UNCLASSIFIED

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
July 1990

3. REPORT TYPE AND DATES COVERED
Final Jan 90 - Jun 90

4. TITLE AND SUBTITLE
PROJECTILE SUPERSONIC DRAG CHARACTERISTICS

5. FUNDING NUMBERS
1L162618AH80

6. AUTHOR(S)
Ilmars Celmins

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Ballistic Research Laboratory
ATTN: SLCBR-LF-F
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
BRL-MR-3843

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

An observation of projectile free flight behavior - that above Mach 2.5, velocity is linear with distance - leads to a proposed simple functional form for the drag coefficient. Equations are derived that allow the determination of both the zero-yaw drag coefficient (as a function of Mach number) and the yaw-drag coefficient from as few as two test firings. Good agreement with free-flight range data has been obtained.

14. SUBJECT TERMS
Drag
Supersonic
Drag Coefficient

15. NUMBER OF PAGES
22

16. PRICE CODE

| | | | |
|---|---|---|---|
| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | Same as Report |

NSN 7540-01-280-5500

UNCLASSIFIED

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

INTENTIONALLY LEFT BLANK.

## Table of Contents

INTENTIONALLY LEFT BLANK.

## List of Figures

## List of Tables

INTENTIONALLY LEFT BLANK.

## I. Introduction

This report discusses the ramifications of a simple observation of projectile free flight behavior. The observation is that for certain projectile types, when velocity is plotted against range, the data lie in a straight line, as long as the velocity is above Mach 2.5. Examples of this behavior are shown in Figures 1A and 1B. These figures are derived from calculated trajectories based on the standard firing tables data for these rounds. Figure 1A shows three large caliber fin-stabilized projectiles. Figure 1B shows four other projectiles including a spike-nosed high explosive projectile (M831) and a .50 caliber sabot-launched armor piercing projectile (SLAP). The diversity of these projectiles seems to imply that the observation holds true for a variety of projectile types.

## II. Implications

There are several implications of this behavior. The first is that the derivative of velocity with respect to range is constant (the slope of the line). If range is expressed in units of the projectile reference length, $\ell$, then this derivative is the term dV/ds in the drag equation[1]:

$$C_D = -(dV/ds)(1/V)(2m/\rho S\ell) \qquad (1)$$

For any given shot of a direct-fire weapon, the only variable term in this equation is the velocity, V. Rewriting V as Ma (Mach number times sound speed) and combining all of the constants into one term, K:

$$K = -(dV/ds)(1/a)(2m/\rho S\ell) \qquad (2)$$

Equation (1) becomes:

$$C_D = K/M \qquad (3)$$

This is an extremely simple form for the drag equation, with several important implications. One implication is that one test shot can be fired, the factor K can be determined, and drag as a function of Mach number is then known for that projectile type for all Mach numbers above 2.5. Unfortunately, the effects of projectile yaw make things a little more complicated. Drag is assumed to depend on two independent variables: the Mach number, M, and $\delta^2$, the square of the yaw. The drag equation is thus written as:

$$C_D(M, \delta^2) = C_{D0}(M) + C_{D\delta^2}\delta^2 \qquad (4)$$

where $C_{D0}$ is the 'zero-yaw drag coefficient' and $C_{D\delta^2}$ is the 'yaw-drag coefficient'.

Another important result is obtained when Equation (3) for $C_D$ is entered in the drag force equation[1]:

$$D = \tfrac{1}{2}\rho V^2 S C_D$$

$$D = \tfrac{1}{2}\rho (Ma)^2 S\,(K/M)$$

$$D = \tfrac{1}{2}\rho a^2 S\,K\,M \qquad (5)$$

Again, for a given shot, the only variable is the Mach number. Thus, the drag force is directly proportional to the projectile velocity.

## III. Applications

There are several applications with varying levels of usefulness. The first is an alternative method of reducing free-flight spark range data for drag by using the slope of a velocity vs. range plot. However, because the technique is limited to specific projectile types and velocities, the method has limited usefulness when compared with the present data reduction techniques.

A more useful application would be to use the technique to obtain a value of $C_D$ for velocity/range data that consists of sparse measurements (e.g. skyscreens). Since the velocity degradation is a straight line, it is possible to obtain a value of $C_D$ if velocity is only measured at two points (preferably far apart). The technique can also be used to extract $C_D$ from doppler radar data. A FORTRAN program that calculates $C_D$ from an arbitrary set of velocity/range data points is included as Appendix A.

Other applications are based on the fact that what one obtains from the velocity/range data is actually the variation of $C_D$ with Mach number, not just a value of $C_D$ at a particular Mach number. Thus, a $C_D$ curve can be determined from one test round.

This leads to perhaps the most useful application - the more accurate determination of the yaw-drag coefficient and $C_{D0}$ by the elimination of the Mach number variations. For a single shot, the drag will depend on both the zero-yaw drag and the yaw-drag components. The yaw-drag is dependent on the average yaw value for that shot. If the firing is done over a long range, the yaw should damp out and one should get the value of $C_{D0}$. However, for shorter distances such as the free flight spark ranges, the yaw-drag will have a significant effect.

One common technique for determining $C_{D0}$ and $C_{D_{\delta^2}}$ is to fire groups of shots at different Mach levels (e.g. five shots at $M=3$, five shots at $M=4$, etc.). For each of these groups, the measured value of $C_D$ for each shot is plotted against the average square yaw for that shot. A straight line is then fitted to the data, with the slope of the line being $C_{D_{\delta^2}}$ and the intercept being $C_{D0}$ at that Mach number (see Equation 4). However, if there is some Mach number variation within the group, there is no simple way to eliminate the drag variation with Mach number from the data.

(One method for compensating for Mach number variation, the "Q-function", is described in Reference 2. In order to apply this technique, however, at least two low-yaw data points are required at significantly different Mach numbers. These points are then used to determine the $C_{D0}$ variation with Mach number .)

