components of Total Drag Coefficients for 18 Constant Volume Slender Bodies of Revolution at Zero Incidence for Mach numbers from 2.0 to 12.0 with Experimental Aerodynamic Characteristics for Three of the Bodies", NASA TN D-6536, October, 1971. Title describes context of report.
- Kaufmann, W., "Fluid Mechanics", McGraw-Hill Book Company, Inc., New York, 1963, p. 397, Flat plate C_D to Mach 10.
- Trujillo, A.A., "Summary of Static Stability and Drag Characteristics of Axisymmetric Low-Drag Shapes for the Subsonic to Hypersonic Mach Number Range", Sandia Laboratories Research Report SC-RR-68-304, August 1968, Drag predictions to $M = 12$.

LIST OF SYMBOLS

$A_{\text{base body}}$	Area of body exposed to base pressure (cal) ²
$A_{\text{sect fin}}$	Area of fin exposed to base pressure (cal) ²
A_{ref}	Reference area (.785 cal ²)
$A_{\text{wetted surface}}$	Area of particular surface assigned viscous flow drag (cal ²)
C_D	Total drag coefficient (Reference Symbol) $= \frac{2D}{\rho v^2 A_{\text{ref}}}$
C_{DBB}	Pressure drag coefficient - body
C_{DBF}	Pressure drag coefficient - 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_{DVF}	Viscous drag coefficient - fins
C_{DWB}	Wave drag coefficient - body (nose)
C_{DWF}	Wave drag coefficient - fin
Δ_{CDB}	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

LIST OF SYMBOLS (continued)

b	Intercept of $C_D - M$ characteristic
c	Chord length of base fin (cal)
d	Representative diameter of cylindrical reference area (1.0 cal)
h	Height of fin blade (cal)
j	Length of leading edge of fin (cal)
k	Slope of $C_D - M$ characteristic
l_a	Length of after body of projectile (cal)
l_n	Axial length of projectile nose (cal)
l_{sn}	Slant height of projectile nose (cal)
n	Number of blades per fin assembly
t	Representative fin thickness (cal)
w	Slope of $C_{F1} - M$ characteristic
v	Projectile velocity (cal/sec)
z	Intercept of $C_{F1} - M$ characteristic
β	Thermodynamic parameter $(M^2 - 1)^{1/2}$
ρ	Ambient air density

SPECIAL NOTATION

H-P 97 refers to the Hewlitt Packard calculator for which the program listing of Appendix D is written.

References to "hypersonic flow" indicate the Mach regime $5 < M < 10$. This designation is arbitrary.

APPENDIX A

PATCH PROCEDURE FOR TRANSITION TO HYPERSONIC REGIME

The body base drag coefficient for $2 < M < 5$ is given by

$$C_{DBB} = - .048 M + .265$$

and acquires a value of .025 at $M = 5$. For the assumed decrement to .010 at $M = 10$:

$$- .048 M + .265 = - k M + b ,$$

or

$$.025 = b - 5 k$$

with

$$.01 = (b - 10 k) ,$$

whereby

$$b = .003$$

and

$$k = .04 .$$

Thus

$$C_{DBB} = .04 - .003 M .$$

The skin friction coefficient is similarly determined. At $M = 10$ the extrapolated decrement produces $C_{F1} = .0002$. This leads to

