BRL-MR-3847

DTIC FILE COPY

(2)

MEMORANDUM REPORT BRL-MR-3847

BRL

AD-A224 800

A DATABASE STORAGE SYSTEM AND THE SONIC DIGITIZER METHOD FOR RADIOGRAPHIC DATA REDUCTION USED BY THE PENETRATION MECHANICS BRANCH

TIMOTHY G. FARRAND

JUNE 1990

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

NOTICES

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1990	Memorandum 1986-1989

4. TITLE AND SUBTITLE
A Database Storage System and the Sonic Digitizer Method for Radiographic Data Reduction Used by the Penetration Mechanics Branch

5. FUNDING NUMBERS
1L162618AH80

6. AUTHOR(S)
Timothy G. Farrand

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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-3847

11. SUPPLEMENTARY NOTES

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

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

A data reduction, storage, and analysis system is used by one team of the Penetration Mechanics Branch of the Terminal Ballistic Division (TBD) of the Ballistic Research Laboratory (BRL). The reduction of penetrator/target interaction, as recorded via radiographs, and the analysis of the data in the computer data storage system are described in detail.

14. SUBJECT TERMS
~~Digitizer~~; Ballistics ~~Limit~~; Databases; Radiographic Analysis; Data Reduction; ~~Data Manipulation~~

15. NUMBER OF PAGES
96

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	SAR

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

INTENTIONALLY LEFT BLANK.

LIST OF TABLES

INTENTIONALLY LEFT BLANK.

ACKNOWLEDGMENTS

The author would like to give his sincere gratitude to Norman Van Renssealear, Mike Keele, and the Range 110 technicians (E. Deal, B. McKay, V. Torbert, J. Koontz, M. Clark, B. Edmanson, and D. English) for their numerous suggestions, helpful hints, and patience in the development of the computerized system. The author would also like to thank J. Spangler and L. Magness for their contributions in the original setup and transfer of the digitizing data.

INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

Maintaining and referencing past data is of major importance in various technical departments. With the recent developments of database storage systems, the storage and tabulation of simple records has become much easier. However, manipulating and quickly tabulating the data in a standard format are often beyond the capability of many of the patented software packages. Therefore, data generated by the Armor/Anti-Armor (A/AA) Concepts team of the Penetration Mechanics Branch (PMB) in the Terminal Ballistic Division (TBD) of the Ballistics Research Laboratory (BRL) at the range 110 facility are stored in a computer storage base using simple BASIC programs. In this format, the programs can be easily adjusted to tabulate and manipulate (graph) the data without purchasing additional peripherals to a software package.

With the addition of computerized digitizing equipment, raw data generated from model-scale, terminal ballistic radiographs (which record the penetrator/target interaction) are easily convertible to files accessed via the database. Therefore, all terminal ballistic data are easily stored in the BASIC formatted database.

2. BACKGROUND

The data of interest to the A/AA Concepts team involve all relevant information on the interaction of a kinetic energy projectile impacting a model-scale screening target. The penetrator designers desire to determine the characteristics (mechanical properties) of the projectile which will make the best penetrator and/or perforator. The projectile under analysis is typically push launched from a laboratory 26-mm smooth-barrel gun system. It is packed in a polypropylux sabot which discards prior to impact with the target. The targets evaluated consist of semi-infinite blocks (armor where the rear face effects do not influence the penetration), monolithic finite targets, spaced-array targets, and composite targets. The performance of the projectile is often ranked in terms of a limit velocity, defined as the velocity at which the projectile will just perforate a finite target. In the A/AA Concepts team, the limit velocity is typically determined by the Lambert Jonas method (Lambert and Jonas 1976). Lambert and Jonas developed a curve-fitting routine which derives the limit velocity by using the striking velocity and residual velocity data pairs in a regression fit to the following equation:

$$V_R = A\ (V_S^{1/P} - V_L^{1/P})^P$$

where,

V_S = striking velocity (m/s),

V_R = residual velocity (m/s),

V_L = limit velocity, derived by the empirical fit (m/s), and

A and P = empirical parameters (nondimensional).

The point where the residual velocity decreases to zero is the determined limit velocity. Against a specific target, the better-performing projectiles have lower limit velocities. Another measure of the projectile's performance is its penetration into semi-infinite armor. At a specified velocity, the better-performing projectiles have deeper measured depths into the semi-infinite armor. Although both of these are measures of the ballistic performance of the projectiles, the characteristics of the failure behavior of the various materials are also of interest to the projectile designers.

The varying failure mechanisms observed for the various penetrator materials and geometries produce significant data for the performance analysis of the projectiles. The database is organized in a manner where the individual ballistic shot data, the rod geometries, and material properties are easily accessed. This is accomplished by storing both the ballistic performance data of the projectile and its material properties (mechanical and physical) all in one data file. The material properties of the projectile are often limited to the data supplied by the manufacturer (ultimate tensile strength, yield strength, ductility, etc.); but, occasionally, the properties are also determined at the BRL. The storage database must be capable of storing and retrieving both sets (BRL and manufacturer) of mechanical and material properties. The individual test data stored consist of all pre-shot measures (projectile mass, length, diameter, etc.), all in-flight measures prior to impact (velocity, pitch, and yaw), any between-plate measures (where applicable), and the behind-armor measures (residual projectile and target fragment velocities and masses). Also, any post-mortem target measures (loss of target mass and perforation hole dimensions) are included. The in-flight pre-impact and post-impact data are gathered from the flash radiograph system which is described in many BRL reports (Grabarek and Herr 1966).

In 1980, Mr. Magness was the sole collector of the penetration data. He developed a simple program to store and retrieve data in a BASIC ASCII format. At the time, the only available computer was a Hewlett Packard 9830. On this computer, in conjunction with the 9867B mass memory system, two independent programs were used to enter the data in a coded format. One of these data storage programs was used for monolithic targets, and the other was used for triple-spaced-array targets. The data were stored in a coded format for two reasons. First, only those persons familiar with the coding system could access the files. Second, using numeric inputs rather than the alphanumeric conserves disk space. The data stored in each program consisted of two matrices and one single variable "N" (the total number of shots stored). The "N" variable was read by the computer followed by a 1 x 100 matrix for the storage of the manufacturer- and BRL-generated mechanical and material properties. Next an "N" by 50 matrix containing the pertinent data for each shot of the single- and triple-array targets was entered. For the limited data input at the time, these programs were sufficient. However, with time, more firing parameters for each shot were considered important enough to store on the Database Storage System (DBSS). Also, as engineers and range technicians began contributing to the database system, the capabilities of the system were exceeded. Therefore, a computer with increased memory and capabilities was required. The storage programs were then converted to the more versatile Hewlett Packard 9845, containing more internal memory (random access memory, RAM). The additional storage space and rapid processing time of the HP9845 allowed for utilization of other programs with the ability to graph selected data quickly and directly from the data files.

For six months in 1986, the author was the sole collector of the penetration data. Recognizing the need for a more efficient method of reducing the radiographs and storing the data in the system used, he developed a point digitizing system which was used on the Hewlett Packard 87. The digitizing system accurately measured the radiographs and stored the data with minimal user prompts. The data were stored on a disk formatted for the HP87; reorganization was necessary for storage in the database system on the HP9845. Mr. James Spangler, an engineering technician (also of the AA/A Concepts team) created a program which could translate the data, via an HP85, to the HP9845 format. The data could be easily added to the current database system.

This method was utilized until 1987, when the A/AA Concepts team purchased a TEMPEST approved IBM PC-AT computer for processing classified material. This computer contained sufficient RAM memory to manipulate the database and store the entire data system on a 20-megabyte Bernoulli data disk. With the introduction of this new equipment, efforts were made to convert all of the programs and files to an IBM BASIC format (which is different from the Hewlett Packard format). Until this time, all of the test data entered were coded and, therefore, unclassified. The approved classification of the IBM PC allowed much of the data to be partially decoded. Some of the codes remained in the database for easy manipulation of the programs with the numeric storage format. As the transfer from the Hewlett Packard basic to the IBM basic was performed, it was realized that the data files could be increased in size by changing the storage format to a binary format. Many of the files in the older ASCII format were divided into two or three subfiles for one material, because the internal memory of the computer was not capable of quickly manipulating such large single files. The binary format not only increased the size of the files, but combined all of the subfiles while increasing the storage space on the disk slightly. Also, the new random access of the files decreased the amount of time required to read and store the files. With additional purchases of IBM-PC clones and a sonic digitizer (SAC GPM-8), the digitizing and storage of the data became a much simpler task. The IBM PCs, in conjunction with the sonic digitizer, are currently used for all of the data reduction and storage.

3. PERTINENT RADIOGRAPHIC DATA MEASUREMENTS

The data generated from the radiographs are divided into three main divisions. First there are the pre-impact measures. These measures consist of the velocity of the projectile and its orientation (pitch and yaw) upon striking the target plate. Second, for targets consisting of more than one plate, there are between-plate measures. The velocities, rotations, flight-line deviations, pitch impacting the next plate, and rod break-up are very important characteristics in the performance of the rod in a spaced-array target. Third, the debris produced behind the armor from the projectile perforating the target plate is a direct measure of its lethality. All of these measures are taken from a flash x-ray system which produces radiographs for each step of the perforation.

These radiographs are triggered by breakscreens. The breakscreens are broken as the projectile passes through them; this, in turn, starts a timer (for a pre-set time interval) which flashes an x-ray tube head (takes a picture) of the projectile in flight. Typically, if a velocity is being determined, two flashes are used. If only a picture of the projectile's break-up is required (i.e., through a narrow section of a spaced-array target), only one flash is taken. For the most thorough calculations, as for the striking conditions, two sets of orthogonal flashes are used. A sample set-up for the x-ray tube heads for the single-array target is shown in Figure 1; a triple target set-up is similar but includes two additional tube heads between each set of plates.

3.1 Pre-impact Measures. Figure 2 is an example of a radiograph from which pre-impact conditions are determined. The striking velocity can be calculated from the radiograph by determining the actual location of the projectile in space and using the time interval between the flashes. The location of the projectile in space is determined by locating a point on the projectile in each flash and referencing it to the orthogonal fiducial wires (reference lines located directly on the film). A similar triangles method is used to determine the magnification factor of the projectile on the film. This is explained in detail in a previous BRL report (Grabarek and Herr 1966). The

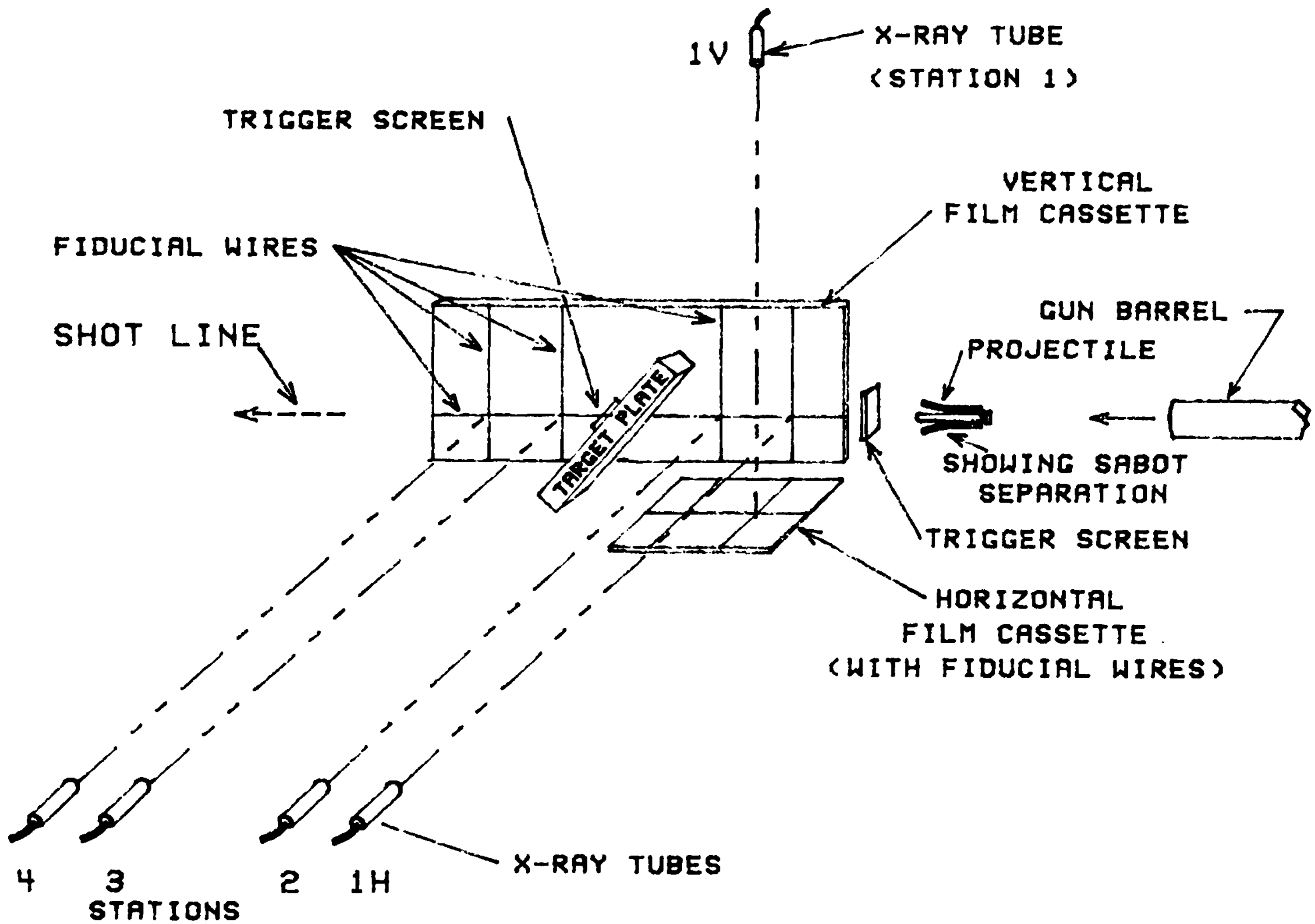


Figure 1. Sample X-Ray Setup.

Note: Projectile is flying from the right to the left on the page.

Figure 2. Sample Radiograph of Pre-Impact Images.

magnification factor is used to calculate the actual location of the projectile in space. By using the time interval between subsequent flashes, the velocity of the projectile can be determined. This method has been documented and is commonly used throughout TBD. However, the calculation of the pitch (alpha,α) and yaw (beta,β) of the projectile impacting the armor is not as standard. Measuring the angle the projectile makes with the fiducial wire does not give the true pitch in space. The true pitch of the projectile is the angle the projectile makes with the direction the projectile is actually traveling (the true flight path). To determine the true flight path, the coordinates of the center of mass of each image of the projectile must be calculated. The line connecting these points will be the true flight path. The angle the projectile makes with the flight path is determined by calculating the centerline of the projectile using its actual coordinates in space. The angle between the centerline and the flight path will be the actual pitch. By using the actual coordinates of the projectile in space rather than directly from the film, no additional errors are introduced to the calculations. This is also the correct procedure for calculating the yaw in the horizontal plane. The combined yaw (β) and pitch (α), gamma (γ), is calculated using the Pythagorean theorem ($\gamma^2 = \alpha^2 + \beta^2$) for small angles (less than 6 degrees). Gamma is the total angle of the projectile impacting a target at normal impact, which was used to determine if the impact was a fair hit. For many of the tests fired against targets at increased obliquity (greater than zero), only one horizontal flash was taken. The performance of the projectile is more sensitive to variations in pitch in the plane of the obliquity of the target; therefore, the horizontal yaw was calculated using only one radiographic image.

Traditionally, the striking calculations were determined by manually measuring the distances from the fiducial wires to two points on each projectile; one is for the fixed point velocity calculation and one is for the center of mass flight-line. These measures were input into a Monroe computer which calculated the velocity of each point using the change in locations in both the vertical and horizontal directions (Z - line of flight and Y - up or down). The flight-line deviation (ETA) had to be calculated manually by taking the arctangent of the change in horizontal location divided by the change in vertical location. The angle the projectile made with the horizontal fiducial wire was then physically measured directly from the radiograph. The difference between the measured angle and the flight path of the projectile determined the yaw impacting the target. The digitizing system performs most of these calculations with minimal physical measuring. Points indicating the intersection of the fiducial wires for reference are digitized first. Next, five points around each projectile image (one for the fixed point velocity and the other four to determine the actual pitch of the projectile) are digitized. Figure 3 depicts the points needed to digitize the striking velocity. Using some minor prompts upon beginning the digitizing process, the computer

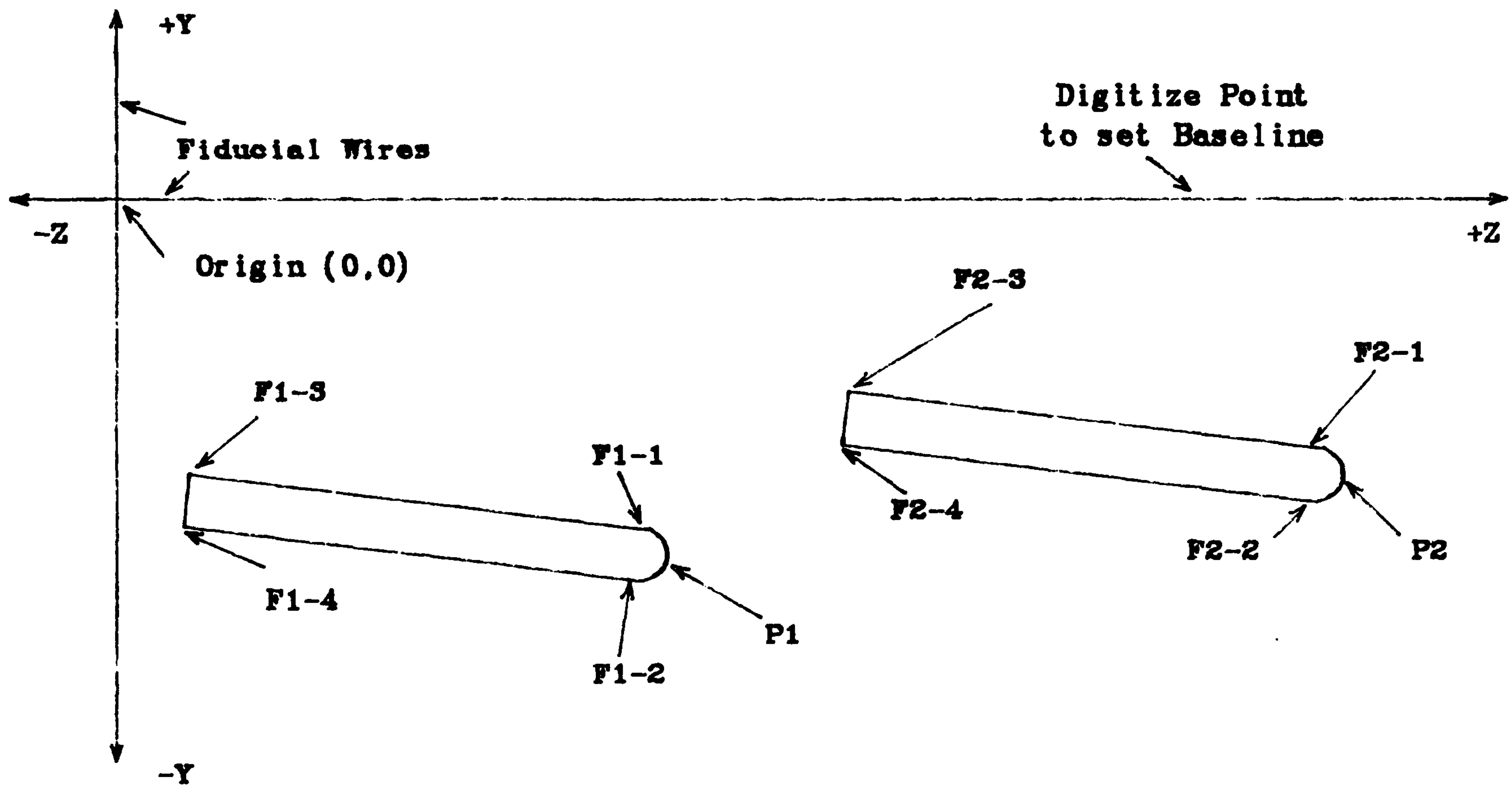


Figure 3. Digitizing Points for Striking Velocity.

can calculate the velocity, the actual pitch and yaw, and the flight path in both planes. Figure 4a shows the digitized coordinates and depicts how the computer calculates the data. Also shown in Figure 4a are two dotted lines depicting the center-of-mass flight line and its parallel vector passing through the horizontal fiducial wire (lines II and I, respectively). The angle I makes with the fiducial wire is the flight-line deviation, ETA (η). The other dotted vectors, III and IV, depict the centerline of the projectile and its parallel vector, respectively. The angle vector IV makes with the horizontal fiducial wire is the apparent pitch, Pimb, at the second flash. The angle II makes with the centerline of the second projectile is the actual pitch, alpha. To calculate the actual pitch, the computer subtracts the flight-line deviation, ETA, from the apparent pitch, Pimb. These equations and the coordinates used in all of the angular and velocity measures are shown in Figure 4b. The computer is capable of quickly determining all of the pertinent data much more accurately and consistently than if performed by hand.