For the case where the drag function has the form K/M, there is another technique. If one assumes that the yaw-drag coefficient, $C_{D_{\delta^2}}$ is a function of yaw only (independent of Mach number), and that $C_{D0}$ has the form K/M, then it can be shown that for a series of range firings one can plot $(M/M_{REF})C_D$ vs. $(M/M_{REF})\delta^2$, and the intercept of a straight line fitted to the data will be $C_{D0}$ at $M_{REF}$, and the slope will be $C_{D_{\delta^2}}$. Alternatively, if $M=1$ is used for $M_{REF}$, the intercept will be the constant, K. A FORTRAN program that does this calculation using a set of $(M, C_D, \delta^2)$ data points is included as Appendix B.

Since Mach number variation is effectively removed from the data, the data points do not have to be at the same Mach number in order to do the fit. Also, since the only fit being done is a straight line, the drag coefficient can be completely defined (both $C_{D0}$ as a function of Mach number and $C_{D_{\delta^2}}$) with just two well-determined data points, providing they are at different yaw levels.

## IV. Examples

An example of each of the applications listed previously will be given. The examples use the data from BRL Transonic Range firings of untraced, ambient temperature, DM13 projectiles. The DM13 is a fin-stabilized KE penetrator with a tungsten core, fired from a 120 mm smoothbore gun tube.

### 1. Determination of $C_D$ From Velocity vs. Range Data

Figure 2 is a plot of velocity vs. range for Transonic Range round number 17682. The range measures position and time, so the velocity was calculated between each two successive timing stations by dividing the difference in distance by the difference in time between the two stations. The resulting average velocity was said to have occurred midway between the two stations because of the assumed linear behavior of velocity with range. Table 1A lists the position, time, and velocity data. A least-squares linear fit was performed on the velocity-range data. The slope of this fit, together with the measured physical properties and meteorological data at the time of the test (Table 1B) were used to determine K, using Equation 2. The value of K for this shot was found to be 1.402.

The values of $C_D$ and M from the standard range reduction for this round number are 0.2904 and 4.823, respectively. At this Mach number, the calculated $C_D$ using Equation 3 is:

$$C_D = K/M = 1.402 / 4.823 = 0.2907$$

### 2. Extrapolation of $C_D$ to Other Mach Numbers

The previous example showed how to determine K and, subsequently, $C_D$ from velocity vs. range data. If one were to start with a value of $C_D$ from a standard range reduction, K can be calculated by:

$$K = C_D M \qquad (6)$$

For round 17682, this yields:

$$K = 0.2904\,(4.823) = 1.401$$

Table 2 contains a round-by-round listing of measured drag data from the BRL Transonic Range. Figure 3 is a plot of $C_D$ vs. M including the measured values from Table 2, as well as the curve $C_D$=1.401/M. The measured value for round 17682 is the solid symbol. The extrapolated drag curve from this one data point is in excellent agreement with the other data. Note that round 17682 had very low yaw, so the curve should be a good approximation of $C_{D0}$. For this reason, most of the other data lie somewhat above the curve.

### 3. Calculation of the Drag Force

Equation 5 can be used to calculate the actual drag force experienced by a projectile. Using values from the previous examples:

$$D = K[\tfrac{1}{2}\rho a^2 S]M = 1.4[\tfrac{1}{2}(1.23)(339.6)^2(0.001137)]M = 112.9\ M$$

At the launch Mach number of 4.86, the drag force is:

$$D = (112.9)(4.86) = 548.7\ \text{N} \qquad (123.4\ \text{lbf})$$

### 4. Determination of $C_{D0}$ and $C_{D\delta^2}$

Figure 4 is a plot of $C_D$ vs. $\delta^2$ for all of the measured data. Most of the scatter in the data is due to Mach number variations (in this case, from $M=3.27$ to $M=4.83$). Figure 5 shows $(M/M_{REF})C_D$ plotted against $(M/M_{REF})\delta^2$, using $M_{REF}=4.7$. In this case, the scatter has been greatly reduced because the Mach number variation has been eliminated. A linear least-squares fit of the data gives the slope, or $C_{D\delta^2}$, as 13.212, and the intercept, or $C_{D0}$ at $M=4.7$, as 0.298. Using Equation 6, the constant K can be calculated as being 1.401. Thus, the drag equation is:

$$C_D(M, \delta^2) = 1.401/M + 13.212\ \delta^2$$

The advantage of this method, however, is that these coefficients can be determined from very limited data. The previous calculation can be repeated using only the three dark data points in Figures 4 and 5. These points are from rounds 17683, 26417, and 17691, which had the highest Mach number, largest yaw, and lowest Mach number, respectively. In this case, the calculated values are: $C_{D\delta^2}=9.976$, $C_{D0}=0.297$, and $K=1.397$. The drag equation is then:

$$C_D(M, \delta^2) = 1.397/M + 9.976\ \delta^2$$

which is a good approximation, considering only three data points were used.

## V. Restrictions

So far, it has not been possible to completely define restrictions on the use of these equations. The restrictions that have been identified are: the projectile velocity must be above Mach 2.5 and the ambient conditions cannot change significantly over the flight path. These restrictions are met by most large- and medium-caliber direct-fire weapons.

One problem with defining restrictions is that it has been difficult to find projectiles that do not obey the equations. In fact, the only projectile found so far that does not exhibit this behavior is the 25 mm M910 training round, which simulates some of the characteristics of the M791.

## VI. Summary

A technique has been described that can be used to completely determine the drag coefficient using very limited drag data. The technique assumes $C_{D0}$ has the form K/M. The overall findings of this report can be summarized as follows:

1. Almost all ammunition examined so far slows down at a rate such that a plot of velocity vs. range will yield a straight line, as long as the velocity is above Mach 2.5.
2. This type of behavior dictates that $C_D$ has the form K/M.
3. The slope of the straight line in a plot of velocity vs. range can be used to determine the value K and, consequently, $C_D$ as a function of Mach number.
4. If $C_{D0}$ has the form K/M and $C_D$ has been determined at (at least) two different yaw levels, $C_D$ as a function of both M and $\delta^2$ can be completely defined.
5. If $C_D$ has the form K/M, the drag force is directly proportional to the projectile velocity.