$$28.75 - 4.166 M = z - w M ,$$

giving

$$z = 13.84 ,$$

with

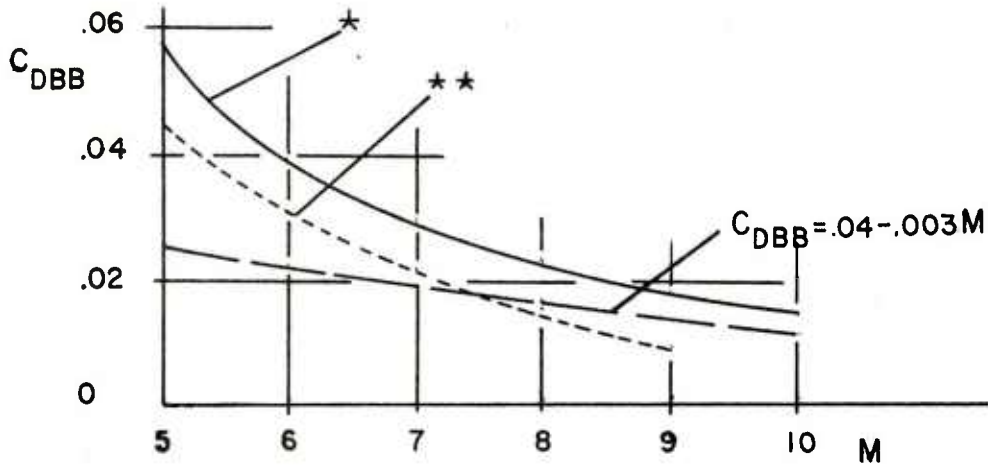
$$w = 1.184 .$$

as suitable coefficients for the range $5 < M < 10$.

APPENDIX B

DISCUSSION OF BIBLIOGRAPHIC DATA

Lyons and Brown*, and Zarin**, offer results of work on cones. The Lyons and Brown base drag coefficient assumes a perfect vacuum in the immediate wake of the body while the Zarin data is predicated on pressure measurements in the model mounted in a wind tunnel facility. The results are compared with values calculated from the current report.



Although the pure cone C_{DBB} is higher than that predicted on the basis of the present report, this represents no contradiction since any non-vacuum base flow will give this result. The Zarin data agrees at $M = 6.5$ within 20% and at $M = 8$ within 7%.

The viscous contribution to the drag is treated by Lyons and Brown* as a boundary layer phenomena with additional components due to induced pressure and transverse curvature effects. Zarin** considers the viscosity to be negligible in comparison with the other terms. Stivers*** offers a conventional treatment whereby the laminar regime is superseded by a transitional and a turbulent flow, and then converts the body of revolution to equivalent flat plate configuration. This present report simply extrapolates from lower Mach number data and agrees, approximately since the Lyons and Brown data is lumped with the wave drag, with the Lyons and Brown results.

* W. C. Lyons, Jr. and H.S. Brown, "The Drag of Slightly Blunted Slender Cones", NOLTR 68-3, January 1968.

** N. A. Zarin, "Base Pressure Measurements on Sharp and Blunt 9° Cones at Mach Numbers from 3.50 to 9.20", BRL MR 1709, November 1965.(AD#369084)

***L.S. Stivers, Jr. "Calculated Pressure Distributions and Components of Total Drag Coefficients for 18 Constant Volume Slender Bodies of Revolution at Zero Incidence for Mach Numbers from 2.0 to 12.0 with experimental Aerodynamic Characteristics for Three of the Bodies", NASA TN D-6536, October, 1971.