3.2 Between-Plate Measures for a Spaced-Array Target. The importance of measuring penetrator data between the plates of a spaced-array target has only recently been fully recognized. The change in velocity, the break-up and/or bending of the rod, and primarily, the induced pitch and rotation of the rod are major factors in the ballistic performance of the projectile.

To determine the measures mentioned above, two x-ray flashes are taken between the individual plates of the target array in the vertical plane. These tube heads are typically triggered by a breakscreen on the front of the first plate of the array, and will flash at pre-set time intervals (capturing two images of the projectile between the plates). Samples of the between-plate radiographs are shown in Figure 5. By relating the location of the images on the film to the reference fiducial wires, the velocity of the projectile can be calculated in the same manner as the striking velocity.

To calculate the velocities and angular measures (manually or by use of the digitizer), a fixed point on each image, the centerline for each image, and the estimated point of impact on the next plate image must be physically drawn on the radiograph. For the manual calculations, the coordinates of the fixed point and of the center of mass for each fragment must be determined. These are input into the Monroe computer to calculate the velocity and the flight line of the projectile. Then the pitch at the time of the second flash can be determined in the same manner as for the striking calculations. However, in this case, rather than having the centerline calculated by the computer, it is physically drawn on the radiograph for clarity for the sometimes severely bent rods. The centerline angle of the projectile with respect to the flight line is the pitch (similar to

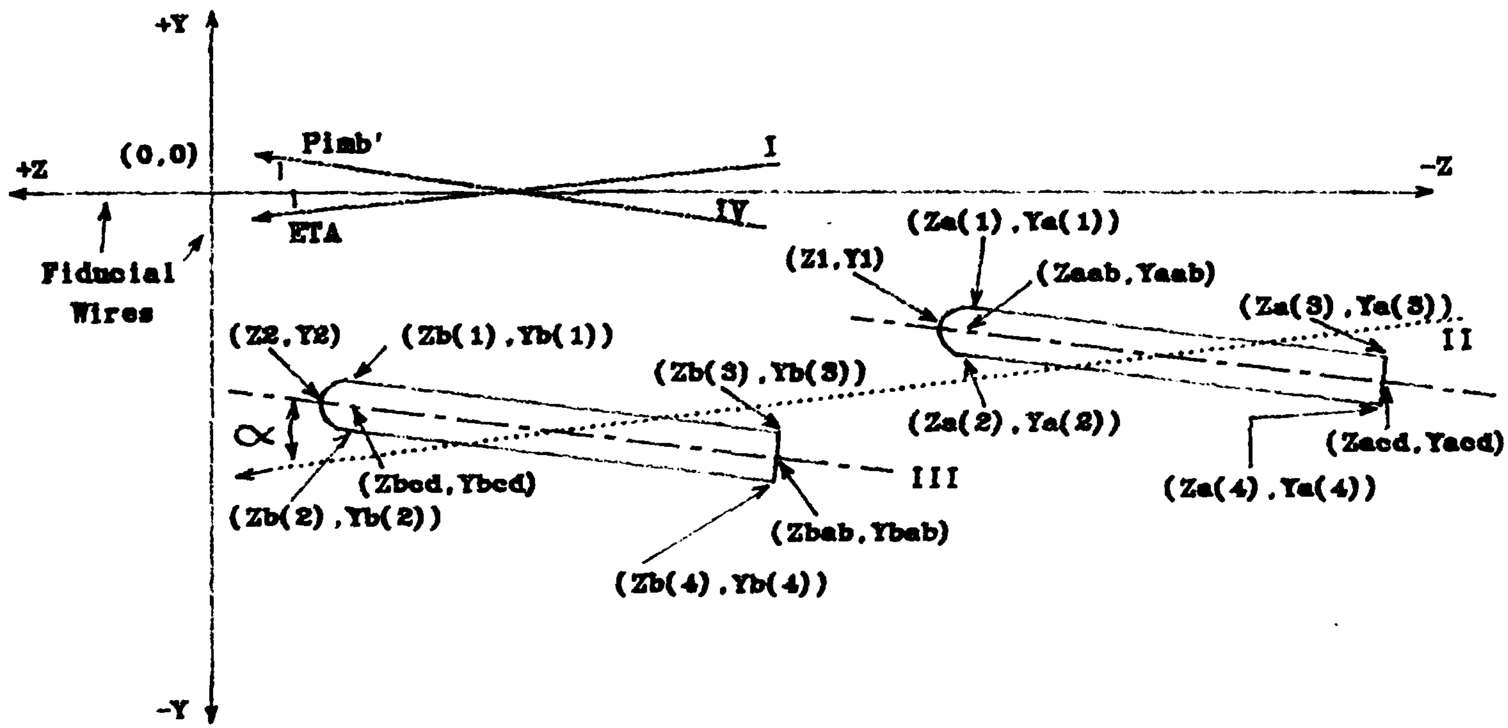


Figure 4a. Striking Velocity Calculation Points.

Coordinates:

```
    Z5 Distance between tube heads      X,Y, and Z are read
G   Z2=-Z       Z1=-Z+Z5   Y=Y   X=X    from digitizer
E   Z2=Z-Z5     Z1=Z       Y=Y   X=X
Diameter    Dia=sqr((Zb(i)-Zb(i+1)) 2 + (Yb(i)-Yb(i+1)) 2)
Length of Center of Mass      Lcm=Ld*Dia/2
Centerline Location:   Average pts i and i+1
Measured Pitch:   Pima = ATN(ABS(Yaab-Yacd))/(ABS(Zaab-Zacd))
Center of Mass  Zacm=Z1+Lcm*cos(Pima)   Yacm=Y1p+Lcm*sin(Pima)
```

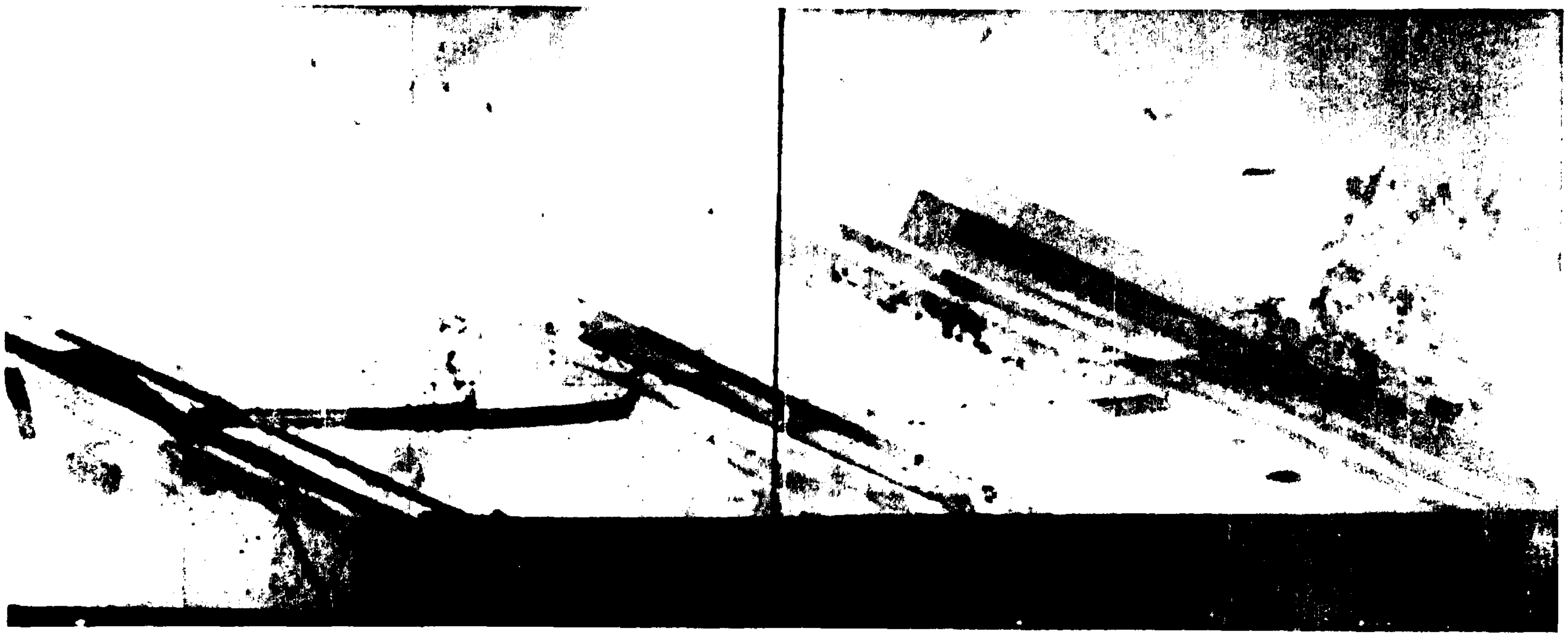
Velocity:

```
    Correction Factor-
     k=(Y5*(X5-X6-X1)-(Y6*(-X1)))/(X5*Y5+X1*Y1)
    I1=(Y2-Y1)*k      I2=(Z2-Z1)*k+Z5
    Vel=SQR(I1*I1+I2*I2)/12/TIME
```

Angles:

```
    Line I is parallel to line II
    Line III is parallel to line IV
    ETA=ATN(I1/I2)    Alpha=Pimb-ETA
```

Figure 4b. Equations for Striking Calculations.



Note: Projectile is flying from the left to the right on the page. Multiple images of three target plates.

Figure 5. Sample Between-Plate Radiograph.

the striking pitch). However, this angle is not the pitch with which the projectile will impact the next plate of the array. To determine this angle, the rotation of the projectile and the time and the distance before the projectile impacts the next plate must be calculated. The difference in the centerline of each image divided by the time between the two flashes will give the rotation rate (degrees/second) of the projectile. This rotation rate, multiplied by the time to impact on the next plate, gives the additional angle (pitch) induced after the flash is taken. The additional angle is added to or subtracted from (depending on the direction of rotation) the pitch at the time of the second flash to determine the pitch of the penetrator upon impact of the next plate.

The hand calculation of these measures involves many steps. First, the velocity is determined for the fixed point and the center of mass as described earlier. Second, the rotation angle must be determined. To do this, extremely long centerline and/or large drafting triangles must be used to physically draw the angle. This angle is divided by the time interval to give the rotation rate. Next, the distance from the nose of the projectile to the estimated point of impact on the following plate is determined. The actual location of the nose and the target plate must be drawn on the film. This is done by measuring the distance from the intersection of the fiducial wires (where the x-ray tube head is located) to the nose of the projectile and also to the location of the impact on the target plate. Multiplying these distances by a correction factor (k) and measuring from the fiducial wires again, the actual location of the nose and the target impact position can be drawn on the film. The distance between these two actual points (the nose and impact location) is measured and is divided by the velocity, resulting in the time before impact on the next plate. The time can then be multiplied by the rotation rate to give the additional pitch induced by the rotation. The additional pitch is added to the pitch at flash 2 to determine the actual impact pitch on the plate.

As mentioned, the severe bending of the rod may also have a detrimental effect on the ballistic performance. A simple measurement of the maximum bend in the rod can be determined. A straight line drawn along the edge of the projectile connecting the nose and tail will show the bend in the rod. By measuring the distance from the drawn line to the edge of the rod where the maximum bend is located, the severity of the bend can be estimated. Also, the location can be determined by measuring the distances along the drawn line to its perpendicular bisector at the point of maximum bend. A "stick" representation of the bent rod can then be determined from these measures. Figure 6 shows the details of these measures with some various examples of the true image and the calculated image. Obviously, performing all of these operations by hand to calculate the velocity, pitch on impact, rotation, flight-line deviation, and bend is very time consuming and introduces a considerable margin for error.

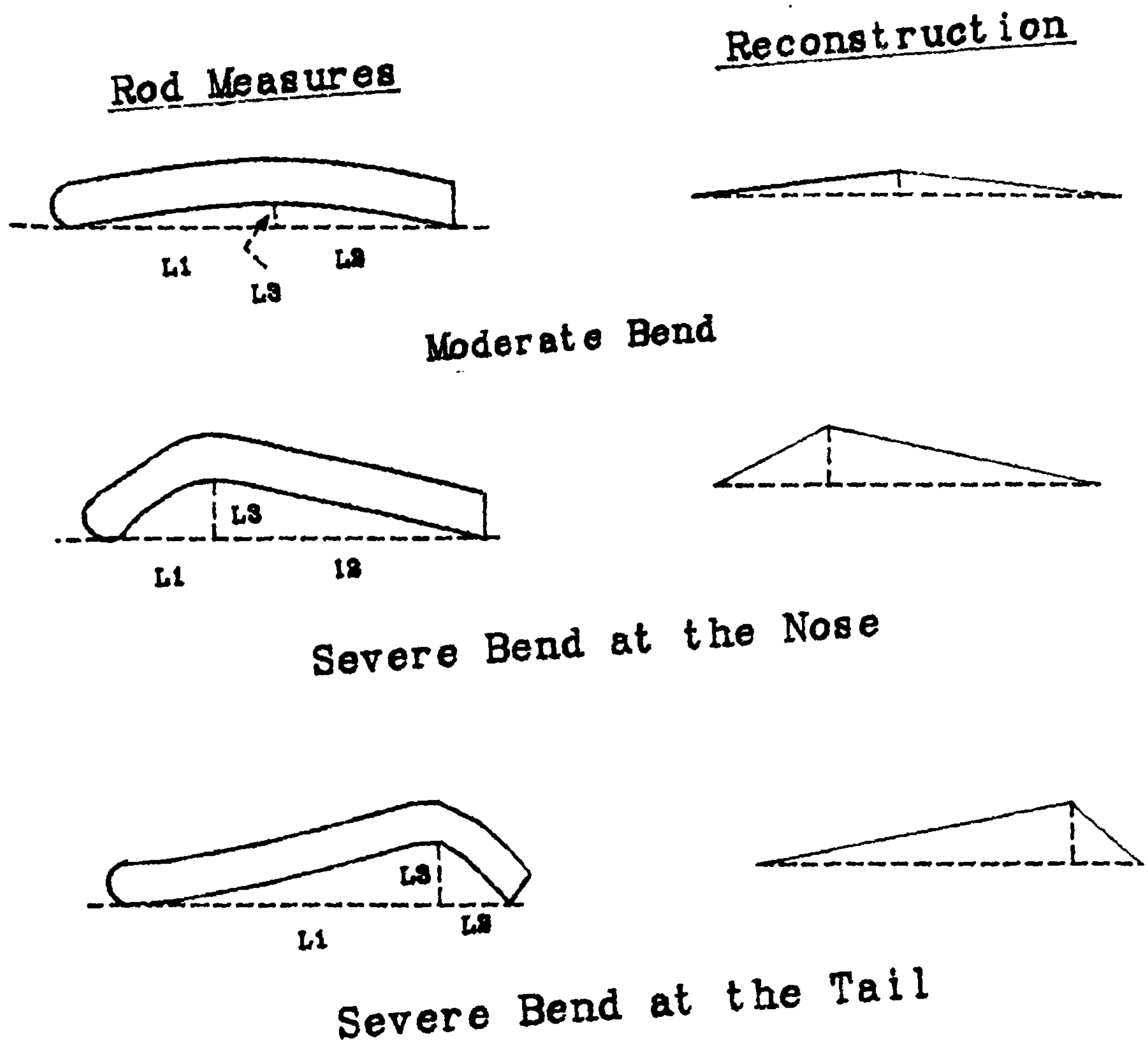


Figure 6. Bend of Projectile.

The procedure for using the digitizer is much easier. First, as with the manual calculation, the fixed points, the target impact intersection, and a centerline on each image must be located. Along the centerline, three points are located: one is at the nose, the second is at the tail, and the third is at the center of mass of the projectile. Between the plates, the intersection of the fiducial wires is first digitized to set the baseline. Then the fixed point on each image is digitized to determine the correct velocity. Next, the three points along the centerline of each image (used in determining the pitch and rotation rates of the rod) and the point of impact on the next target plate are digitized. Figure 7 depicts the typical digitized points for a standard procedure. If the nose or the tail of the projectile is not visible (due to mechanical failure of the x-ray system), an estimated location of the nose or tail (if visible and not deformed) along the centerline will suffice. If the penetrator has already impacted the following plate, the pitch at that instant must be used for the impact pitch. To indicate to the computer that the rod has impacted the next plate, the point digitized on the centerline near the nose of the projectile must be past or further down range than the point digitized for the impact location on the target. Figure 8 is a sample between-plate radiograph where the projectile has already impacted the next plate. The computer will not add any additional angle due to rotation, because the distance to the plate will be less than zero. After all of the points are digitized, the computer calculates the velocity, the rotation rate, the pitch at the second flash, and the pitch impact of the next plate in the same manner as previously performed by hand. Figure 9a depicts the coordinates used in the computer calculations. Also shown in the figure is the projectile impacting on the next target plate (this estimate of the rod location is shown by the dotted silhouette). Figure 9b lists all of the equations used by the computer to perform the calculations which were previously computed by hand. In addition to the pitch, the bend can also be digitized by locating three additional points on the second flash. First a line must be drawn along the edge of the projectile connecting its nose and tail, as discussed earlier. Also, the location of the maximum deflection (bend) is determined. The first point to be digitized is along the line at the tail of the projectile. Then, the corresponding point at the front of the projectile and, finally, the point at the maximum deflection on the actual projectile image are digitized. These points are shown in Figure 6 as L1 through L3. The computer calculates the length of the line, the deflection distance, and the length to the perpendicular bisector. Using these lengths, the reconstructions made in Figure 6 can be developed and saved. The increasingly important measures are now more reproducible, and the margin for error and time required have been greatly reduced by use of the digitizer.