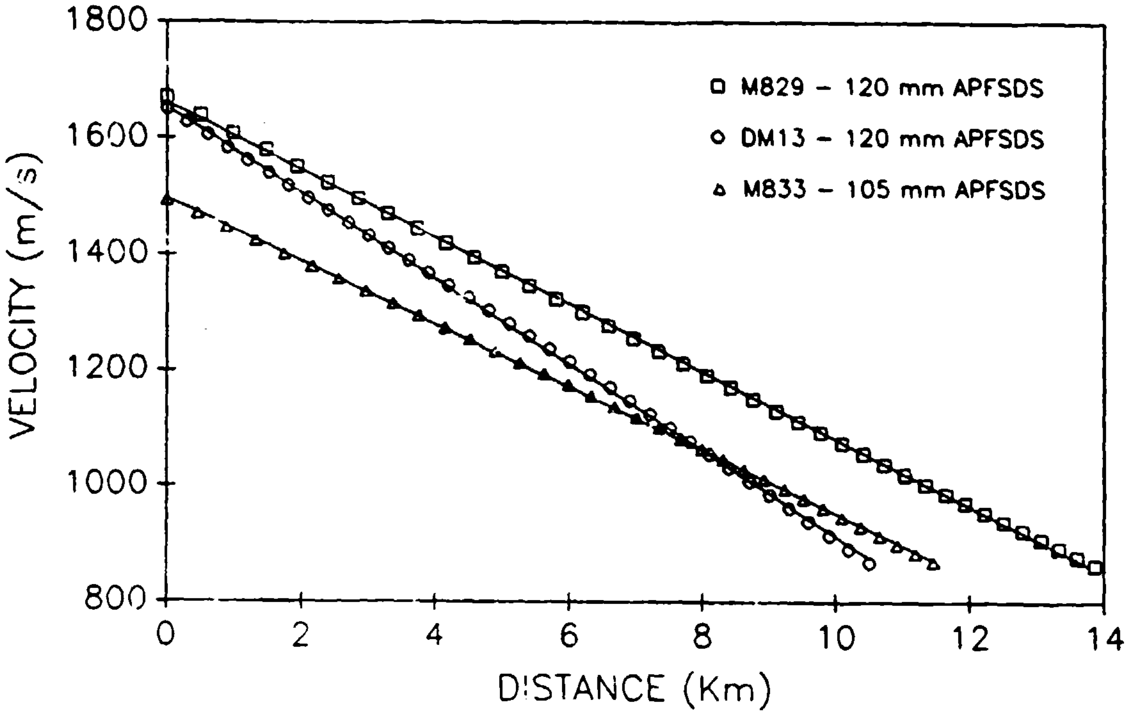

**Figure 1A. Velocity vs. Range, Large Caliber Fin-Stabilized Projectiles.**

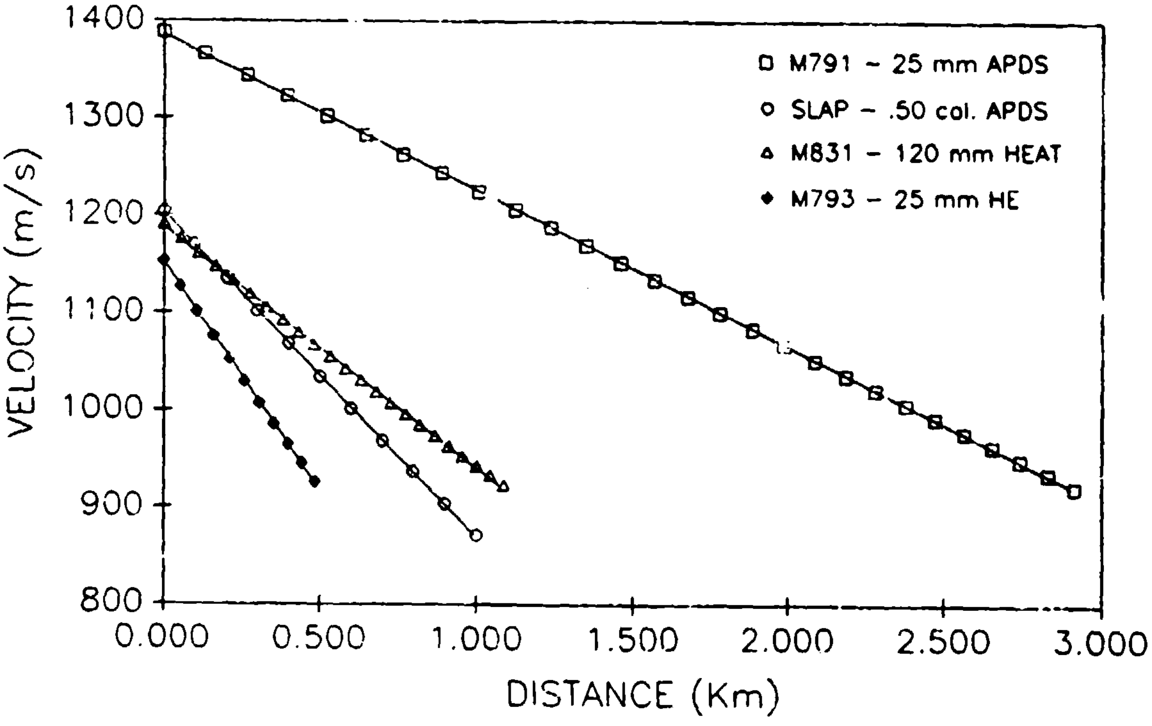

**Figure 1B. Velocity vs. Range, Miscellaneous Projectiles.**

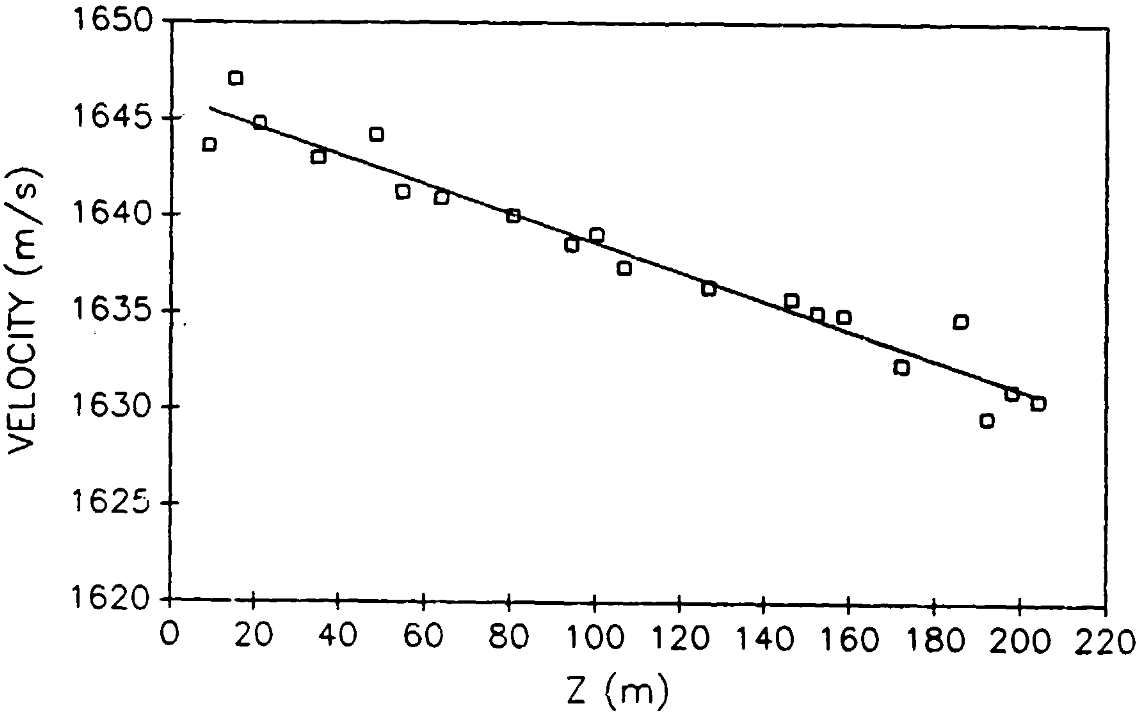