APPENDIX C

FIN-BODY INTERFERENCE DRAG COEFFICIENT INCREMENT

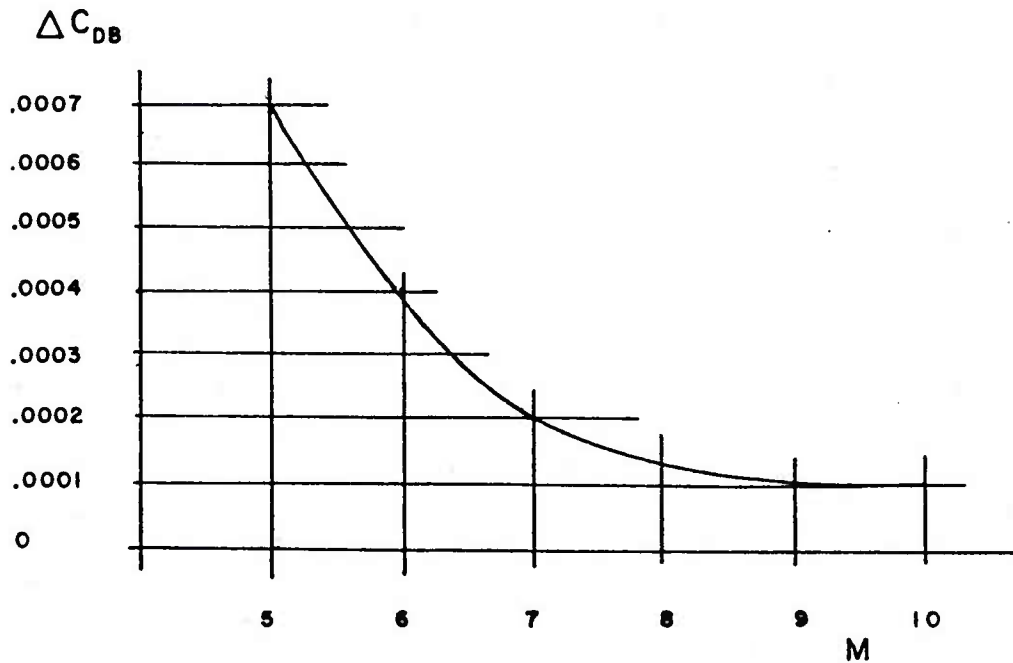
From Reference 4,

$$\Delta C_{DB} = \frac{t}{c} \left[\frac{.825}{M^2} - \frac{.05}{M} \right] [n] \left[\frac{A_{sect}}{A_{ref}} \right]$$

where

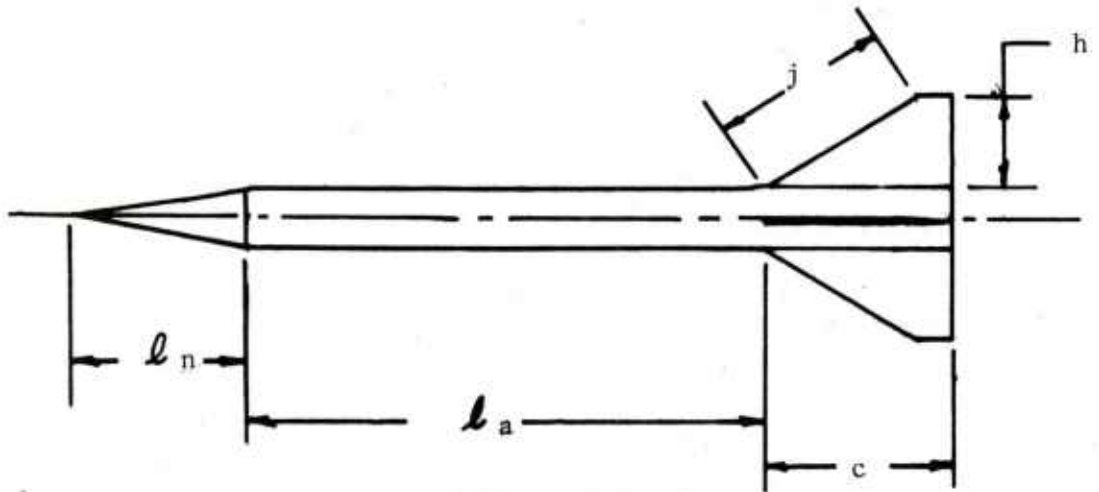
$$\begin{aligned} t &= .157 \text{ cal,} \\ c &= 4.2 \text{ cal,} \\ n &= 4, \\ A_{sect} &= .157 \text{ cal}^2, \text{ and} \\ A_{ref} &= .7854 \text{ cal}^2, \end{aligned}$$

which leads to the result shown below.



APPENDIX D

PROGRAM LISTING FOR H-P 97 DESK CALCULATOR



Input Storage Registers

1	l_n	Nose length
2	l_a	Afterbody length
3	h	Fin blade height
4	t	Fin thickness
5	c	Fin blade length at root
6	j	Fin leading edge length
7	n	Number of fin blades
I	M	Mach number

Note that the program automatically decrements in unit Mach gradient. Decimal gradients can be employed by insertion at step 187.