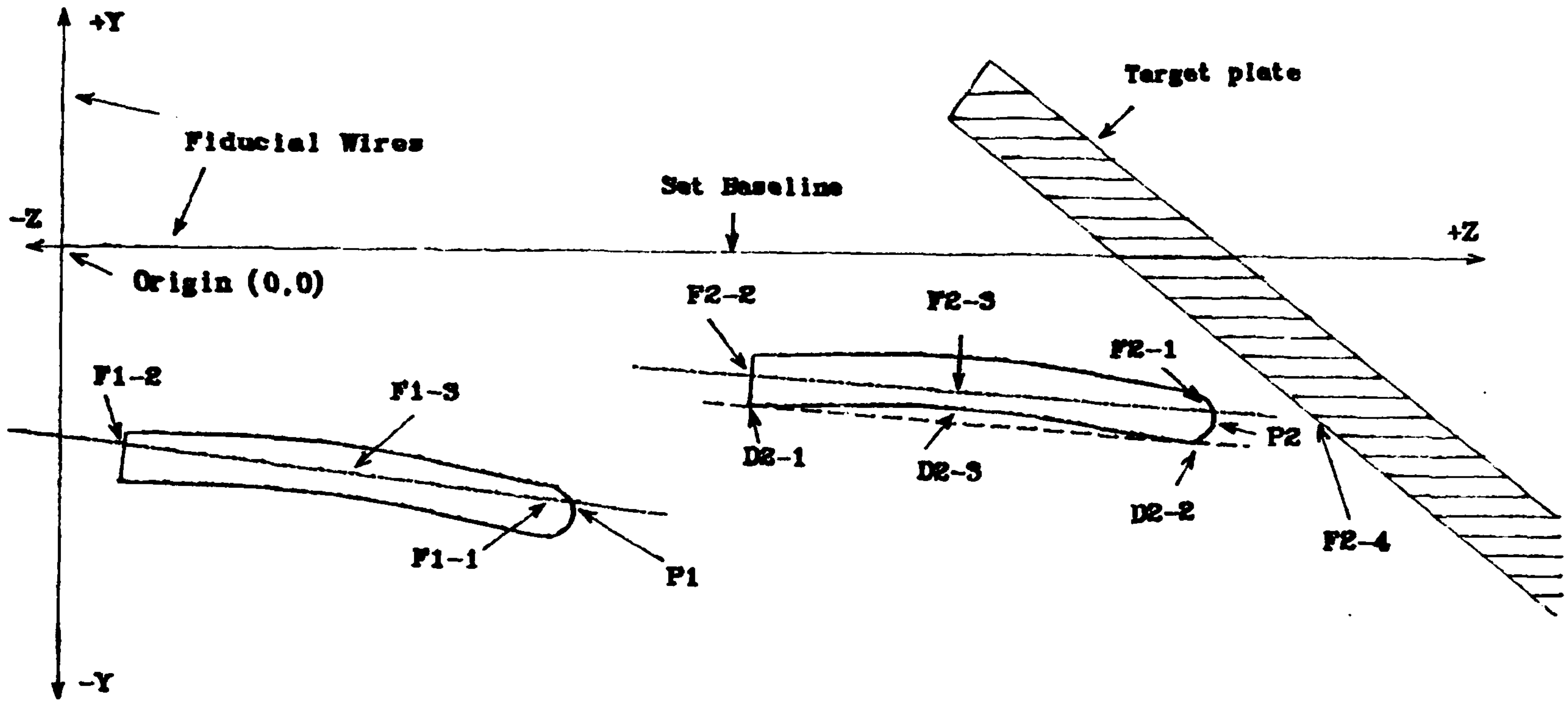


Figure 7. Digitizing Points Between the Plates.

Note: Projectile is flying from left to right on the page.

Figure 8. Sample Radiograph of Projectile Impact on Next Plate.

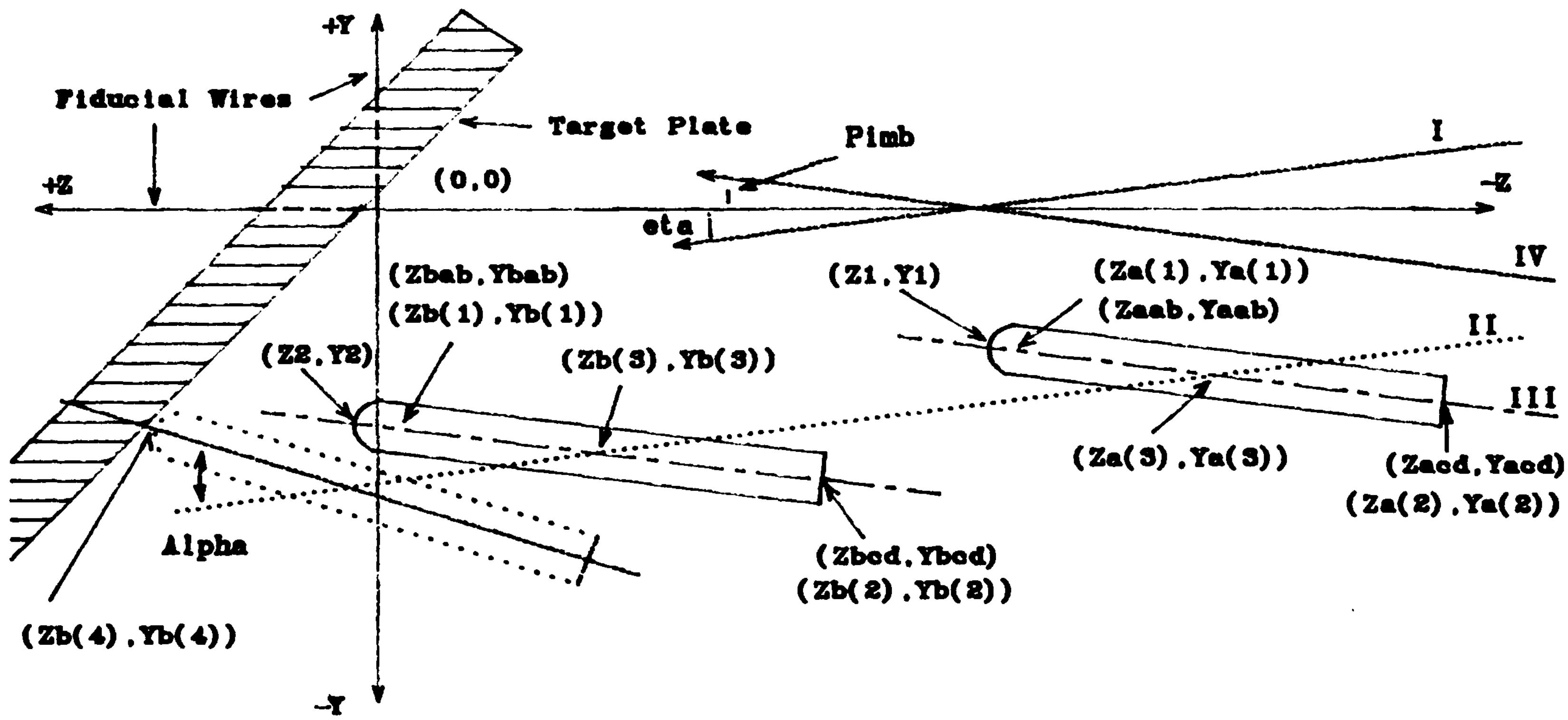


Figure 9a. Between-Plate Digitizing Calculation Points.

```
Coordinates are digitized as shown in previous figure
Veloctiy and ETA are calculated similar to striking

Angles and Rotation:

    Line II is parallel to line I
    Line III is parallel to line IV
    Pima=ATN(ABS(Yaab-Yacd)/ABS(Zaab-Aacd))
    Pimb=ATN(ABS(Ybab-Ybcd)/ABS(Zbab-Zbcd))
    Rot.=(Pima-Pimb)/(Time)
    Dist to Plate=((Zb(4)-Zb(1)) 2+(Yb(4)-Yb(1)) 2) .5
    Time to PLate= Dist/(12*Vel)
    Add. Angle= Rot.*Time to Plate
    Angle on Impact= Pimb+AA-ETA(center of mass)
```

Figure 9b. Equations for Between-Plate Calculations.

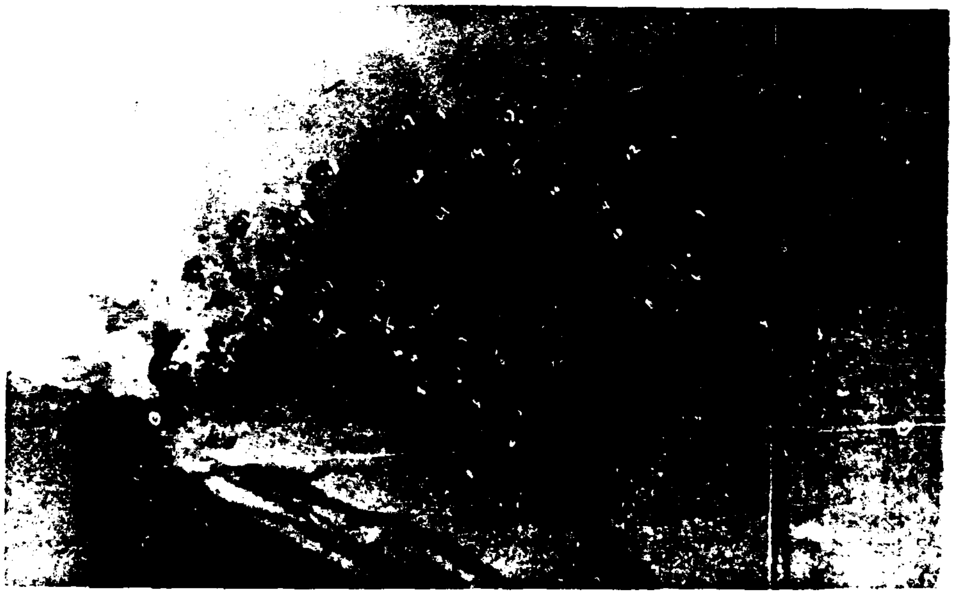
3.3 Residual Radiographic Measures. Once the penetrator has successfully perforated the armor plate, it must be capable of producing lethal debris to be an effective projectile. The two methods of measuring this debris are: first, by use of the radiographs, and second, by using witness packages (a sequence of plates of increasing thickness) located behind the target. To characterize the behind-armor debris fully using either method is a very time consuming and costly task. Therefore, this procedure is only performed if a specific request has been made and funds are allotted.

A radiograph cassette placed behind the target in the vertical plane is used to calculate the residual behind-armor characterization. Again, two x-ray tube heads, initiated by a breakscreen on the rear face of the target, flash at pre-set times. Figure 10 shows two sample radiographs of the residual debris. The location of the residual penetrator in relation to the fiducial wires must be measured from the images. By inputting these values into the Monroe computer, the velocity of the residual penetrator and its departure angle from the horizontal (calculated using the arctangent of the change in Y divided by change in Z) can be determined. In addition to the velocity of the penetrator, its orientation and mass are important. As can be seen from the two photographs in Figure 10, the upper figure shows a projectile that is tumbling through space, typical for residual penetrators close to the limit velocity. The bottom photograph shows a projectile that is flying very nearly straight with considerable residual mass, typical for striking velocities well above the limit velocity. Obviously, the fragment which is more undisturbed by the target will be more lethal to behind-armor obstacles.

The actual orientation of the projectile in the low overmatch condition (V_S near V_L) is not of importance and is also difficult to measure. However, the orientation of the projectile in the lower picture is important, due to its lethality, and can be measured. The characteristics determined for the residual projectile consist of the flight-line deviation (ETA, η), the pitch (alpha, α), the change in pitch (delta alpha, $\Delta\alpha$), and the time delays. All of these measures are determined in the same manner as the between-plate measures, by drawing the centerline on the residual fragments and determining the orientation of each image with respect to the fiducial wires in actual space. The high lethality of the major residual piece is included in the total behind-armor debris.

However, for a full behind-armor analysis, two additional tube heads in the horizontal plane are required. Using all four flashes, the location of each fragment ejected from the target and the residual penetrator pieces are matched in the vertical and horizontal planes. Their coordinates are input into the Monroe computer and the actual velocity in space can be determined. By using the

a. Overmatch Condition Very Near Limit Velocity.



b. High Overmatch Condition (V_S/V_L>>1)

Figure 10. Sample Residual Radiographs.

additional two tube heads, an accurate measure of the velocity and direction in space can be determined. Also, the second view gives all three dimensions of the fragment; therefore, the exact mass of the fragment can be calculated (this method is discussed later). Obviously, performing this task for all shots, each having a total number of fragments ranging from 10 to 400 (for small-scale testing), is very tedious work. Currently, it has not been proven, to the knowledge of the author, that the total behind-armor debris for the model (one-quarter) scale can be scaled to the large caliber testing. Therefore, in the model-scale testing performed in the indoor ranges, only the major target fragments and residual penetrators are measured. However, for small caliber testing (25 mm and less), a full behind-armor analysis can be conducted, if requested. Also, even if not requested, the AA/A Concepts team does its own quick analysis of the radiographic behind-armor debris for future reference. The quick analysis includes measuring the velocities and fragments, and estimating the masses for all of the easily recognizable debris which appear in the vertical plane. The easily recognizable debris can be quickly matched in one x-ray flash to the next. By using only the vertical plane and only matching recognizable fragments, the amount of time required to make the analysis is reduced considerably.

However, performing the quick behind-armor radiographic reduction by hand still requires extra effort for the engineer and/or technician. As mentioned earlier, one method of determining the location of each fragment is by inputting its measured coordinates from the x-ray images into the Monroe computer, which calculates the velocity and departure angle for each fragment. A faster approach to calculate the velocity and angle of the fragment is performed by use of a graphical method. By using the correction factor calculated in the striking velocity, then physically measuring the distance from the intersection of the fiducial wire to the fragment image in each flash, the actual location in space at the instant of the picture is calculated. The velocity is found by measuring the distance between the two actual locations. The distance traveled by the projectile divided by the time between the subsequent flashes gives its speed. The departure angle is determined graphically by using large triangles to physically draw the angle between the horizontal fiducial wire and the flight path of the fragment. The last step, measuring the mass of the fragments, is always performed in the same way, regardless of the method of determining the velocity and angle of departure. The mass of the target fragment is estimated by measuring the two dimensions of the fragment (viewed in the vertical plane) and estimating the third dimension, then multiplying each dimension by the correction factor. The corrected dimensions of the target fragments are then multiplied by the density of the target (125 grams/cubic in for steel). The residual penetrator fragment masses are calculated somewhat differently. The rod typically remains cylindrical in shape. Therefore, the length of the rod is measured and corrected for its actual length using the correction factor. The corrected length is multiplied by the mass per unit length of the original rod to obtain the mass of the residual penetrator. The mass per unit length is determined by calculating the cross-sectional area of the cylindrical rod and multiplying by the material density. These methods of determining the masses for both the target fragments and residual penetrator pieces have proven accurate in most experiments. Repeating these three steps, measuring the velocity, determining the departure angle, estimating the mass for 5 to 30 fragments, and storing the data completes the quick behind-armor analysis.

The digitizer can perform the calculations of the velocity and departure angle and even store the data much easier than either of the manual methods. First, the intersection of the fiducial wires must be digitized and the baseline set. Next, the center of mass of each fragment is determined and digitized. Figure 11 shows the ordering of the digitized points and sample coordinates used by the computer for the fragment velocity calculations of fragments 1-3. The coordinates of points Y3(I), Z3(I), Y4(I), Z4(I) on the film and the calculation of the correction factor, K, is performed in the same manner as done for the striking calculations. The computer calculates the actual location of the points by multiplying each coordinate by the correction factor. The distance the projectile travels in each direction, vertically and along the flight line, is computed by incorporating the coordinates of the images and the location of the tube heads. Using the Pythagorean theorem, the total distance the projectile traveled is determined. This distance, divided by the time between the flashes, gives the speed of the fragment in the vertical plane. The departure angle is computed by taking the arctangent of the distance the fragment traveled up or down divided by the distance it traveled along the flight-line. If the alpha of the residual fragment is requested, 3 points along the centerline of each image are digitized, see Figure 11. The computer then calculates the velocity, flight line, and change in flight line as computed for the between plate measures. After the computer has calculated the velocity and angle for each fragment, it will store them in separate files. However, the mass of each fragment still must be measured by hand and input into the data file manually as discussed earlier. The versatility of the program enables the user either to measure the quick behind-armor debris or simply measure the main residual penetrator or target plug. The simple prompts will store the data in the appropriate files, one for behind-armor data and one for the database system.