**Figure 2. Velocity vs. Range, Transonic Range Round 17682.**

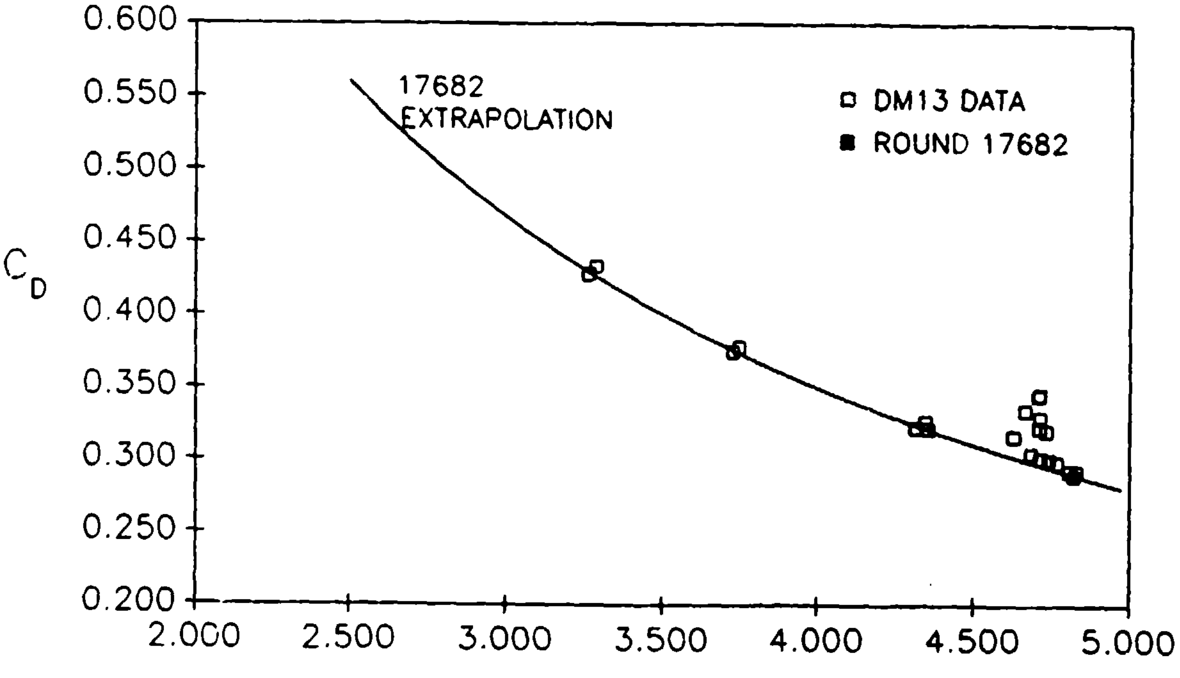

**Figure 3. Coefficient of Drag vs. Mach Number.**

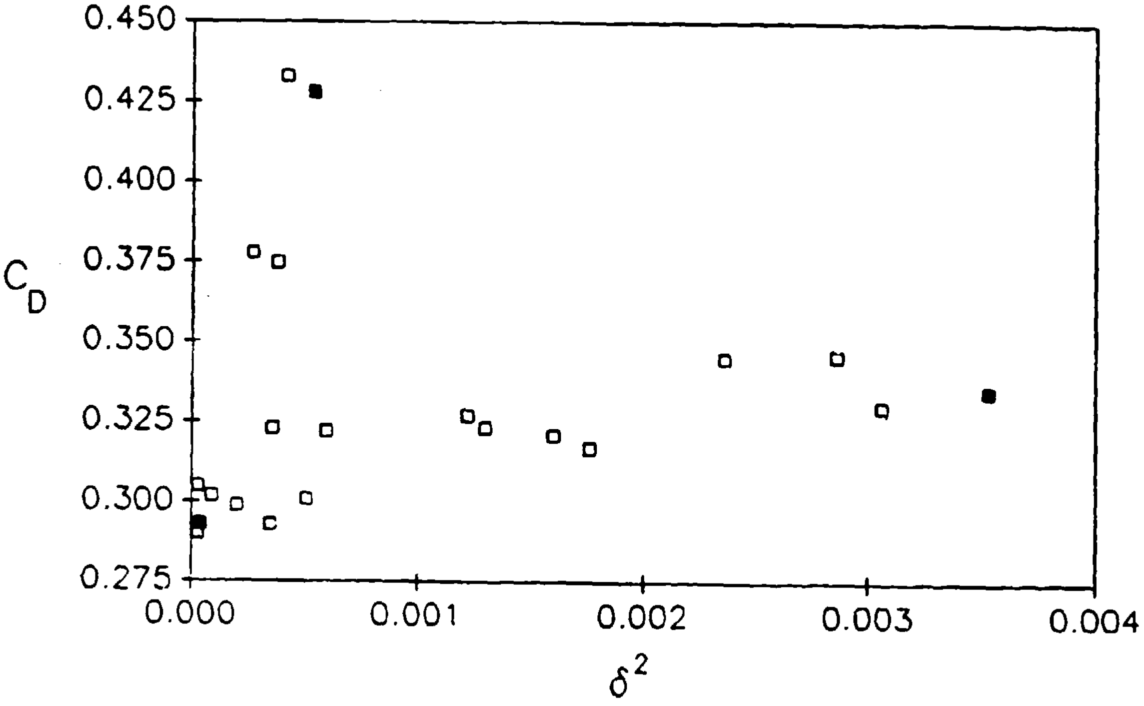