Printed Output

Mach number	M	10.00000000	***
Body wave	CDWB	0.060375023	***
Body base	CDEB	0.010000000	***
Body viscous	CDVB	0.023724305	***
Body total	CDTB	0.094099329	***
Fin wave	CDWF	0.002855548	***
Fin sectional	CDBF	0.007995944	***
Fin viscous	CDVF	0.007924091	***
Fin total	CDTF	0.018775584	***
Projectile	CD	0.112874912	***

Program Listing

001	*LBLC	21 15	020	x	-35
002	RCLI	36 46	021	e ^x	33
003	PRTX	-14	022	RCLA	36 11
004	LN	32	023	x	-35
005	.	-62	024	.	-62
006	2	02	025	7	07
007	8	08	026	x	-35
008	CHS	-22	027	PRTX	-14
009	x	-35	028	STOA	35 11
010	e ^x	33	029	CLX	-51
011	STOA	35 11	030	RCLI	36 46
012	CLX	-51	031	.	-62
013	RCL1	36 01	032	0	00
014	LN	32	033	0	00
015	1	01	034	3	03
016	.	-62	035	CHS	-22
017	7	07	036	x	-35
018	3	03	037	.	-62
019	CHS	-22	038	0	00
			039	4	04
			040	0	00
			041	+	-55
			042	PRTX	-14
			043	STOB	35 12
			044	CLX	-51

045	RCL1	36 01	093	+	-55
046	X ²	53	094	RCLB	36 12
047	.	-62	095	+	-55
048	5	05	096	PRTX	-14
049	X ²	53	097	ST08	35 08
050	+	-55	098	CLX	-51
051	√X	54	099	RCL3	36 03
052	.	-62	100	RCL6	36 06
053	5	05	101	÷	-24
054	x	-35	102	SIN ⁻¹	16 41
055	RCL2	36 02	103	TAN	43
056	+	-55	104	STOE	35 15
057	Pi	16-24	105	RCL3	36 03
058	x	-35	106	X ²	53
059	ST09	35 09	107	RCLE	36 15
060	Pi	16-24	108	÷	-24
061	÷	-24	109	2	02
062	4	04	110	÷	-24
063	x	-35	111	STOE	35 15
064	.	-62	112	RCL3	36 03
065	0	00	113	÷	-24
066	0	00	114	2	02
067	0	00	115	x	-35
068	1	01	116	CHS	-22
069	7	07	117	RCL5	36 05
070	3	03	118	+	-55
071	x	-35	119	RCL3	36 03
072	STOC	35 13	120	x	-35
073	CLX	-51	121	RCLE	36 15
074	RCLI	36 46	122	+	-55
075	1	01	123	ST0A	35 11
076	.	-62	124	Pi	16-24
077	1	01	125	÷	-24
078	8	08	126	4	04
079	4	04	127	x	-35
080	CHS	-22	128	STOE	35 15
081	x	-35	129	RCL4	36 04
082	1	01	130	RCL6	36 06
083	3	03	131	÷	-24
084	.	-62	132	X ²	53
085	8	08	133	RCLE	36 15
086	4	04	134	x	-35
087	+	-55	135	RCL7	36 07
088	RCLC	36 13	136	x	-35
089	x	-35	137	STOE	35 15
090	PRTX	-14	138	CLX	-51
091	STOC	35 13	139	RCLI	36 46
092	RCLA	36 11	140	X ²	53
			141	1	01

142	-	-45
143	IX	54
144	RCL5	36 15
145	=	-24
146	1/X	52
147	PRTX	-14
148	STOD	35 14
149	RCLB	36 12
150	RCL7	36 07
151	x	-35
152	RCL3	36 03
153	x	-35
154	RCL4	36 04
155	x	-35
156	Pi	16-24
157	=	-24
158	4	04
159	x	-35
160	PRTX	-14
161	STOE	35 15
162	CLX	-51
163	RCLA	36 11
164	2	02
165	x	-35
166	RCL9	36 09
167	=	-24
168	RCLC	36 13
169	x	-35
170	RCL7	36 07
171	x	-35
172	1	01
173	.	-62
174	1	01
175	5	05
176	=	-24
177	PRTX	-14
178	RCL5	36 15
179	+	-55
180	RCLD	36 14
181	+	-55
182	PRTX	-14
183	RCL8	36 08
184	+	-55
185	PRTX	-14
186	SPC	16-11
187	DSZI	16 25 46
188	GTOC	22 13
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