4. COMPUTER PROCESS FOR READING RADIOGRAPHS

4.1 Digitizing Programs. The preceding sections detail the manual and digitizing calculations of the data currently available to the A/AA Concepts team. Comparing the time spent on manual

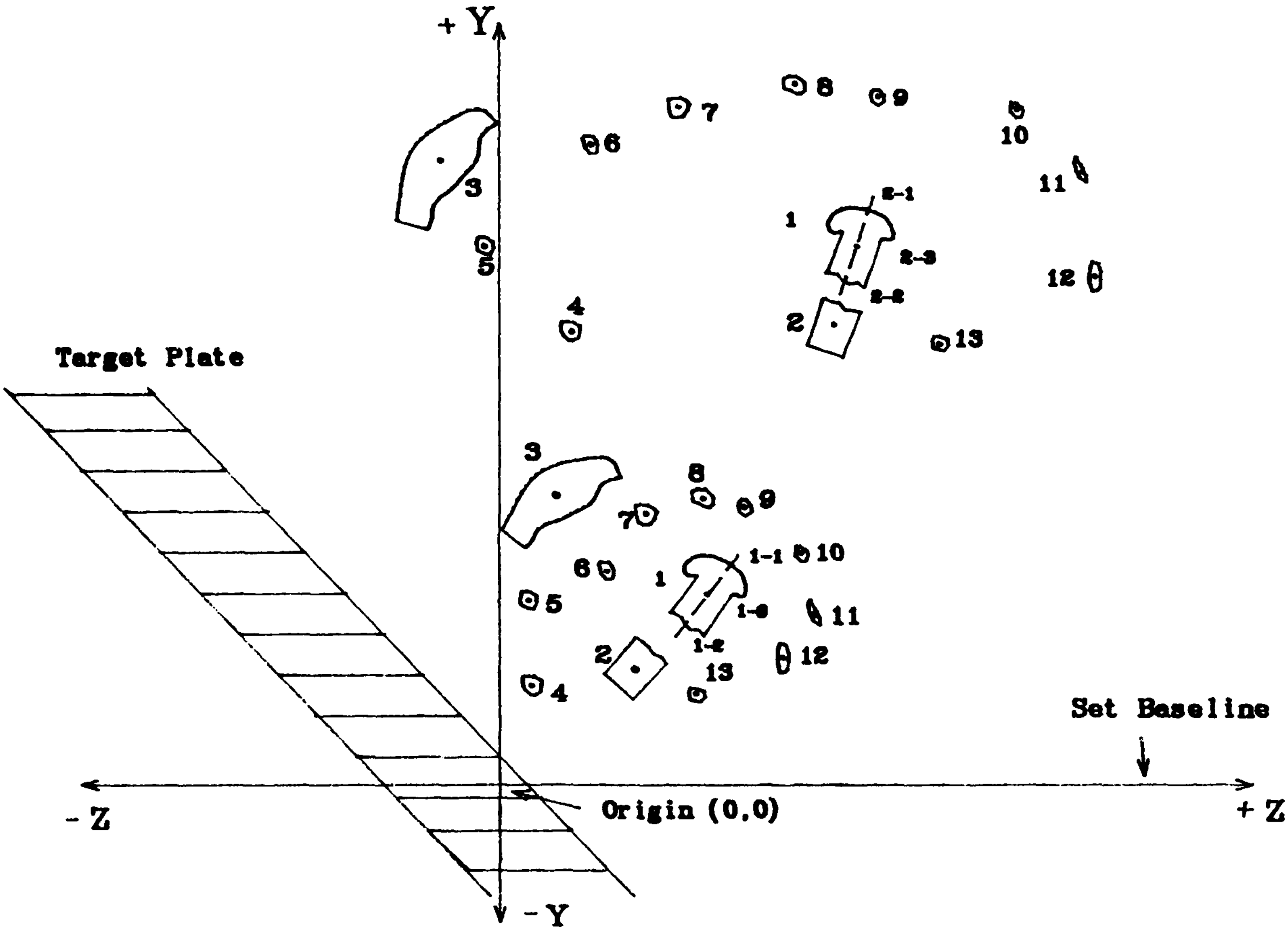


Figure 11. Digitizing Points for Residuals.

calculations to the computer time required to perform the same calculations, the digitizing system is obviously very efficient.

The digitizer utilizes two programs, one for monolithic targets and one for spaced-array targets (two or three target plates). The details of the individual steps required for the reduction of the radiographs using the digitizer are described in the user manuals for each program, included in Appendix A. However, an overview of the programs will be discussed here. A menu is designed on the personal computer, used primarily for digitizing the radiographs, to access the programs simply with one command. The programs themselves are described in the following section.

SPEED1 is the program for monolithic targets. It reads the striking and behind-armor radiographs. SPEED3 is the program for the spaced-array targets. Similar to SPEED1, this program reads the striking and behind-armor radiographs, but also includes the between-plate measures. Both programs begin with prompts for the shot number, date, length to diameter ratio (L/D), and range where the test was conducted (110-E or 110-G). The SPEED1 program also includes a prompt for the obliquity of the target. After the prompts are completed, a menu containing the options to reduce the radiograph appears. These options are chosen by the function keys on the computer. Both programs have the options STRIKING, EXIT V, PRINT, STORE, and QUIT. The options perform the reduction of the radiograph using the calculations described previously. STRIKING is the label used for the striking calculations and EXIT V for the behind-armor calculations. In addition, the SPEED3 program contains a section for reducing the between-plate radiographs, VR1 and VR2. This key is used for either the first residual (between the first and second plates, VR1) or the second residual (between the second and third plates, VR2) The PRINT prompt prints the data on paper or to the screen. Sample printouts produced by the SPEED1 and SPEED3 programs are tabulated in Tables 1 and 2, respectively. QUIT not only ends the program, but it also returns back to the directory containing the program. The STORE prompt stores the data in a behind-armor storage format (used only for specific test programs) and/or in the database storage format. The individual data files for the behind-armor and database system are stored on a disk located in a separate disk drive. The behind-armor storage portion of the program requests only the shot number for storage. The program stores the data in an ASCII file, then opens a file entering blank spaces at the beginning for the data describing the penetrator material, the target material, and the striking conditions. The correct values for these parameters must be entered using the keyboard at a later time. The second portion of the file is an N (number of shots) by five matrix. In this matrix, the entries for the type of fragment (penetrator or target, plus whether or not it lies on the outer edge of the fragment spray), the velocity of the fragment, the

Table 1. Sample Printout for Single Target.

```
        SHOT NUMBER  3700    DATE 21 April 1989

              STRIKING RESULTS     for Range E
              DISTANCE BETWEEN HEADS IS   12
         Time (usec)     190.6     K =  0.7715
         ALPHA =      1.25      BETA =   -0.25
         ETA 0 =    0.00    GAMMA  =     1.27
                 Fixed Point                  Center of Mass
              X        Y        Z          X        Y        Z
          -0.6200    0.0200   1.7500     -0.6101  -0.0294  -1.0935
                     0.0400  -0.6400              -0.0227  -3.4831

Velocity  (fps/mps)   4440/1353                  4441/1353
     Eta   (deg)       0.00                        0.00

                         BEHIND ARMOR DEBRIS
                   Distance between heads is 4
        K = 0.7715                  TIME (usec)    200.80
           No. of Fragments =   4
      #         Y        Z        ETA          VEL         Type        Mass

                                          f/s      m/s                 grams
      1       0.0700   5.1800
              0.1300   4.2600    0.81      1366      416
      2      -1.0000   5.0200
             -1.6900   3.8700   -9.70      1311      400
      3       0.0400   1.5500
              0.5900  -0.1900    9.07      1117      341
      4      -0.3800   0.9700
             -0.8400  -0.7000   -7.46      1135      346

          CONE ANGLE  18.78      Center of Fragment Spray   -0.32
```

Table 2. Sample Printout for Triple Target.

```
SHOT NUMBER  0      DATE  21 April 1989
        FIRST RESIDUAL RESULTS
 Time (usec)  55.7  K =  0.7627     Head Distance   4
 ALPHA 1 =    0.50   Delta Angle =    0.00  Rotation Rate          0
alpha'   0.08  Add. Angle =     0.00  Distance to Plate    2.53

      Fixed Point                  Center of Mass
     X        Y        Z         X        Y        Z
 0.3043    0.1848  -3.7029      0.3043   0.0482  -0.6836
           0.1590  -5.4033               0.0165  -2.3761

Velocity  (fps/mps)  4044/1232                 4053/1235
   Eta    (deg)        -0.50                     -0.50

      SECOND RESIDUAL RESULTS
 Time (usec)  60.7  K =  0.7627     Head Distance   4
 ALPHA 2 =    4.25   Delta Angle =    2.25  Rotation Rate    35724
alpha'   4.29  Add. Angle =     1.06  Distance to Plate    1.39

      Fixed Point                  Center of Mass
     X        Y        Z         X        Y        Z
 0.3043    0.1860   2.9099      0.3043   0.0863   0.4304
           0.3293   1.4167               0.1528  -1.0681

Velocity  (fps/mps)  3930/1198                 3923/1195
   Eta    (deg)         2.25                      1.00


                BEHIND ARMOR DEBRIS
      K = 0.7627                   TIME (usec)    200.8
      No. of Fragments =   6
  #      Y        Z        ETA          VEL          Type        Mass

                                    f/s      m/s
  1    3.259    4.1077
       6.8542    5.2829    29.2      2329      710
  2    4.523    3.6601
       9.0169    4.0134    38.8      2272      693
  3    5.033    2.6786
       9.8863    1.9535    47.0      2099      640
  4    4.187    1.7302
       7.9287    0.2819    44.6      1687      514
  5    5.104    1.3451
       5.9571   -2.3995    29.6       546      166
  6    2.363   -1.7341
       4.1818   -6.3290    70.3       611      186

    CONE ANGLE  41.10     Center of Fragment Spray   0.00
```

departure angle, the estimated mass, and the recovered mass are included. The digitizer only calculates and stores the velocities and departure angles for the fragments; the masses and identification of the fragments must also be entered via the keyboard at a later time.

The storage of the information used in the standard database system requires approximately six or seven additional entries from the keyboard addressing the coded target-penetrator combination (T-designation) and specifications of the residual rod and between-plate measures (for spaced targets). The program stores the data in a 1 x 50 matrix. The program will store the T-designation, the identified residual fragments, and any calculations made for the velocities and angles of the projectile before, during, and after impact with the target. The first nine columns are the same for all of the targets. They consist of T-designation, shot number, and striking conditions. The headings of the following 41 entries depend on the type of target: monolithic, double, or triple-spaced array. These columns describe the velocities, masses, and target measures for each of the individual targets. For the spaced-array targets, there are more velocities and angles recorded in place of the detailed target measures for the single target plate. The SPEED1 program stores all of the single data in one format, whereas the SPEED3 program stores the data in the format determined by the T-designation, either double or triple targets. The number of entries per shot in the database was recently increased from 50 to 75. Therefore, as the importance of additional data is realized, the last 25 columns will be assigned values. Data generated for a semi-infinite target are not stored directly into the database because of the limited data produced by the radiograph. The primary data stored for the semi-infinite data are the post-mortem measures of the target plate after it has been sectioned. Currently, all of the semi-infinite data are entered manually as performed in the past. However, since a new program using the digitizing system for measuring the semi-infinite data is being incorporated within the database, a section for measuring the semi-infinite data may be incorporated in the single target digitizing program, SPEED1.

4.2 Computer Manipulation.

4.2.1 Individual Shot Data Storage. The storage file created by the digitizer for the database system is a simple 1 x 50 matrix as described earlier. It contains all of the data related to velocities and angles that the digitizer can calculate and store automatically. Also, the shot number, the number of pieces in the spaced array, and codes for the T-designation are input from the keyboard into the file. Before any corrections or additions are made to the matrix, the data must be combined in a file with other shots for the same penetrator material. The combined file may perhaps only contain one shot, but usually contains a whole series of shots (5-9 shots) for one particular material and a specific target. A program titled DBS-STR is used to combine the individual files and to make corrections and additions to the individual files. The program begins with a prompt for the filename, which will be a code for the material property (i e., G90 for GTE 90% tungsten). Next, a menu with the following choices appears: CREATE, ADD, ADJUST, CORRECT, DELETE, PRINT, or END. Again, the PRINT prompt will print the data either to the screen or on paper. The END prompt ends the program and returns the directory to the disk drive containing the program. The CREATE prompt will create a new file with the filename addressed above. This is used when the individual shots are first being combined to make one file. The computer will prompt for the file (shot number) to be added to the storage file. It will then repeat the prompt until an "N" is entered. At this point, a file containing a matrix of number of shots (N) by fifty is created. The ADD prompt is used to add files (shot numbers) to an existing file. The prompt will be the same as for CREATE, except the file does not create a new file, but simply adds the data to the old file. The ADJUST prompt allows the user to add the masses and any information detailing the break-up of the projectile and the size of the perforation holes in each of the target plates. The program prompts for the shot number to be adjusted, and then it selects the correct column headings (single, triple, or double target) according to the T-designation. Codes for the columns (i.e., for lost or not measured) can also be accessed by entering "C" for the requested value. The codes are listed in Appendix B. After all of the additional data are input for the first shot, the program will prompt for another shot. If no other shots are to be stored, the program will store the now complete data set. The CORRECT prompt will correct any shot number and column in the file being accessed. It simply prompts for the shot number and the column to be corrected. The current value is listed, followed by a request for the new correct value. When all corrections are complete, the file is stored. The DELETE command allows the user to remove a shot number from the file. A simple command requesting the shot number to be deleted appears, and then the file is restored. After the combined file has been adjusted and corrected, it can be transferred to the main database system.

To transfer the older Hewlett Packard files to the main database system, the file must first be transferred from the HP87 4.5-in disk to the 3.25-in disk. Then it can be transferred to the IBM via a connection device (RS-32 cable) that allows the data to be converted from HP BASIC to IBM BASIC. Once the file is on a 4.5-in floppy formatted for the IBM, it can be added to the current database on the Bernoulli 20-megabyte disk by a simple program. Since the data file will already be on an IBM floppy disk on the new IBM digitizing system, only one simple program, called TRANSFER, is needed to add the data to the current database system. It adds the data to a current binary database file or, if no data for the material exist, it creates a new file in the binary database format. If a new file is created, a 1 x 150 matrix to store the material property data is created at the beginning of the file. As the file is being converted to the new format, the target thickness, obliquity, and type of target are automatically input into the last six columns (70-75) of the shot data. Once the file is in the database system, the limit velocity of the target and any other modifications can be made.

The program used to read, tabulate, correct, and add to the database files is entitled TABLES. This program is an enhanced combination of the two initial programs created in 1980, resulting in a tremendous increase in capability. As described earlier, the files have been changed from the old ASCII format to a random access binary format. Because the newer method of reading the files requires a more advanced type of BASIC, a new BASIC compiler called QUICKBASIC version 4.0 (copyright) is used whenever the files are accessed. The QUICKBASIC, because it is a compiler, will also perform the basic operations much more quickly than the ordinary BASIC. The binary format used in the storage is a random access format, which allows the program to read only the data which are currently needed. For this reason, the program has the ability to perform many more functions with the increased amounts of data. The program will read the T-designation, record the number (location of the file) for each material, and separate only the data pertaining to the requested T-designation. To correct a file, the program recalls the data in the particular shot and restores the new data input, only reading or writing to the files containing the requested T-designation. In the past, the whole file had to be accessed to make simple corrections. Obviously, this was a waste of memory and computer time as compared to the newer method. The program is capable of tabulating files for single-plate finite targets, double-spaced-array targets, triple-spaced-array targets, and for semi-infinite targets. Samples of each tabulation can be seen in Tables 3 through 6, respectively. As can be seen from these tables, the material and target designations are still printed on the paper in a coded format. Therefore, the printouts are still unclassified. However, simple adjustments to the program during printout will permit a formal classified printout of the data. In addition to tabulating the data in the standard format, the program is designed to correct any data in the file. This correction is performed similarly to the DBS-STR program; prompts for the shot number and column to be corrected appear, followed by requests for the new value. The new value is then stored in the record number as disussed previously. The program is also capable of manually entering the data if needed, as for the semi-infinite data. It will prompt for the filename of the file being added and the T-designation of the data to be entered. It reads the number of shots in the current file and adds the additional data. It prompts for the columns to be input according to the T-designation assigned. After all of the shots are added, the new data are stored at the end of the random access file. The files are then complete and can be accessed at any time.

Table 3. Sample Single Target Printout From Database.

Series Fired 4 - 1983

Limit Velocity = 1161 A= .99 P= 4.4 S= 1

Sh.#	Alpha (deg)	Beta (deg)	Gamma (deg)	Vs (m/s)	Ms (g)	EtaR (deg)	AlphaR (deg)	Vr (m/s)	Mr (g)	Pen. (cm)
-1379	1.00D	0.00	1.00	1264	64.95	NA	NA	Lost	Lost	CP
1385	0.00	0.50R	0.50	1203	64.96	1.0D	NA	770	6.40	CP
1387	0.75U	0.00	0.75	1120	64.98	NA	NA	0	0.00	NM
1389	0.25U	0.00	0.25	1388	64.94	0.0	NA	1198	19.58	CP
1400	1.00D	0.50L	1.10	1140	64.97	NA	NA	0	0.00	NM

Sh.#	M.rec (g)	EtaP (deg)	Vpl (m/s)	Mpl (g)	Mpr (g)	L.p (	W.p cm	Th.)	EHL (cm)	EHW (cm)	Blg (cm)	Wt.L (g)
-1379	None	Lost	Lost	Lost	None	----NM----			1.8	1.8	1.1	NR.
	BHN= 302											
1385	None	(---------Spall-----Fragments----)							1.5	1.5	0.9	NR.
	BHN= 302											
1387	0.00	NA	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.4	NR.
	BHN= 286											
1389	None	(---------Spall-----Fragments----)							1.9	1.9	1.2	NR.
	BHN= 302											
1400	0.00	NA	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.7	NR.
	BHN= 286											

Sh.#	Cone (deg)	CoFS (deg)	EntHL (cm)	EntW (cm)	CenL (cm)	CenW (cm)	#Pcs.	M.R.Dia. (inch)	BL (cm)	BW (cm)
-1379	Lost	Lost	NM	NM	NA	NA	Lost	Lost	NM	NM
1385	NM	NM	NM	NM	1.0	1.0	1	Broken	NM	NM
1387	NA	NA	NM	NM	NA	NA	PP	PP	NM	NM
1389	NM	NM	NM	NM	1.1	1.1	1	Broken	NM	NM
1400	NA	NA	2.0	2.0	0.9	0.9	PP	PP	NM	NM

Table 4. Sample Triple Target Printout From Database.

Series Fired 3 - 1981

Limit Velocity = 1061 A= .87 P= 3.4 S= 77

Sh.No.	Alpha (deg)	Beta (deg)	Gamma (deg)	VS (m/s)	MS (g)	Eta3 (deg)	VR (m/s)	MR (g)	Pene (cm)
962	0.25U	0.25L	0.40	1575	65.02	0.0	1265	14.46	CP
965	0.50U	0.00	0.50	1372	64.99	7.0U	1117	8.51	CP
969	0.25D	0.50R	0.60	1264	65.02	18.5U	755	8.51	CP
971	0.50D	0.00	0.50	1077	65.02	30.0U	474	7.92	CP
972	0.25D	0.00	0.25	1061	65.01	NA	0	0.00	0.5

Sh.No.	Eta1 (deg)	Alph1 (deg)	VR1 (m/s)	MR1 (g)	Eta2 (deg)	Alpha2 (deg)	VR2 (m/s)	MR2 (g)	BG/L (cm)
962	0.00	1.25U	1572	59.65	0.00	1.75U	1511	47.12	1.0
	BHN1= 387			BHN2= 137		BHN3= 269			
965	0.25D	0.00	1365	60.01	1.25U	1.75U	1297	47.77	0.8
	BHN1= 375			BHN2= 149		BHN3= 269			
969	0.50D	0.25U	1253	60.01	0.75U	0.50U	1195	48.66	1.0
	BHN1= 387			BHN2= 146		BHN3= 277			
971	0.00	0.75D	1072	57.00	0.00	0.00	Lost	Lost	0.9
	BHN1= 375			BHN2= 137		BHN3= 277			
972	0.00	0.00	1036	57.58	0.25U	9.00U	990	47.50	NM
	BHN1= 351			BHN2= 143		BHN3= 302			

Sh.No	VP (m/s)	MP (g)	PL#1 CL (cm)	PL#1 CW (cm)	PL#2 CL (cm)	PL#2 CW (cm)	PL#3 CL (cm)	PL#3 CW (cm)	BlgL (cm)	BlgW (cm)	#Pc1	#Pc2
962	Frag	Frag	NM	NM	NM	NM	2.5	1.8	6.9	3.3	1	1
965	657	15.66	NM	NM	2.8	1.4	2.3	1.4	7.6	3.0	1	1
969	284	11.34	NM	NM	2.5	1.3	2.0	1.1	6.3	3.0	1	1
971	147	5.50	NM	NM	2.5	1.1	2.0	1.1	5.6	2.3	1	1
972	PP	NA	NM	NM	2.5	1.0	NM	NM	0.0	0.0	1	1

Table 5. Sample Double Target Printout From Database.