**Figure 4.** Coefficient of Drag vs. Delta Squared, Raw Data.

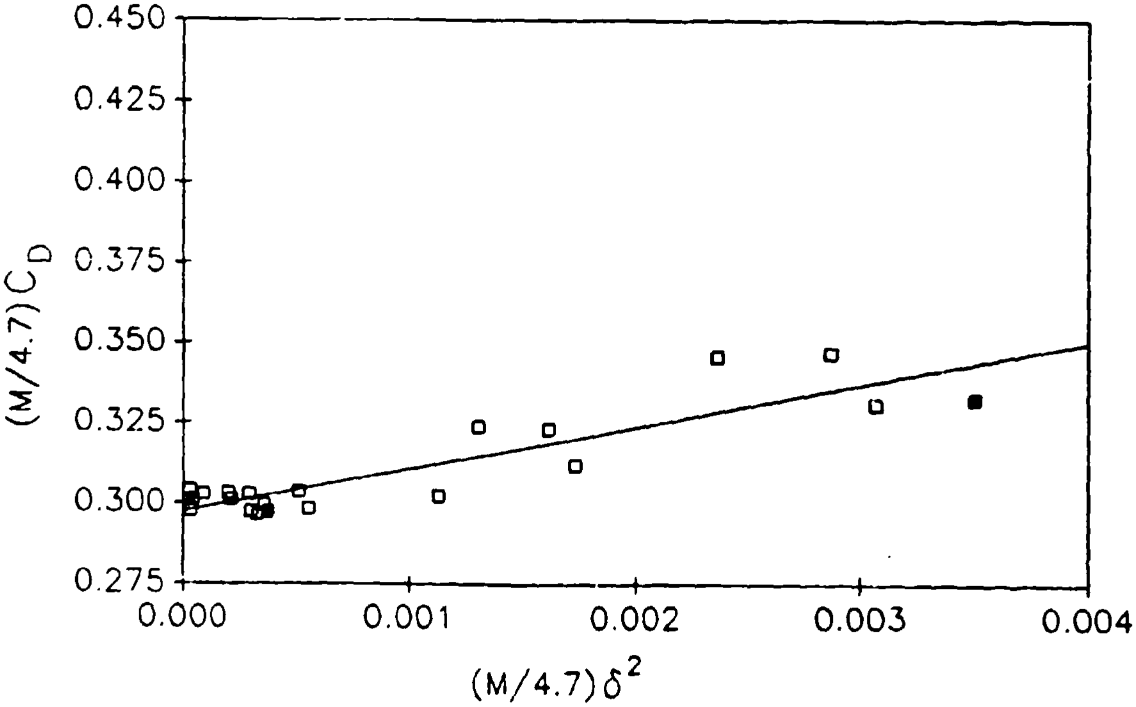

**Figure 5.** Coefficient of Drag vs. Delta Squared, Corrected for Mach Number

Table 1A. Time, Position, and Velocity for Transonic Range Round 17682.