Series Fired 11 - 1986

Limit Velocity = 1248 A= .55 P= 3.5 S= 49

Sh.No.	Alpha (deg)	Beta (deg)	Gamma (deg)	VS (m/s)	MS (g)	EtaR (deg)	VR (m/s)	MR (g)	Pene (cm)
1853	0.50U	0.00	0.50	1420	88.46	18.7U	566	9.43	CP
1854	0.25U	0.00	0.25	1359	88.48	68.7U	295	Frag.	CP
1855	0.00	0.00	0.00	1309	88.90	0.0U	454	Frag.	CP
1856	0.50U	0.00	0.50	1249	88.52	74.0U	128	Frag.	CP
1861	0.75U	0.75L	1.06	1225	88.35	NA	0	0.00	1.7

Sh.No.	Eta1 (deg)	Alph1 (deg)	VR1 (m/s)	MR1 (g)	Vp (m/s)	Mp (g)	BL (cm)	BW (cm)	BG/L (cm)
1853	Lost	Lost	Lost	Lost	371	11.02	NM	NM	NM
	BHN1=	512		BHN2= 512					
1854	0.75U	3.75U	1321	Lost	204	10.79	NM	NM	NM
	BHN1=	512		BHN2= 512					
1855	Lost	Lost	Lost	Lost	243	15.62	NM	NM	NM
	BHN1=	512		BHN2= 477					
1856	0.50U	1.25U	1075	64.60	128	17.18	NM	NM	NM
	BHN1=	477		BHN2= 477					
1861	0.00	1.25U	1149	63.75	0	0.00	2.0	2.0	NM
	BHN1=	477		BHN2= 477					

	PL#1				PL#2							
Sh.No	EnHL (cm)	EnHW (cm)	CL (cm)	CW	CL (cm)	CW	ExHL (cm)	ExHW (cm)	#Pc1	#Pc2	Cone (deg)	CoFS (deg)
1853	4.0	2.1	2.8	1.6	2.4	1.7	4.5	3.0	Lost	Frag	57.1	47.2U
1854	4.5	2.2	3.5	1.6	2.3	1.5	4.3	2.2	1	Frag	56.3	53.8U
1855	4.0	2.1	3.0	1.5	3.3	1.6	3.2	1.9	Lost	Frag	37.9	61.7U
1856	4.2	2.1	2.7	1.6	1.0	1.4	1.8	2.4	1	Lost	0.0	74.1U
1861	4.0	1.9	2.7	1.3	NA	NA	0.0	0.0	1	Lost	NA	NA

Table 6. Sample Semi-Infinite Target Printout From Database.

Series Fired 11 - 1985
L/D = 20 Density is 18.6

Sh.#	Gamma (deg)	Vs (m/s)	Ms (g)	K.E. (J)	Area (scm)	M/A (g/scm)	KE/A (J/scm)	Norm P/L	Norm Pene. (mm)
1393	NM	1545	65.00	77578	0.294	221	263602	0.95	114.3
2197	0.50	957	64.92	29728	0.294	221	101014	0.37	44.2
2198	0.00	1271	64.91	52429	0.294	221	178148	0.67	80.8
2199	0.35	1619	64.69	84781	0.294	220	288078	1.02	121.9
2200	NM	1682	64.94	91862	0.294	221	312135	1.07	129.0
2205	0.56	1066	64.96	36909	0.294	221	125412	0.50	60.2

Sh.#	Rise (cm)	Vol base (cc)	Vol total (cc)	KE/Vt (J/cc)	KE/Vb (J/cc)	plV^2 *10^6	Dt/Dp	Area hole (scm)	M/A hole (g/scm)
1393	NM	NM	NM	NC	NC	532	NM	NC	NC
2197	0.10	2.49	2.61	11390	11939	204	1.41	0.59	110.83
	BHN= 269								
2198	0.09	3.73	3.79	13834	14056	360	1.29	0.49	133.30
	BHN= 269								
2199	0.00	9.74	9.74	8704	8704	585	1.70	0.85	76.15
	BHN= 286								
2200	0.00	11.50	11.50	7988	7988	634	1.70	0.85	76.45
	BHN= 269								
2205	0.06	3.68	3.75	9842	10030	253	1.49	0.65	99.88
	BHN= 269								

4.2.2 Material Property Data Storage. Each file in the main database storage system contains one particular penetrator material. The properties of each material are used in the characterization of the projectile. These properties include the penetrator characteristics such as percentage tungsten, amount of cold working (swaging), density, hardness, and mechanical properties. The mechanical properties primarily consist of data obtained from a static tensile test: the yield strength, ultimate tensile strength, fracture stress, elastic modulus, elongation, and Poisson's ratio. However, some compression and dynamic properties are being included such as Charpy impact (notched and un-notched) and various compression tests. Typically, the manufacturer provides the property data and, occasionally, BRL also conducts some mechanical tests of its own. A more recent evaluation of some dynamic properties generated by the Fraunhofer-Institut fur Angewandte Materialforschung (IFAM) of Germany has proven to be an efficient method of comparing material properties to ballistic performance. The dynamic methods used by the IFAM may be adopted by the U.S.; therefore, adequate space to store all of these new data and the traditional data must be allocated in each file.

Each file allocates space at the beginning for a 1 x 150 matrix (previously a 1 x 100) where all of the individual material properties are stored. Currently only the first 60 columns are being used for primarily static mechanical properties. The additional space is available if a more detailed evaluation of the penetrator materials is performed and is to be stored. The current data stored in each column are listed in Appendix B.

The space for the material property matrix is allocated when the file is created. At that point, the matrix will consist of 150 parameters all being assigned a negative one (-1) value. This value is not a practical value for any of the current properties listed. To insert the correct values for the material properties, a program titled MATPRO is used. This program is designed solely to add, correct, and tabulate the material matrix. It only accesses the material matrix, and it does not access the individual shot data. The program begins with a prompt for the filename which already contains the individual shot data. It only reads the beginning 1 x 150 material matrix and will prompt to add or tabulate these data to the screen or to paper. The current tabulation format is shown in Table 7. The ADD section of the program will either add the entire data set, prompting for each column heading in sequence from 1 to 60, or add only specific, requested columns. To correct the data in the material matrix, the data must first be tabulated; the ADD section is then used to change values in the columns of interest.

Table 7. Sample Printout of Material Property Data.

	Tensile	Compressive
Yield Str., 0.2% (MPa/Ksi)	800.0/ 116	
Ult. Tens. Str.(MPa/Ksi)	1430.0/ 207	
Fracture stress (MPa/Ksi)		
Young's Mod., E,(GPa/Msi)	119.0/ 17	
Bulk Modulus,K,(GPa/Msi)		
Poisson's ratio	0.220	
Pl. Poisson's ratio		
Elongation(%)	20.5	
Hardness (Rc)	40.5	
Density (g/cc)	18.60	
Fract. Tough.(MPa(I)1/2)		

Impact properties	Unnotched	Std.Notched
Elas. Imp. En. (Joules/ft-lb)		
Ave.		
Inia. Energy (Joules/ft-lb)		
Ave.		
Tot. Imp. En. (Joules/ft-lb)		
Ave.	320/ 434	11/ 15
Peak Force (KN/Klb)		
Ave.	44/ 10	22/ 5
Mid. Defl. at Inia. (mm)		
Ave.		
Mid. Defl. at Frac. (mm)		
Ave.	11.0	

The data set is complete after all of the shot data are entered and the material matrix is added. To make the database more useful, it must be capable of tabulating the data in a manageable format and easily accessing the data to a graphical form (plot). A plot of any column vs. another column or any combination of columns vs. other combinations of columns can reveal many recognizable trends in the data. The program devised to do this is another basic program used in the QUICKBASIC mode, called DBS-PLOT. It is used in conjunction with the HP 7475A Plotter. DBS-PLOT is capable of reading any specific file, any combination of files, any file in a specific program, or all of the files in the data set. Any specific T-designation, any number of T-designations, all T-designations for a certain type of target (triple, single, double, or semi-infinite), or all of the T-designations can be chosen. A listing of the X and Y data to be plotted, along with the material, T-designation, L/D, density, color, and geometry of the point to be plotted is printed as the data are read. The color and geometry of the points are determined by the density and L/D of the rod. However, with adjustments to one section of the program, the color and/or geometry of the points can be changed to represent other factors. Because it is a BASIC program, adjustments such as those mentioned can be easily made as well as the combining of columns (dividing one by another, etc.) for the plotting routine. The versatility of the DBS-PLOT program has made it a very useful tool in the analysis of the ballistic data. Since the material properties are stored with the ballistic results, it is easy to correlate the two, if any correlation exists. A sample plot comparing density and L/D ratios of 10, 15, and 20 for striking velocity vs. penetration is shown in Figure 12. In this plot, the densities are shown by different shadings instead of different colors because of the black and white colors of the report. The L/D of 10, 15, and 20 are designated by the square, triangular, and hexagonal (6-sided) figures, respectively. The different densities shown are 17.6, 17.9, and 18.6 grams/cubic centimeter for the unshaded, partially shaded, and shaded figures, respectively. It is evident from the plot that the increase in both density and L/D ratio increase the penetration of the rod. This sample plot demonstrates one method of utilizing the database.

As mentioned earlier, an important correlating factor of one material to another is its limit velocity against a specified target. In order to make the limit velocities readily available, another quick program was developed to read all of the files in the database and store only the filename, date of the test, T-designation, number of shots fired, and the limit velocity. A similar program was written to store the semi-infinite data. Instead of the limit velocity and number of shots, the semi-infinite program stores the striking velocity and depth of penetration for each shot. These two user-friendly programs are titled MAKSUM and MAKSSI, respectively. Once started, the program

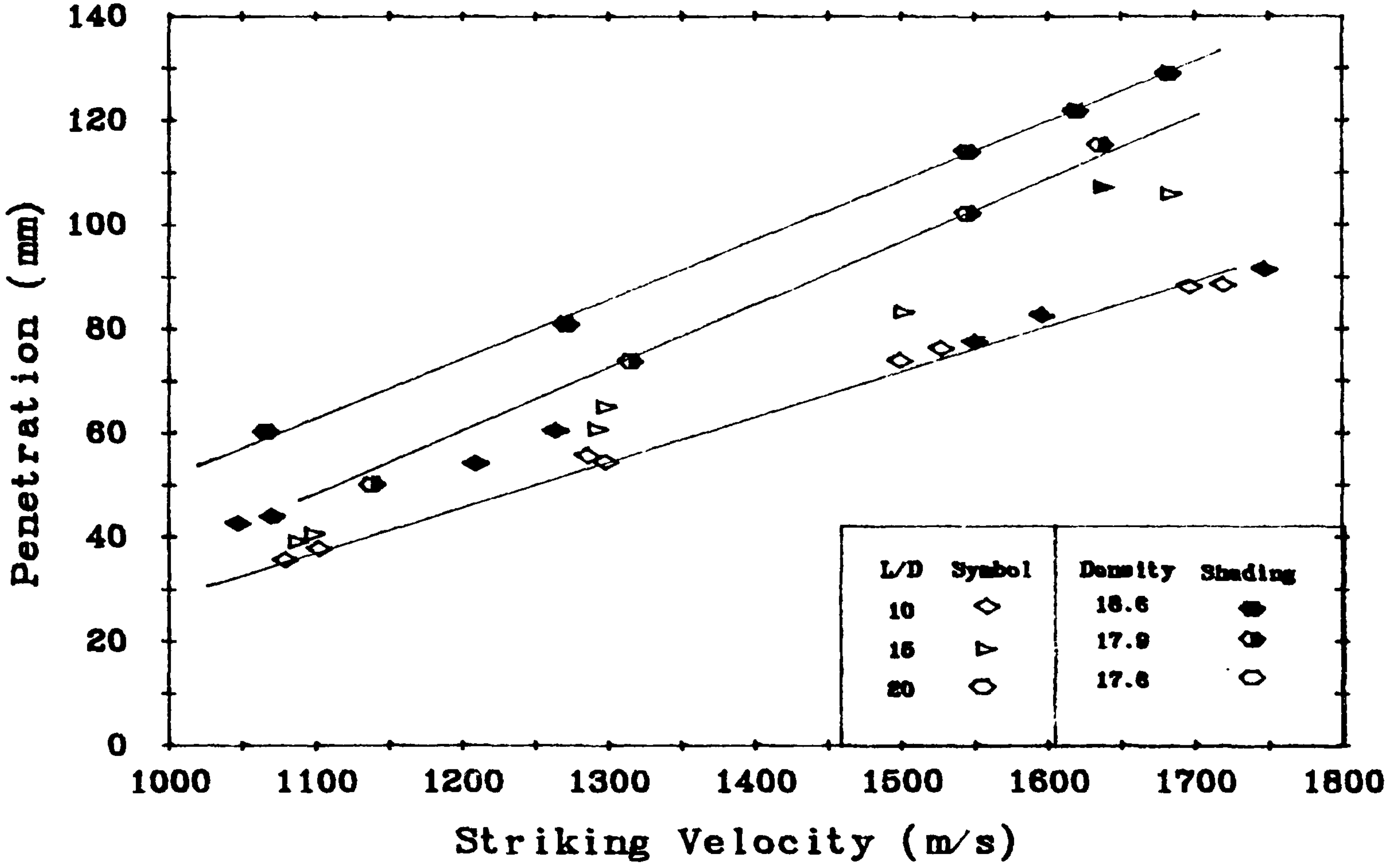


Figure 12. Sample Plot Using the Database System.

prompts for the date (month and year; i.e., 0189 for January 1989) before beginning. Running time of the program is approximately 15 minutes to read the complete database (currently consisting of over 4000 shots) and store the desired information. A program to access the summary data is titled SIFIL, which also prompts for the material or materials to be listed, the T-designations to be listed, and the testing program where the shots were fired: MAT - model scale test, LRP - long rod penetrator, SLAP - 0.50-cal. saboted light armored penetrator, or MISC. Once the data are read into the internal memory (RAM) of the computer (approximately 1-2 minutes), any of the requested data can be tabulated in a matter of seconds. Another useful method of comparing limit velocities, L/D ratios, and materials is to tabulate the limit velocities in a matrix containing L/D ratios and materials. The matrix in table format will give a quick overview of how the limit velocity changes for a specific material as the L/D ratio increases, and how the limit velocities vary as a function of the material properties. A simple adjustment was made to SIFIL and stored as SUMTAB to create this program.

4.2.3 Behind-Armor Debris Storage. Following the digitizing and storing of the behind-armor debris data generated from the radiographs, the files must be adjusted when the masses and target measures are added. The program to do this for the behind-armor debris files is appropriately titled ADJUST. It begins with a prompt for the shot number to be adjusted. After it reads the file, it displays a menu with three options: PRINT, ADJUST, or QUIT. The PRINT option will tabulate the data either on paper or to the screen (see Table 8). The QUIT option will end the program and return the current directory back to the primary directory. The final option, ADJUST, allows the user to input the additional information not computed by the digitizer. In the ADJUST option, the specifics of the target (type, thickness, and obliquity) and striking conditions are entered. Next, all of the masses (including recovered masses, if any) are input for each fragment. Then the file is complete and can be accessed for tabulation or a comparison with similar data. The file can also be combined with various other behind-armor files to create a summary file of all of the debris data for a specific penetrator geometry and material. As the summary files are created, debris dispersion angles are determined by statistically weighting the debris in terms of mass, energy, or quantity, and are stored. A sample output for the summary files is shown in Table 9. The table is divided into separate sections for each target evaluated. Within each division, the shots are arranged in decreasing order of overmatch (striking velocity divided by limit velocity). The columns consist of the number of identifiable fragments, weight loss of the target, cone angle in the vertical direction, and the various average angles of departure. The average weighted angles estimate the direction of the concentration of debris with respect to the total number, total mass, and kinetic energy. These ETA values are calculated using the following statistical equations:

Table 8. Sample Radiographic Behind-Armor Debris Printout.

```
Shot Number :  11
Alpha is  4.25 D
Beta is  3 R
Striking Vel. is  1214
Target weight loss is -1111 grams
Number of Fragments : 8
```

FRAG. TYPE	DEP. ANGLE (DEG.)	VELOCITY (M/S)	MASS (g)	MASS REC. (g)
TGT.(MAX)	5.50D	845	0.40	NONE
TGT.(MAX)	9.00D	885	0.63	NONE
MAIN TGT.	2.50U	888	0.42	NONE
MAIN TGT.	12.50U	308	0.59	NONE
TGT.(MAX)	10.50U	813	0.64	NONE
MAIN TGT.(MAX)	9.50U	861	1.25	NONE
TGT.(MAX)	9.50U	1011	0.32	NONE
MAIN PEN.(MAX)	0.25D	1179	60.89	NONE

Table 9. Sample Summary Radiographic Printout.

Shot No.	Vs/Vl	No. Frag	Wt. Loss (g)	Tot Mass (g)	Tot KE (J)	Eta No. (deg)	Eta Mass (deg)	Eta Energy (deg)
				2.0 /0				
3	1.073	1	11111	71.3	1709.3	-9.00	-9.00	-9.00
4	1.053	1	11111	46.9	1144.3	-4.25	-4.25	-4.25
8	1.040	1	-1111	105.0	1855.6	14.00	14.00	14.00
6	1.014	1	-11111	29.9	174.6	13.75	13.75	13.75
7	1.009	2	-1111	191.7	1594.7	10.50	10.18	10.18
2	-0.001	1	1111	17.1	3131.3	1.25	1.25	1.25
				.31 /80				
23	1.317	12	-1111	18.0	1944.2	51.58	56.55	56.18
24	1.138	1	-1111	0.6	46.6	21.00	21.00	21.00
29	1.133	14	-1111	11.4	547.1	54.36	54.92	55.92
				.5 /70.5 RHA				
190	1.470	9	-1	37.1	10244.3	34.98	37.16	24.22
191	1.158	5	-1	5.4	477.0	34.82	31.37	30.02
192	1.053	4	-1	20.0	646.2	32.90	27.75	28.17
193	1.052	6	-1	32.0	336.0	39.12	3.97	4.11
194	1.006	13	-1	22.5	1043.0	28.81	28.73	28.29
				1.25 /0				
1	1.667	1	11111	40.9	27612.5	1.00	1.00	1.00
12	-0.001	10	-11111	119.7	25414.8	-0.40	-1.45	-0.75
				0.75 /60				
14	1.500	5	-11111	35.4	18288.0	11.75	5.72	5.83
22	1.010	1	-1111	2.3	170.6	-4.50	-4.50	-4.50
13	-0.001	9	-1111	16.9	6245.1	9.83	10.82	10.81
				XTRA				
11	3.954	8	-1111	65.1	43741.3	3.72	0.11	-0.11
21	2.433	22	-1111	100.8	55229.4	22.02	8.11	3.25
32	3.565	6	-1111	69.2	49755.9	0.58	0.64	0.65
33	1.947	31	-1111	84.4	41646.6	0.39	0.24	0.21
34	1.372	21	-1111	64.4	17962.7	4.17	7.02	6.50
42	-1.215	16	-11	26.3	1133.7	29.16	29.51	29.37

ETA number = the average departure angle.

$$\text{ETA no.} = \frac{\sum \text{ETA value}}{\text{total eta}} ,$$

ETA mass = the average departure angle with respect to mass

$$\text{ETA Mass} = \frac{\sum \text{ETA} * \text{mass}}{\text{total mass}} ,$$

ETA kinetic energy (KE) = the average departure angle with respect to KE.

$$\text{ETA KE} = \frac{\sum \text{ETA} * \text{KE}}{\text{total KE}} .$$

The tabulation of the files gives a quick overview of the amount and direction of the behind-armor debris generated by a specific penetrator with relation to overmatch, target thickness, and obliquity. Tables for different projectiles can be compared for the same target series.

5. WITNESS PACKAGE STORAGE

5.1 Data Reduction. The other detailed analysis method for the behind-armor debris is the witness package system. The witness package was developed by the Vulnerability/Lethality Division (VLD) of the BRL. The details of the witness package are discussed in various BRL (VLD) reports (Brainard, Danish, and Tanenbaum 1987). However, a brief description will be mentioned here.

The concept of the witness package is to establish the energy and direction of each fragment perforating the target to estimate their lethality to the vehicle being examined. The witness package design, used in the coordinated efforts of TBD and VLD, involve five mild steel plates of increasing thickness (1/32 to 1/8 in) separated by one inch of styrofoam. Figure 13 shows a sample witness package arrangement. They are assembled then placed behind and parallel to the rear face of the target plate. The location of the package with respect to the target plate prior to the test is recorded. The relation of the bottom and right side of the witness package to the bottom

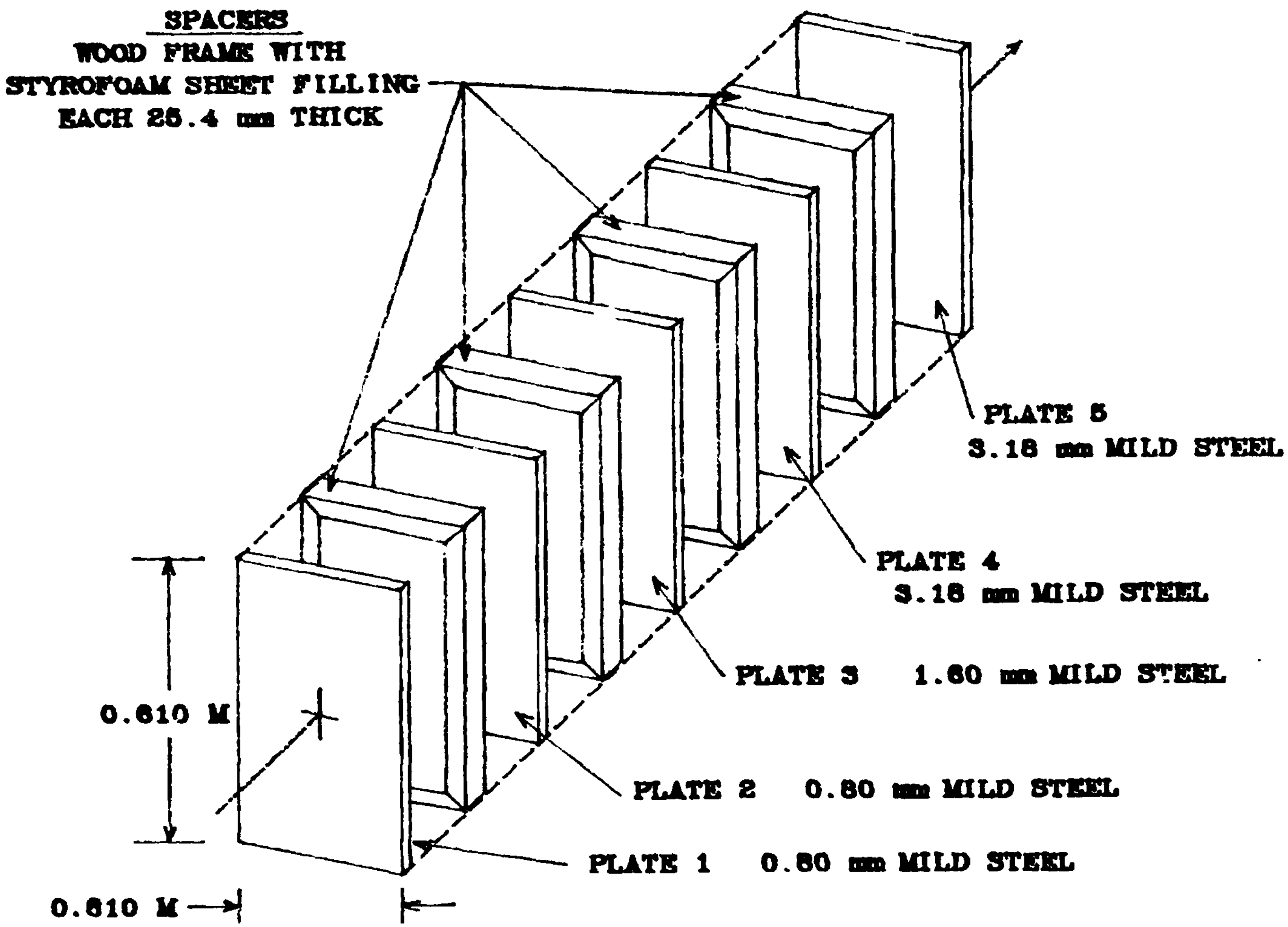


Figure 13. Witness Package Assembly.

and right side of the target plate is determined. Also, the distance from the witness package to the rear face of the target plate is measured. This is shown in Figure 14a. Note that the method mentioned here is for smaller caliber testing. For large caliber testing, the witness package is placed at one-half the obliquity angle of the target, as shown in Figure 14b. Obviously, for the two different setups, different methods of analysis are employed. Only the small caliber setups will be discussed in this report.

After the test, the location of the perforation hole in the armor plate is recorded. The witness package is disassembled, and the location and size of each perforation in the individual witness plates are recorded. The perforation hole is projected onto the witness package, where all of the fragments are measured in relation to the hole. In the majority of the initial tests by TBD, the coordinates and hole sizes were measured by hand (using a tape measure). Then the data were manually input into a database for future reference and transferred to VLD. The VLD correlated the perforation hole of the armor to the location and size of each perforation in the witness plate to determine the energy and direction of each fragment produced.

As the need for the witness package data (also, the number of perforations) increased, a computer program used in conjunction with a sonic digitizer was developed to measure and store the data. A contracting firm, HP White Laboratory, produced the program and reported a considerable decrease in required time to process the witness packages. The program follows simple user commands that allow the user to enter and exit the program quickly at any time without losing the existing data. The digitizing begins with prompts for the target, shot number, location of witness package, etc. Once the beginning prompts are input, the projected exit hole location is digitized as the origin (0,0) on the witness plate. Four points around each perforation hole are digitized. These points define a rectangle (producing the area of the hole) whose center of mass is the location of the perforation with respect to the projected exit hole. The program stores all of these raw data in a binary format which can be easily transferred to the standard ASCII format currently used by the A/AA Concepts team. The digitizing program is being acquired by TBD from the contracting firm for future analysis of witness packages. However, the VLD has recently developed a system of viewing the witness plates on a screen and automatically storing the size and location of the perforation holes. If at all possible, this method will also be employed by TBD rather than the tedious digitizing of points for each perforation hole.

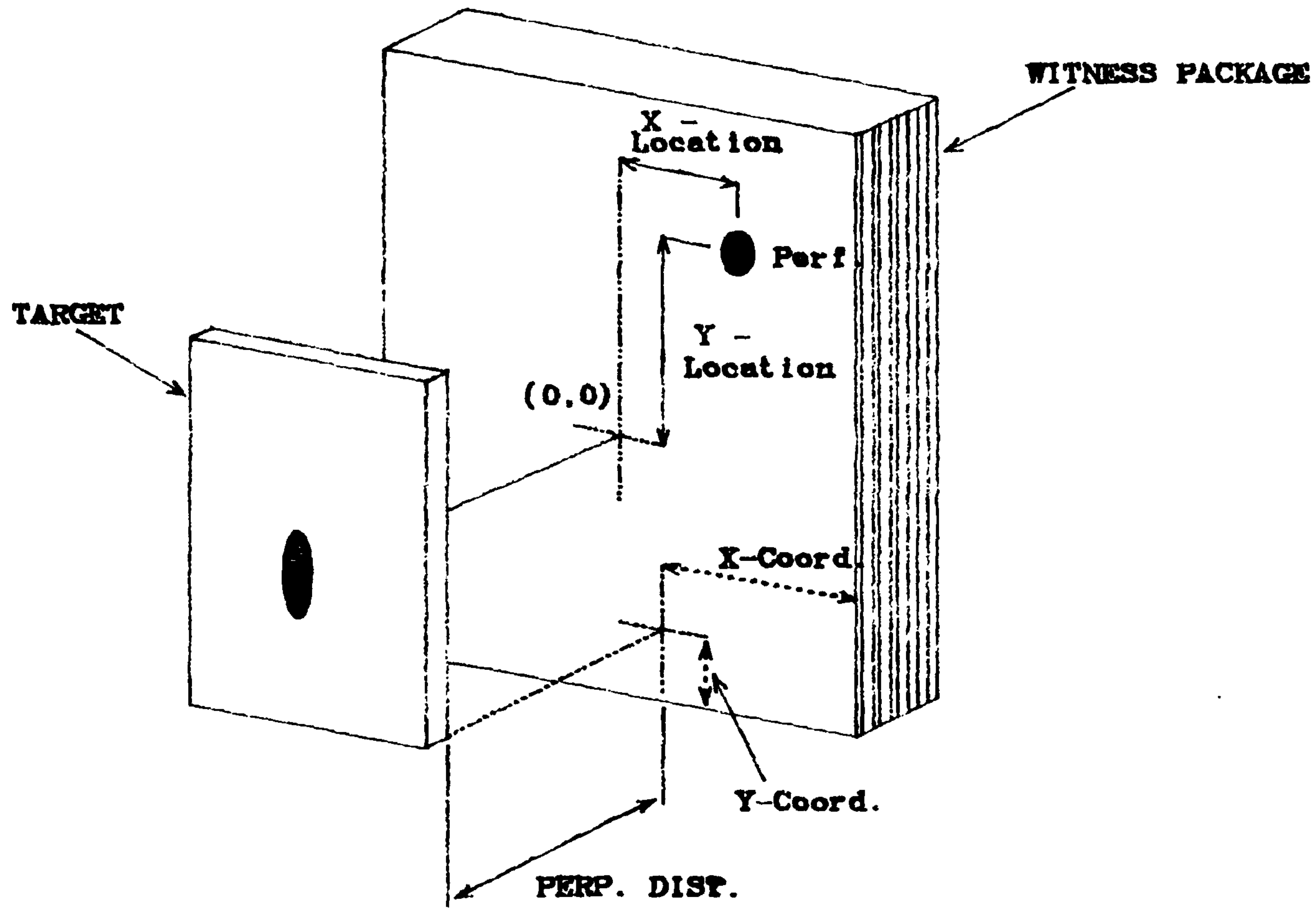


Figure 14a. Witness Package Orientation.

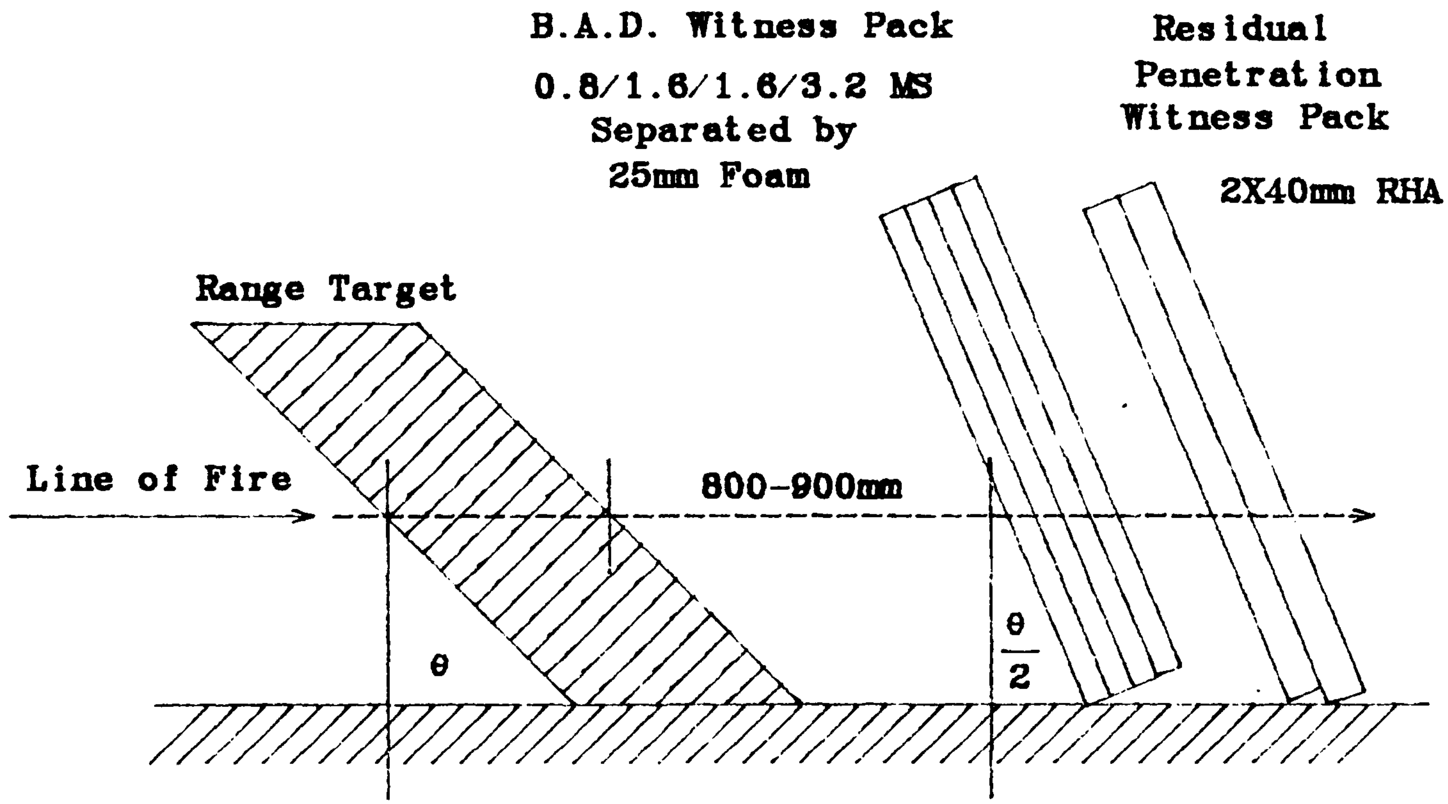


Figure 14b. Witness Package Setup for Large Caliber Testing.

5.2 Computer Storage. The raw data determined by any of the methods described above are entered into a storage bank where they can be retrieved and manipulated by the A/AA Concepts team. The witness package program that stores and retrieves the data is titled WITPACK. All of the pre-impact data (e.g., relation of target to witness package, shot number, etc.) are entered into the program. Next, all of the individual perforation hole data for each witness package, location (X and Y coordinates), and size (length and width) are entered. In addition to simply determining the area of the hole, the program will calculate the departure angle in both directions by using the exit hole coordinates, the distance to the witness package, and the location of the individual perforation hole. After all of the individual data are entered, the cone angle and average departure angle in both directions are determined. The tabulation of the data, as shown in Table 10, describes the conditions prior to setup and the overview of the shot at the top of the table. The remainder of the table is separated into sections for each witness plate. Within each section, the location, size, and departure angle for each perforation are described.

Although the witness package perforation data obtained by the TBD do not completely quantify the amount of lethality (energy of each of the fragments), the raw data can nonetheless be summarized to give an overview of the behind-armor debris generated. A technique similar to the radiographic summary is used. A program that combines all of the shots from one material and arranges them in decreasing degrees of overmatch is employed.

The program will calculate and tabulate the total number of fragments on the first plate, the total number of plates perforated, the weight loss of the target, the cone angles in the vertical and horizontal directions, the total perforated area on the first plate, and the weighted averages of the departure angles by fragment number and area. The equation for the departure angle for the number is the same as for the radiographic measures. The equation for the weighted value for the area is shown below.

ETA Area = average departure angle weighted for the area of the hole produced.

$$\text{ETA Area} = \frac{\sum \text{ETA} * \text{hole area}}{\text{total hole area}}.$$

A sample printout from this file is shown in Table 11. Printouts for different projectiles can be compared in order to evaluate the amount and direction of the debris produced against the same target.

Table 10. Sample Witness Package Printout.