| Measured | | Calculated | |
|---|---|---|---|
| Time (millisec.) | Range (meters) | Range (meters) | Velocity (meters/sec.) |
| 292.6346 | 5.772 | 8.937 | 1643.617 |
| 296.4863 | 12.103 | 15.089 | 1647.069 |
| 300.1130 | 18.076 | 21.100 | 1644.795 |
| 303.7899 | 24.124 | 34.919 | 1643.029 |
| 316.9303 | 45.714 | 48.698 | 1644.226 |
| 320.5601 | 51.682 | 54.809 | 1641.255 |
| 324.3706 | 57.936 | 63.872 | 1640.940 |
| 331.6055 | 69.808 | 80.653 | 1640.045 |
| 344.8312 | 91.499 | 94.277 | 1638.571 |
| 348.2219 | 97.056 | 100.265 | 1639.088 |
| 352.1388 | 103.475 | 106.816 | 1637.364 |
| 356.2205 | 110.158 | 126.686 | 1636.366 |
| 376.4219 | 143.215 | 146.268 | 1635.766 |
| 380.1552 | 149.322 | 152.334 | 1635.065 |
| 383.8402 | 155.347 | 158.588 | 1634.923 |
| 387.8047 | 161.828 | 172.141 | 1632.375 |
| 400.4403 | 182.454 | 185.959 | 1634.753 |
| 404.7283 | 189.464 | 192.208 | 1629.679 |
| 408.0961 | 194.953 | 198.013 | 1631.065 |
| 411.8493 | 201.074 | 204.124 | 1530.585 |
| 415.5895 | 207.173 | | |

Table 1B. Projectile Physical Properties and Ambient Conditions.

| | |
|---|---|
| $\ell = .03805$ m | reference length, projectile body diameter |
| $S = 0.001137$ m$^2$ | reference area |
| $m = 4.4282$ Kg | projectile mass |
| $\rho = 1.234$ Kg/m$^3$ | air density |
| $a = 339.63$ m/s | sound speed |

Table 2. Transonic Range Data for DM13 Projectiles.

| Round No. | Mach No. | $C_D$ | $\delta^2$ |
|---|---|---|---|
| 17683 | 4.832 | 0.293 | 0.00004 |
| 17682 | 4.823 | 0.290 | 0.00003 |
| 17681 | 4.807 | 0.293 | 0.00035 |
| 17692 | 4.767 | 0.299 | 0.00020 |
| 26443 | 4.743 | 0.301 | 0.00051 |
| 26390 | 4.735 | 0.321 | 0.00160 |
| 26442 | 4.715 | 0.302 | 0.00009 |
| 26391 | 4.714 | 0.330 | 0.00306 |
| 26289 | 4.714 | 0.346 | 0.00286 |
| 26288 | 4.713 | 0.323 | 0.00130 |
| 26417 | 4.711 | 0.345 | 0.00236 |
| 26444 | 4.687 | 0.305 | 0.00003 |
| 30691 | 4.666 | 0.335 | 0.00353 |
| 30687 | 4.630 | 0.317 | 0.00176 |
| 17685 | 4.357 | 0.322 | 0.00060 |
| 17686 | 4.347 | 0.327 | 0.00122 |
| 17687 | 4.317 | 0.323 | 0.00036 |
| 17688 | 3.748 | 0.378 | 0.00027 |
| 17689 | 3.728 | 0.375 | 0.00038 |
| 17690 | 3.288 | 0.433 | 0.00042 |
| 17691 | 3.265 | 0.428 | 0.00054 |

INTENTIONALLY LEFT BLANK.

## References

1.) Murphy, C.H., "Free Flight Motion of Symmetric Missiles," US Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Report No. 1216, July 1963. (AD 442757)

2) Thomas, R.N., "Some Comments on the Form of the Drag Coefficient at Supersonic Velocity," BRL Report No. 542, April 1945. (AD 494220)

INTENTIONALLY LEFT BLANK.

# List of Symbols

| Symbol | | Description | Equation |
|---|---|---|---|
| $a$ | = | speed of sound | |
| $C_D$ | = | coefficient of drag | $-(dV/ds)(1/V)(2m/\rho S\ell)$ |
| $C_{D_0}$ | = | zero-yaw drag coefficient | |
| $C_{D\delta^2}$ | = | quadratic yaw drag coefficient | |
| $D$ | = | drag force | $\frac{1}{2}\rho V^2 SC_D$ |
| $K$ | = | drag constant | $C_D M$ |
| $\ell$ | = | projectile reference length, usually body diameter | |
| $m$ | = | projectile mass | |
| $M$ | = | Mach number | |
| $s$ | = | dimensionless arc length along the trajectory | |
| $S$ | = | reference area | $\pi\ell^2/4$ |
| $V$ | = | projectile velocity | |
| $\delta^2$ | = | effective squared yaw | |
| $\rho$ | = | air density | |

INTENTIONALLY LEFT BLANK.