Shot No. 102   Vs/Vl = 1.063

Witness Pack Measurements

Perp. Dist. to W.P. (cm)=	61.595	
Corner Coord. to W.P.(cm)=	23.50 ,	19.68
Exit Hole Coord. (cm)=	6.35 ,	7.62
Center of Spray X	2.14	deg
Center of Spray Y	-0.58	deg
Cone Angle X	6.72	
Cone Angle Y	4.41	
Entrance Hole L	2.79	
Entrance Hole W	7.97	
Entrance Hole X	6.54	
Entrance Hole Y	7.97	
Weight Loss g	120.00	

Plate No.	No. of Perfs
1	13
2	8
3	5
4	3

Center Hole L	2.20
Center Hole W	2.15
Center Hole X	6.45
Center Hole Y	7.79

****** Coordinates measured from exit hole ********

Frag #	X (cm)	Y (cm)	Length (cm)	Width (cm)	EtaX (deg)	EtaY (deg)	Area (sq cm)
			First Plate				
1	-1.30	1.75	0.06	0.03	-1.21	1.62	0.00
2	4.22	-0.41	0.07	0.08	3.92	-0.38	0.01
3	5.93	-2.76	0.87	1.09	5.50	-2.56	0.95
4	2.72	-2.57	1.57	0.89	2.53	-2.38	1.40
5	1.30	-0.55	1.01	0.47	1.21	-0.51	0.47
6	-0.27	-0.75	0.64	0.32	-0.25	-0.70	0.20
7	0.13	-1.24	0.50	0.31	0.12	-1.15	0.16
8	1.31	-1.43	1.36	1.10	1.22	-1.33	1.49
9	0.51	-1.96	0.02	0.02	0.48	-1.82	0.00
10	0.13	-2.43	0.32	0.23	0.12	-2.26	0.07
11	0.57	-3.00	0.21	0.10	0.53	-2.79	0.02
12	-0.19	-2.92	0.11	0.03	-0.17	-2.71	0.00
13	-0.19	-2.92	0.11	0.03	-0.17	-2.71	0.00
			Second Plate				
1	-0.09	-0.72	0.74	0.49	-0.08	-0.64	0.36
2	0.45	-2.39	0.23	0.12	0.41	-2.13	0.03
3	0.38	-1.35	0.42	0.18	0.34	-1.21	0.08
4	1.77	-0.48	0.47	0.35	1.59	-0.43	0.16
5	1.65	-1.46	1.34	1.11	1.48	-1.30	1.49
6	3.11	-2.23	1.59	1.16	2.78	-2.00	1.85
7	6.27	-2.82	1.01	0.74	5.58	-2.52	0.75
8	6.27	-2.82	1.01	0.74	5.58	-2.52	0.75
			Third Plate				
1	-0.21	-0.81	0.64	0.57	-0.18	-0.70	0.36
2	1.61	-1.43	1.02	0.64	1.38	-1.23	0.65
3	3.20	-2.24	1.34	0.97	2.75	-1.93	1.30
4	6.28	-3.09	0.82	0.51	5.38	-2.65	0.42
5	6.28	-3.09	0.82	0.51	5.38	-2.65	0.42
			Fourth Plate				
1	1.58	-1.35	0.32	0.06	1.30	-1.12	0.02
2	3.06	-2.67	1.01	0.69	2.53	-2.21	0.70
3	3.06	-2.67	1.01	0.69	2.53	-2.21	0.70

Table 11. Sample Summary Witness Package Printout.

Shot No.	Vs/Vl	No. Frag	# Pl Perf.	Cone Angle X (deg)	Cone Angle Y (deg)	Wt. Loss (g)	Eta No. (deg)	Eta Area (deg)	Tot. Area (sqcm)
TOTAL NUMBER OF SHOTS IS 25									
20mm GHHA /60 Shots for the series 2									
120	1.005	28	3	17.03	20.42	139	55.00	55.99	7.00
121	1.005	37	4	16.12	20.97	138	54.57	56.47	9.59
1.25 HHA /0 Shots for the series 5									
103	1.141	22	4	6.32	8.64	132	-0.56	-1.18	5.68
-100	1.119	25	4	8.43	5.53	145	-0.93	-1.06	4.23
102	1.063	13	4	6.72	4.41	120	-1.51	-1.79	4.79
101	1.048	18	4	6.24	4.45	108	-2.72	-3.12	6.19
104	1.031	17	4	14.57	6.99	167	-0.23	-0.03	6.45
0.5 RHA /70.5 Shots for the series 3									
110	1.349	139	3	17.72	37.91	102	45.50	44.23	7.78
109	1.200	29	3	13.29	7.21	82	56.64	55.83	1.05
106	1.025	23	3	8.48	24.87	61	50.70	52.89	0.58
0.75 RHA /60 (UHT) Shots for the series 3									
168	1.542	158	4	24.96	43.79	0	35.64	39.61	11.49
117	1.008	21	4	12.49	17.61	67	46.78	46.23	5.43
113	1.002	26	2	9.96	14.95	51	50.49	52.78	1.90
2.0 RHA /0 Shots for the series 3									
10027	1.072	7	3	14.25	9.63	29	11.98	12.08	12.19
10028	1.016	7	2	9.77	36.63	61	14.66	3.78	9.13
10031	0.999	4	1	3.81	6.89	39	15.21	15.42	3.68
1.25 HHA /60 Shots for the series 5									
1009	1.087	23	3	34.12	46.40	226	58.62	49.86	38.98
10010	1.052	18	4	18.47	33.85	207	56.83	52.55	41.82
10011	1.039	2	3	19.79	11.71	133	69.30	75.07	12.02
10012	1.036	6	4	11.26	22.00	195	58.44	61.11	23.21
10013	1.004	1	1	0.00	0.00	3137	86.86	86.86	0.10
3/4 HHA /70.5 Shots for the series 4									
1006	1.103	33	3	35.53	35.11	1119	71.29	74.61	23.95
1008	1.088	9	3	22.56	33.77	82	73.43	84.39	51.73
1003	1.017	9	3	8.23	30.96	79	75.15	71.33	14.06
1007	0.956	2	3	4.14	0.76	-1	87.68	87.54	5.58

6. CONCLUSIONS

The digitizing system and database are very useful tools for the Armor/Anti-Armor Concepts team of the Terminal Ballistic Division. These tools have simplified the task of reducing all of the valuable data generated from the radiographs of the penetrator/target interaction. First, the digitizer has not only increased the reproducibility of the results, but has reduced the time and effort required to perform the many calculations involved in measuring the radiographs. Second, the time consuming and tedious manual storage of the radiographic data into the database has been reduced considerably. Third, the database system has made the comparison of material properties to ballistic results a much easier task. The files and programs used in the database storage system are constructed in the simple BASIC format. Therefore, anyone who has access to the programs and has the knowledge of the BASIC computer language can easily make the adjustments and improvements in the programs if newer and better methods develop.

The database system has decreased the time required to acquire the data from the radiographs and witness plates. In effect, the engineers now have more time to analyze the data rather than spending the majority of their efforts in the reduction, manual manipulation, and tabulation of the raw data. Therefore, the database system, including possible improvements for future applications, streamlines the process by which the A/AA Concepts team performs the terminal ballistic evaluation of new penetrator material concepts.

The database system is not solely for the use of the A/AA Concepts team. It could be incorporated with other teams in TBD that use the range 110 facility. Also, since the data stored in the system are easily convertible to the ASCII format, they could be transferred to some of the patented software storage base systems, if an engineer desired. Coordination with the A/AA Concepts team will be necessary to achieve full access to the system.

7. REFERENCES

Brainard, P., M. Danish, and P. Tanenbaum. "A Witness Plate Technique for Collection of Behind-Armor Debris Data." BRL-TR-2782, U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1987.

Lambert, J. P. and G. H. Jonas. "Towards Standardization in Terminal Ballistic Testing: Velocity Presentation." BRL Report 1852, (AD A021389), U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1976.

Grabarek, C. and E. L. Herr. "X-Ray Multi-Flash System for Measurement of Projectile Performance at the Target." BRL Technical Note 1634, (AD 807619), U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1966.

INTENTIONALLY LEFT BLANK.

APPENDIX A:
USERS MANUAL FOR DIGITIZING PROGRAMS

Intentionally Left Blank.

The age of computers is overwhelming the nation. Almost all industries and businesses use some type of computer to help in their daily procedures. And now, finally, a computer-controlled automated digitizing system has been developed to perform the specialized task of reducing radiographs for Range 110 of the Terminal Ballistic Division (TBD).

The system uses a sonic digitizer (SAC GP-8) in conjunction with an IBM PC. A similar system has already been proven to increase the accuracy and reproducibility of the data. This newer system will increase the size of the area to be digitized, perhaps allowing for large-scale computations, and because of the IBM format, easing information transfers to database systems. The programs in the IBM use the same techniques as previously performed by hand to calculate all measures related to the velocity, pitch and yaw, and flight-line deviations. The computer performs the calculations much quicker and more reliably than hand calculations. The programs are also arranged to store the data, via simple prompts, in a format currently used by the Armor/Anti-Armor Concepts team for the behind-armor debris and the database system storage.

However, typical with any computer device, the system is only as smart as its operator. The computer is not capable of interpreting the radiographs; it only calculates numbers from the input values. Therefore, a visual analysis of the radiographs to determine the quality of the input data must be made before the digitizing begins (i.e., an adequate amount of projectile visible in the image to insure pitch and yaw values will be correct). In addition, the radiographs must be physically marked at the points to be digitized to insure the reproducibility of the data. Also, for the storage section of the programs, simple prompts must appear pertaining to the between-plate storage (number of pieces between the plates) and for the behind-armor storage (identification of primary residual and target fragments).

The first step in digitizing any data is reviewing the radiographs to insure the fiducial wires are straight. Next, the intersection of the left fiducial wires, in the two images of concern, must be marked. This sets the origin for the digitizer. Last, the digitized points on each image for the separate sequence of flashes are marked. Once the radiograph is correctly marked, it can be digitized. The program for either the single targets or the spaced-array targets is selected. Each program will begin with a series of computer prompts to set the date, shot number, and geometry (L/D) of the rod. Before each series of flashes is digitized, the computer will also prompt for the head separation and the time between subsequent flashes. Details of each sequence of flashes will be addressed in the following sections.

STRIKING RADIOGRAPHS

The radiographs used to calculate accurate striking velocities, pitch, and yaw consist of a vertical view (side film) and a horizontal view (bottom film) with the two projectile images in each. Two images are needed for calculating the flight line of the projectile, used in the pitch and yaw determination. The computer calculates the coordinates of the center of mass of each image in actual space to determine the actual flight line. The correct pitch and yaw are then determined in relation to that flight line. Sometimes, due to mechanical failure, only one flash is available in the horizontal plane; in these cases, the velocity can still be calculated, but, the yaw value may be misleading.

As mentioned, the first point marked on the radiograph is the intersection of the left fiducial wires for the two tube heads of interest. For E-range, the tube head behind the projectiles is used, and for G-range the tube head in front of the projectiles is used. Five points on each image of the projectile are then marked. One matching fixed point (typically the nose or tail) on each flash is marked, P1 and P2, which are used for the velocity calculation. Four points around the projectile are designated: one on the upper side near the front, one directly below it, and then two more near the tail of the projectile - one on top and one on the bottom. These four points on each flash are used to calculate the pitch and the actual flight line. All five of the points are depicted in Figures A1 and A2, showing the striking velocity for their respective ranges, G and E. The same sequence of five points per image is also marked on the bottom film, as shown in Figures A3 and A4. If one image on the bottom film is missing, the X-coordinate and apparent pitch are still calculated using the five points on the available image. The computer prompts lead the user through each step for either one, two, or no flashes on the bottom film. Both views on the side film are required to calculate the striking velocity.

BEHIND-ARMOR RADIOGRAPHS

The residual radiographic images consist of two x-ray tube heads placed behind the target in the vertical plane. A horizontal film is neglected for various reasons (i.e., debris hitting the film and witness packs blocking the view). Therefore, the measures used are only in the vertical plane. Because of this, the velocities calculated are minimum values, and the angles are only the component in the vertical plane. However, in past results, the residual penetrator only deviates slightly in the horizontal plane, so these velocities calculated are fairly representative.