## Appendix A: FORTRAN Code that Calculates $C_D$ from Position and Velocity Data.

```
C     ***************************************************************
C     CALC_CD.FOR
C     THIS PROGRAM CALCULATES CD FROM Z-V DATA
C     ***************************************************************

      PARAMETER(MAX = 100)             ! MAXIMUM NUMBER OF POINTS
      CHARACTER*50 FNIN, FNOUT, STRING, FNOUT2
      CHARACTER RND*20
      DIMENSION Z(MAX), V(MAX), C(2)

 100  FORMAT(A)

C     ***************************************************************
C     GET ROUND DESIGNATION.  INPUT DATA MUST BE IN A FILE CALLED
C     "ROUND"_ZV.DAT WERE "ROUND" CAN BE EITHER A ROUND TYPE OR
C     A ROUND NUMBER
C     ***************************************************************
      WRITE(6,*)
      WRITE(6,*)'ENTER ROUND DESIGNATION'
      READ(5,100)RND

      FNIN = RND//'_ZV.DAT'
      FNOUT = RND//'.CD'

C     ***************************************************************
C     READ Z-V PAIRS FROM FILE AND CALCULATE AVERAGE VELOCITY
C     ***************************************************************
      SUM = 0.
      OPEN( UNIT=1, FILE=FNIN, STATUS='OLD', READONLY )
         DO 10 I=1,MAX
           READ(1,*,END=11)Z(I),V(I)
           SUM = SUM + V(I)
 10      CONTINUE
 11   CLOSE(1)
      N = I - 1
      AVG_V = SUM / FLOAT(N)

C     ***************************************************************
C     ENTER PHYSICAL PROPERTIES AND ATMOSPHERIC DATA
C     ***************************************************************
      WRITE(6,*)
      WRITE(6,*)'ENTER PROJECTILE DIAMETER, l (M)'
      READ(5,*)XL
      WRITE(6,*)
      WRITE(6,*)'ENTER PROJECTILE MASS, m (KG)'
      READ(5,*)XMASS
      WRITE(6,*)
```

```
      WRITE(6,*)'ENTER AIR DENSITY, rho (KG/M**3)'
      READ(5,*)RHO
      WRITE(6,*)
      WRITE(6,*)'ENTER VELOCITY OF SOUND, a (M/S)'
      READ(5,*)A
      WRITE(6,*)
      AVG_M = AVG_V / A
      WRITE(6,*)'ENTER REFERENCE MACH NUMBER, M*'
      WRITE(6,*)' (AVERAGE MACH NUMBER IS ',AVG_M,' )'
      READ(5,*)XMSTAR

C     ******************************************************************
C     CALCULATE THE FACTOR K AND CD AT THE REFERENCE MACH NUMBER
C     ******************************************************************
      PI = 3.1415927
      S = (PI/4.) * XL**2              ! REFERENCE AREA
      RDF = (RHO*S*XL) / (2.*XMASS)    ! RELATIVE DENSITY FACTOR

      CALL LSQ1( Z, V, N, C )

      DRAGDOWN = C(2)
      DVDS = C(2) * XL

      XK = -DVDS / (RDF*A)
      CDREF = XK / XMSTAR

      WRITE(6,*)
      WRITE(6,*)'CD(M) = K/M,    K = ',XK
      WRITE(6,*)'CD(MREF) = ',CDREF
      WRITE(6,*)

C     ******************************************************************
C     SAVE CD vs. M AS PLOTTABLE FILE
C     ******************************************************************
      XMIN = 2.5
      XMAX = 5.0
      XSTEP = (XMAX-XMIN) / FLOAT(MAX)
      XM = XMIN - XSTEP
      OPEN(UNIT=2,FILE=FNOUT,STATUS='NEW')
         DO 20 J=1,MAX
           XM = XM + XSTEP
           CD = XK / XM
           WRITE(2,*)XM,CD
 20      CONTINUE
      CLOSE(2)

      STOP
      END
```

```
C     --------------------------------------------------------------
C     SUBROUTINE TO CALCULATE LINEAR LEAST SQUARES FIT
C     --------------------------------------------------------------
      SUBROUTINE LSQ1(X,Y,N,C)
      PARAMETER ( MAX=100 )
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      REAL*4 X(MAX),Y(MAX),C(2),SUM,ERROR
      RN=FLOAT(N)
      SUMX=0.0
      SUMY=0.0
      SUMXY=0.0
      SUMX2=0.0
      DO 10 J=1,N
         DUBX = X(J)           ! DOUBLE PRECISION X
         DUBY = Y(J)
         SUMX = SUMX + DUBX
         SUMY = SUMY + DUBY
         SUMXY = SUMXY + DUBX*DUBY
         SUMX2 = SUMX2 + DUBX**2
 10   CONTINUE
      DUBC2 = (RN*SUMXY-SUMX*SUMY) / (RN*SUMX2-SUMX**2)
      DUBC1 = (SUMY/RN) - (DUBC2*SUMX/RN)
      C(2) = DUBC2
      C(1) = DUBC1
      RETURN
      END
```

INTENTIONALLY LEFT BLANK.

## Appendix B: FORTRAN Code that Calculates $C_{D0}$ and $C_{D\delta^2}$ from (M, $C_D$, $\delta^2$) Data.

```
C     ****************************************************************
C     CD_DELSQ.FOR
C     THIS PROGRAM CALCULATES CDO AND CD-DELSQ
C     FROM RAW M, DELSQ, CD DATA
C     ****************************************************************

      PARAMETER(MAX = 100)              ! MAXIMUM NUMBER OF POINTS
      CHARACTER FNIN*50
      DIMENSION XM(MAX), CD(MAX), DELSQ(MAX), NR(MAX)
      DIMENSION DELSQ2(MAX), CD2(MAX), CDO(MAX), C(2)

 100  FORMAT(A)

C     ****************************************************************
C     READ DATA FROM FILE AND CALCULATE AVERAGE MACH NUMBER
C     ****************************************************************
      WRITE(6,*)
      WRITE(6,*)'ENTER INPUT FILENAME'
      READ(5,100)FNIN
      SUM = 0.
      OPEN( UNIT=1, FILE=FNIN, STATUS='OLD' )
         DO 10 I=1,MAX
           READ(1,*,END=11)XM(I),CD(I),DELSQ(I)
           SUM = SUM + XM(I)
 10      CONTINUE
 11   CLOSE(1)
      N = I - 1
      AVG_M = SUM / FLOAT(N)

C     ****************************************************************
C     GET REFERENCE MACH NUMBER AND SHIFT ALL DATA TO THAT MACH NO.
C     ****************************************************************
      WRITE(6,*)
      WRITE(6,*)'ENTER REFERENCE MACH NUMBER'
      WRITE(6,*)' (AVERAGE MACH NUMBER IS ',AVG_M,')'
      READ(5,*)XMREF

      DO 20 I=1,N
         RATIO = XM(I) / XMREF
         CD2(I) = CD(I) * RATIO
         DELSQ2(I) = DELSQ(I) * RATIO
 20   CONTINUE
```

```
C     **********************************************************
C     CALCULATE CD0 AND CD-DELSQ AT REFERENCE MACH NUMBER, WITH AND
C     WITHOUT MACH NUMBER CORRECTION
C     **********************************************************
      CALL LSQ1( DELSQ, CD, N, C, ERROR )
      WRITE(6,*)
      WRITE(6,*)'WITHOUT MACH NUMBER CORRECTION'
      WRITE(6,*)'CD0 = ',C(1)
      WRITE(6,*)'CD DELSQ = ',C(2)
      WRITE(6,*)'ERROR = ',ERROR

      CALL LSQ1( DELSQ2, CD2, N, C, ERROR )
      WRITE(6,*)
      WRITE(6,*)'WITH MACH NUMBER CORRECTION'
      WRITE(6,*)'CD0 = ',C(1)
      WRITE(6,*)'CD DELSQ = ',C(2)
      WRITE(6,*)'ERROR = ',ERROR
      WRITE(6,*)
      CD_DELSQ = C(2)

      STOP
      END

C     ----------------------------------------------------------
C     SUBROUTINE TO CALCULATE LINEAR LEAST SQUARES FIT
C     ----------------------------------------------------------
      SUBROUTINE LSQ1(X,Y,N,C,ERROR)
      PARAMETER ( MAX=100 )
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      REAL*4 X(MAX),Y(MAX),YF(MAX),C(2),SUM,ERROR
      RN=FLOAT(N)
      SUMX=0.0
      SUMY=0.0
      SUMXY=0.0
      SUMX2=0.0
      DO 10 J=1,N
         DUBX = X(J)             ! DOUBLE PRECISION X
         DUBY = Y(J)
         SUMX = SUMX + DUBX
         SUMY = SUMY + DUBY
         SUMXY = SUMXY + DUBX*DUBY
         SUMX2 = SUMX2 + DUBX**2
 10   CONTINUE
      DUBC2 = (RN*SUMXY-SUMX*SUMY) / (RN*SUMX2-SUMX**2)
      DUBC1 = (SUMY/RN) - (DUBC2*SUMX/RN)
      C(2) = DUBC2
      C(1) = DUBC1
      SUM = 0.
      DO 20 J=1,N
         YF(J)=C(2)*X(J)+C(1)
         SUM = SUM + (YF(J) - Y(J))**2
 20   CONTINUE
      ERROR =  SUM / FLOAT(N-2)
      RETURN
      END
```

| No of Copies | Organization |
|---|---|
| 1 | Office of the Secretary of Defense<br>OUSD(A)<br>Director, Live Fire Testing<br>ATTN: James F. O'Bryon<br>Washington, DC 20301-3110 |
| 2 | Administrator<br>Defense Technical Info Center<br>ATTN: DTIC-DDA<br>Cameron Station<br>Alexandria, VA 22304-6145 |
| 1 | HQDA (SARD-TR)<br>WASH DC 20310-0001 |
| 1 | Commander<br>US Army Materiel Command<br>ATTN: AMCDRA-ST<br>5001 Eisenhower Avenue<br>Alexandria, VA 22333-0001 |
| 1 | Commander<br>US Army Laboratory Command<br>ATTN: AMSLC-DL<br>Adelphi, MD 20783-1145 |
| 2 | Commander<br>US Army, ARDEC<br>ATTN: SMCAR-IMI-I<br>Picatinny Arsenal, NJ 07806-5000 |
| 2 | Commander<br>US Army, ARDEC<br>ATTN: SMCAR-TDC<br>Picatinny Arsenal, NJ 07806-5000 |
| 1 | Director<br>Benet Weapons Laboratory<br>US Army, ARDEC<br>ATTN: SMCAR-CCB-TL<br>Watervliet, NY 12189-4050 |
| 1 | Commander<br>US Army Armament, Munitions and Chemical Command<br>ATTN: SMCAR-ESP-L<br>Rock Island, IL 61299-5000 |
| 1 | Commander<br>US Army Aviation Systems Command<br>ATTN: AMSAV-DACL<br>4300 Goodfellow Blvd.<br>St. Louis, MO 63120-1798 |

| No of Copies | Organization |
|---|---|
| 1 | Director<br>US Army Aviation Research and Technology Activity<br>Ames Research Center<br>Moffett Field, CA 94035-1099 |
| 1 | Commander<br>US Army Missile Command<br>ATTN: AMSMI-RD-CS-R (DOC)<br>Redstone Arsenal, AL 35898-5010 |
| 1 | Commander<br>US Army Tank-Automotive Command<br>ATTN: AMSTA-TSL (Technical Library)<br>Warren, MI 48397-5000 |
| 1 | Director<br>US Army TRADOC Analysis Command<br>ATTN: ATAA-SL<br>White Sands Missile Range, NM 88002-5502 |
| (Class. only) 1 | Commandant<br>US Army Infantry School<br>ATTN: ATSH-CD (Security Mgr.)<br>Fort Benning, GA 31905-5660 |
| (Unclass. only) 1 | Commandant<br>US Army Infantry School<br>ATTN: ATSH-CD-CSO-OR<br>Fort Benning, GA 31905-5660 |
| 1 | Air Force Armament Laboratory<br>ATTN: AFATL/DLODL<br>Eglin AFB, FL 32542-5000 |

<u>Aberdeen Proving Ground</u>

| No of Copies | Organization |
|---|---|
| 2 | Dir, USAMSAA<br>ATTN: AMXSY-D<br>AMXSY-MP, H. Cohen |
| 1 | Cdr, USATECOM<br>ATTN: AMSTE-TD |
| 3 | Cdr, CRDEC, AMCCOM<br>ATTN: SMCCR-RSP-A<br>SMCCR-MU<br>SMCCR-MSI |
| 1 | Dir, VLAMO<br>ATTN: AMSLC-VL-D |

# DISTRIBUTION LIST

No. of
Copies

2 Commander
US Army Armament Research
Development, and Engineering Center
ATTN: SMCAR-AET-A, R. Kline
J. Grau
Picatinny Arsenal, NJ 07806-5000

1 Commander
US Army Armament Research
Development, and Engineering Center
ATTN: SMCAR-CCL-CA, P. O'Neill
Picatinny Arsenal, NJ 07806-5000

1 Gaylord, Morgan & Dunn, Ltd.
ATTN: Ilmars Celmins
4513 Wharf Point Court
Belcamp, MD 21017

# USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number BRL-MR-3843 Date of Report JULY 1990

2. Date Report Received ______

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

CURRENT ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)