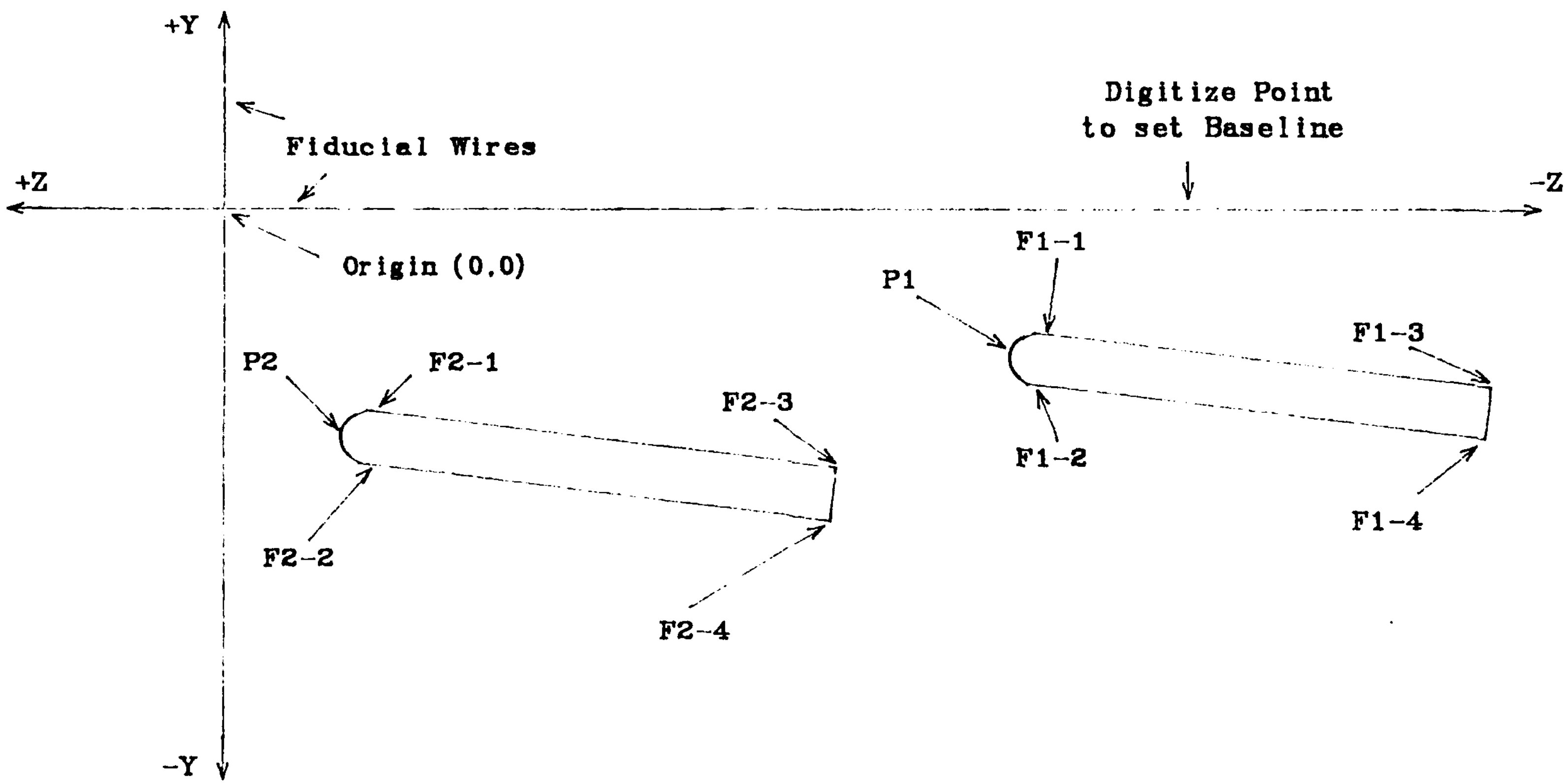


Figure A1. Digitizing Points for Striking in G-Range

Figure A1. Digitizing Points for Striking in G-Range

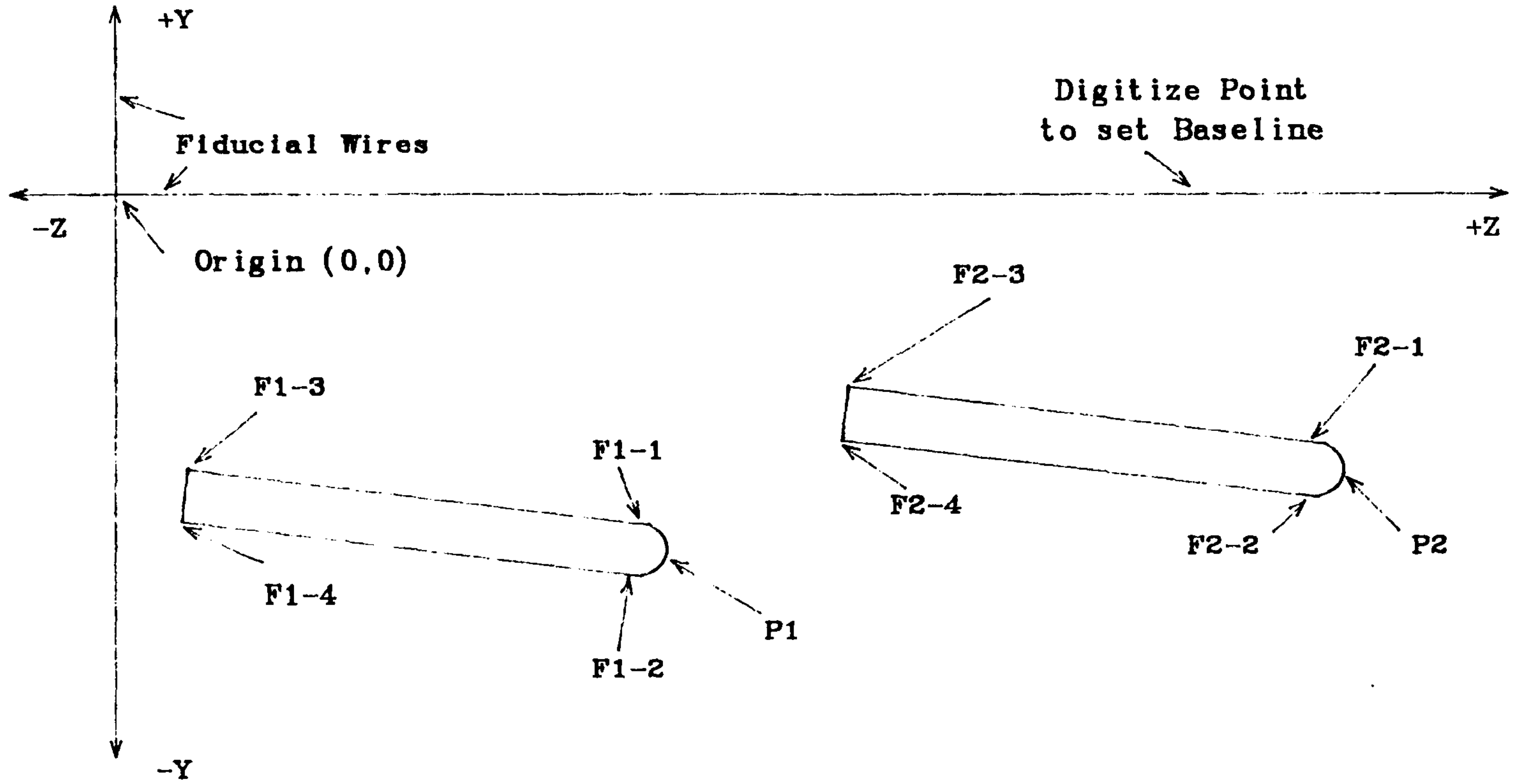


Figure A2. <u>Digitizing Points for Striking in E-Range</u>

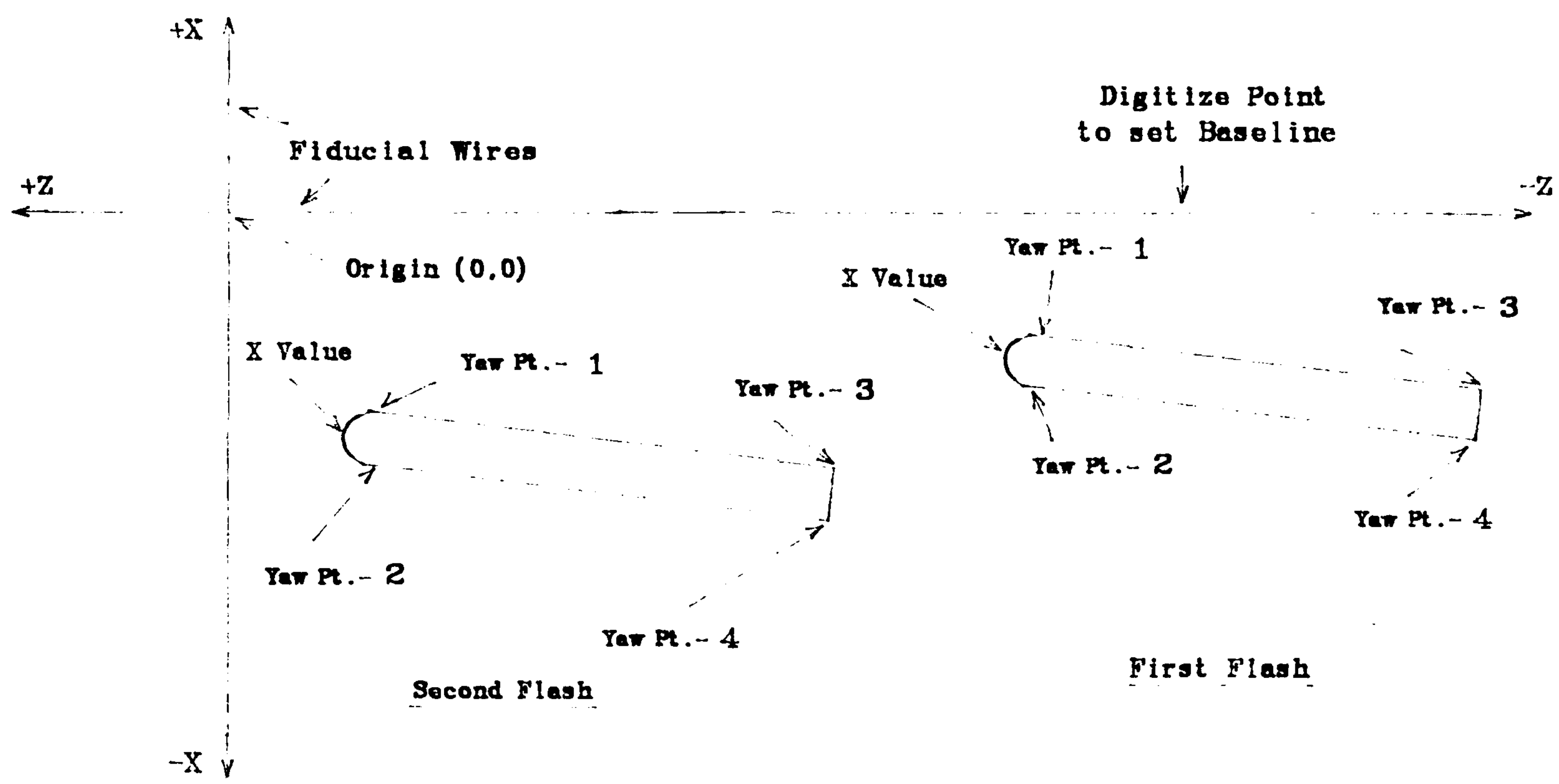


Figure A3. Digitizing Points for Orthogonal Film in G-Range

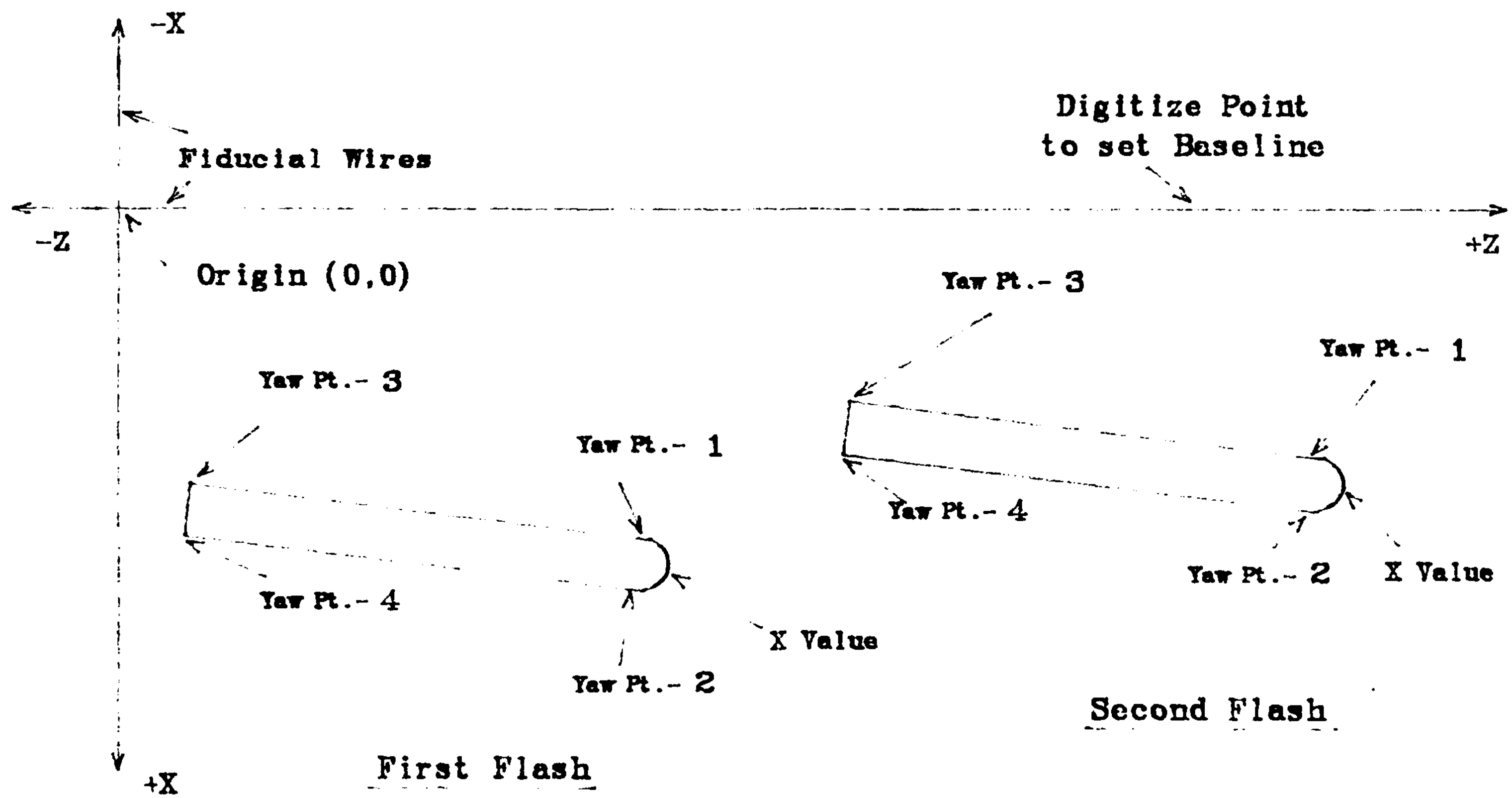


Figure A4. Digitizing Points for Orthogonal Film in E-Range

Again, as for the striking x-rays, the intersection of the left fiducial wires must be located first. For the E-range it will be directly behind the target, and for the G-range it will be the second wire after the target. Next, the fragments in each flash must be matched and numbered in sequence. Also, for storage, the main residual penetrator pieces and main target plug pieces must be identified. The center of mass for each fragment in both flashes must be located; this will be used as the digitizing point. An additional measure of the rotation of the main residual fragment and its relative angle in space (alpha) can also be determined. This is typically only measured if a sizable residual piece is produced. To digitize the fragment, three points along the centerline are marked and digitized. The first is at the nose, the second at the tail, and the third is at the center of mass. The diagrams showing sample behind-armor digitizing points are shown in Figures A5 and A6 for the G and E Range.

BETWEEN-PLATE RADIOGRAPHS

The spaced-target array causes many phenomena to occur to the projectile between the individual plates of the array. These phenomena are examined by flashing two x-ray tube heads between the plates to calculate the velocity, rotations, and pitch of the projectile.

To digitize these flight patterns between the plates takes more care in the initial analysis than for the striking or residual radiographs. First, the fiducial wires must be located and marked, similar to the striking. Next, a fixed point on each image is located and marked, P1 and P2; this may be the front or tail of the projectile. As for the striking, these points are used to calculate the velocity. A centerline must be drawn manually on the radiograph. Often the projectile is fractured or bent; this makes defining the centerline difficult. A trial and error basis is used until the centerline is determined. Because of the complexities occurring between the plates, manually drawing the centerline also gives the user a better "feel" for the action of the projectile. Once the centerline on each flash is completed, a point at the nose of the projectile along the centerline is marked. Also, a point at the rear of the projectile and a point in the center (center of mass) are marked. These points are used to calculate the pitch, actual flight line, and rotation of the rod. An additional point located on the target where the penetrator will first make contact is also marked. The front face of the target in the second flash must be located, and the point of impact must also be estimated. If the projectile has already hit the plate, the point should be digitized behind the point indicating the nose of the projectile. This point is used in determining the distance from the projectile to the target plate, which is used to extrapolate the impact pitch on that target plate. Obviously, if the projectile has already impacted the target, no additional pitch will be applied. In

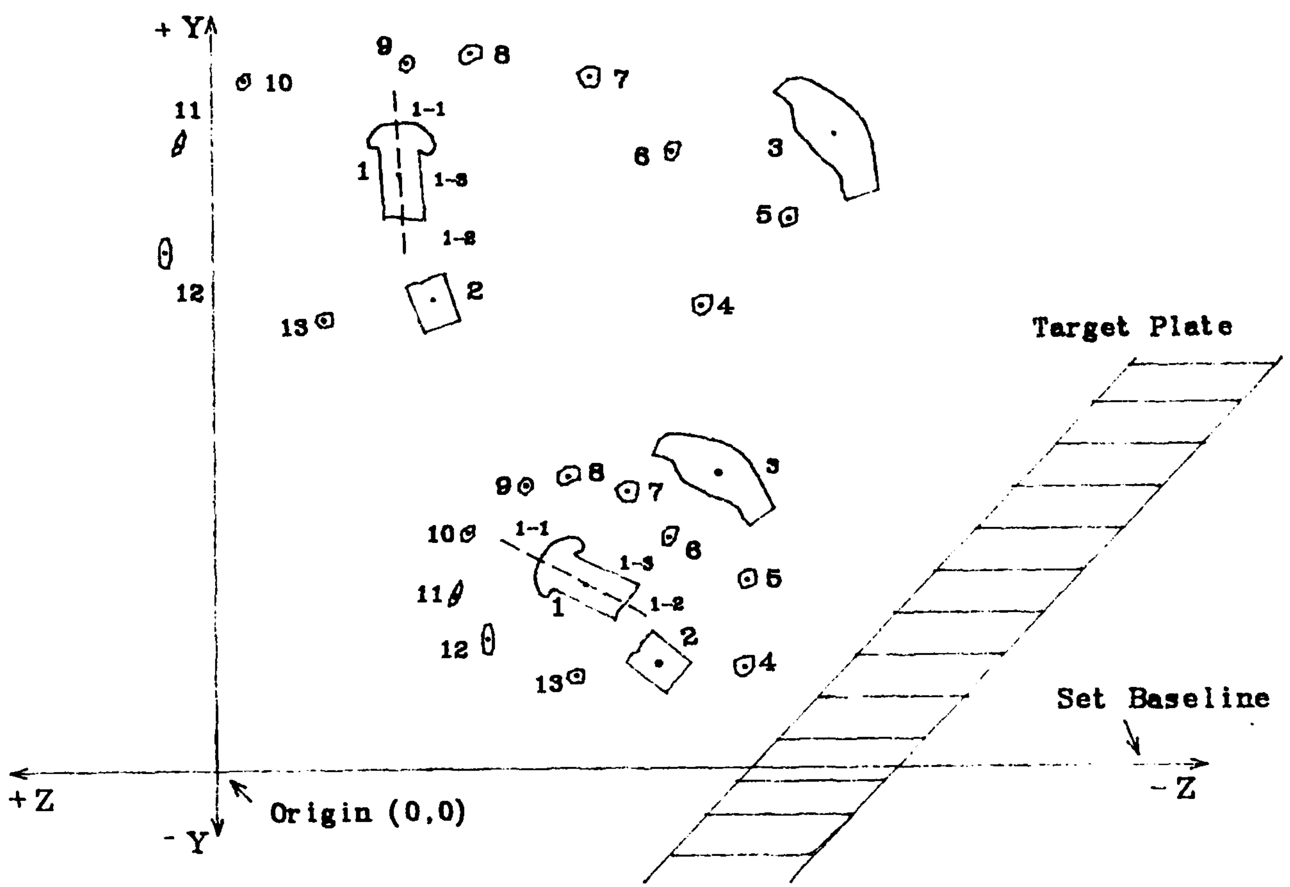


Figure A5. Digitizing Points for BAD in G-Range

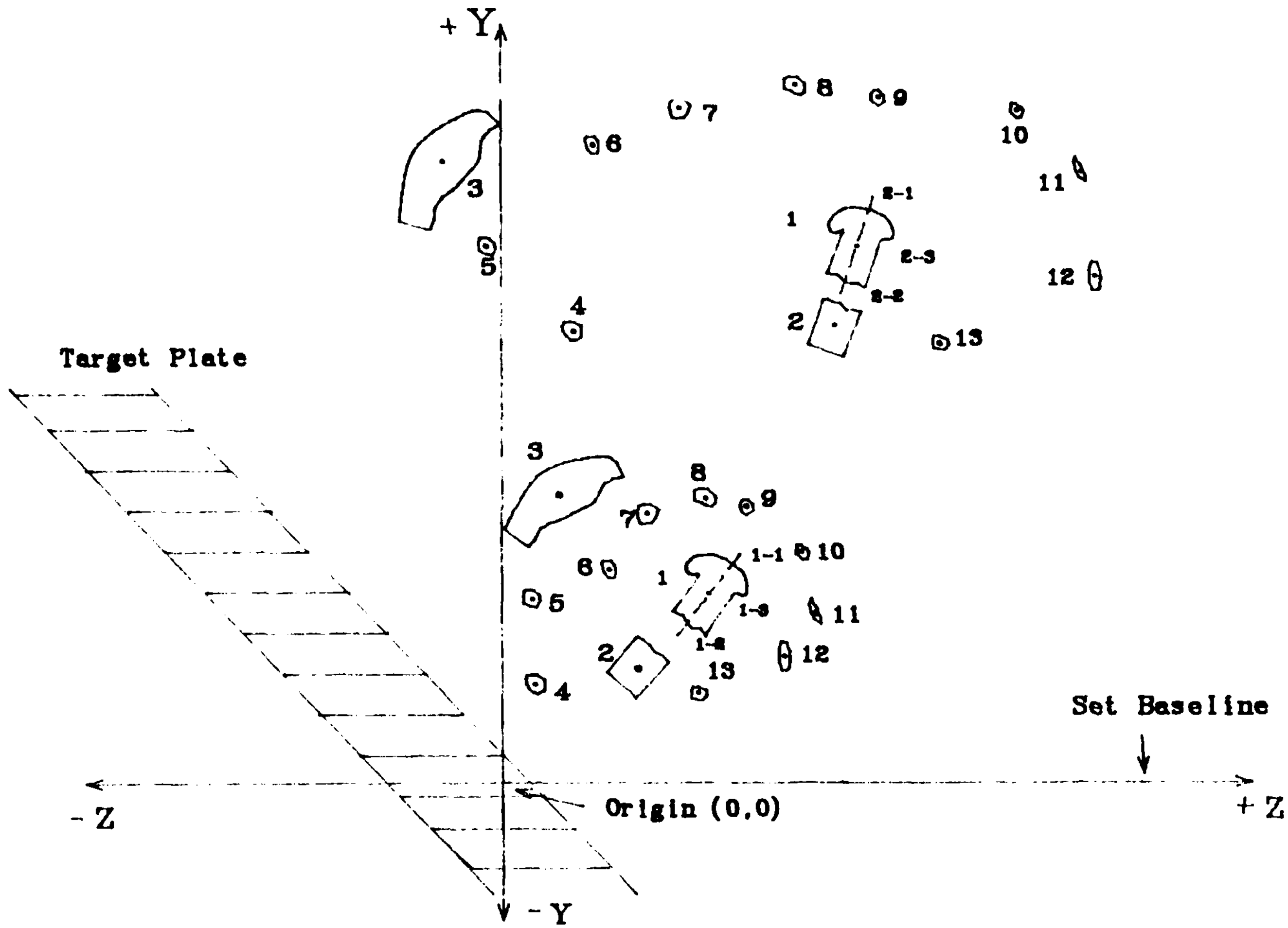


Figure A6. Digitizing Points for BAD in E-Range addition, the bend or deflection of the projectile can be measured, if requested. This consists of marking the second flash of the radiograph with an additional three points. First, a straight line is drawn along the edge of the projectile connecting the front to the rear of the projectile. From this line, it is obvious how the rod is bending. A point at the intersection of the tail and the line and the intersection of the nose and the line are digitized. Next the point of maximum deflection, the point furthest from the line on the edge of the projectile, is digitized. However, users not interested in storing these data may opt to skip this step. The diagrams in Figures A7 and A8 show all of the digitized points for each range.

If all of the x-ray images are clear and spaced correctly, a complete analysis of the ballistic performance of the projectile can be determined via the computer system. As mentioned earlier, the computer only calculates the velocity and angle measures; the user must still manually estimate the masses and lengths of the projectile. The manually estimated masses are not required for immediate storage. The user can save solely the information from the digitizer in a file and enter the masses and pertinent post-mortem measures at a later date.

DATABASE STORAGE

A data file containing only one shot against a certain target is not of much relevance. A much more meaningful file consist of all of the test shots fired for a particular geometry and material projectile against a specific target. This file will give a reference of the overall performance of the projectile. To store the data acquired via the digitizer in this manner, a program was constructed to combine the individual data files. It not only allows the user to combine the individual shots of a series, but also enter the masses, lengths, and target measures, which are not recorded via the digitizing programs. This program, because of its enormous size, was converted to an executable file (DBS.EXE). A file produced from the DBS.EXE program will consist of all the shots fired for a particular geometry and material projectile against a specific target. This data file can then be transferred to a "MAIN" storage database.

The following two sections describe the step-by-step computer prompts and related instructions for the two digitizing programs. SPEED1 is the digitizing program for the single-plate targets, and SPEED3 is for spaced-array targets (triple or double spaced-array targets). Using these prompts and the diagrams in this manual, the digitizing process should be simple and beneficial to anyone shooting a test program in either of the 110 ranges.

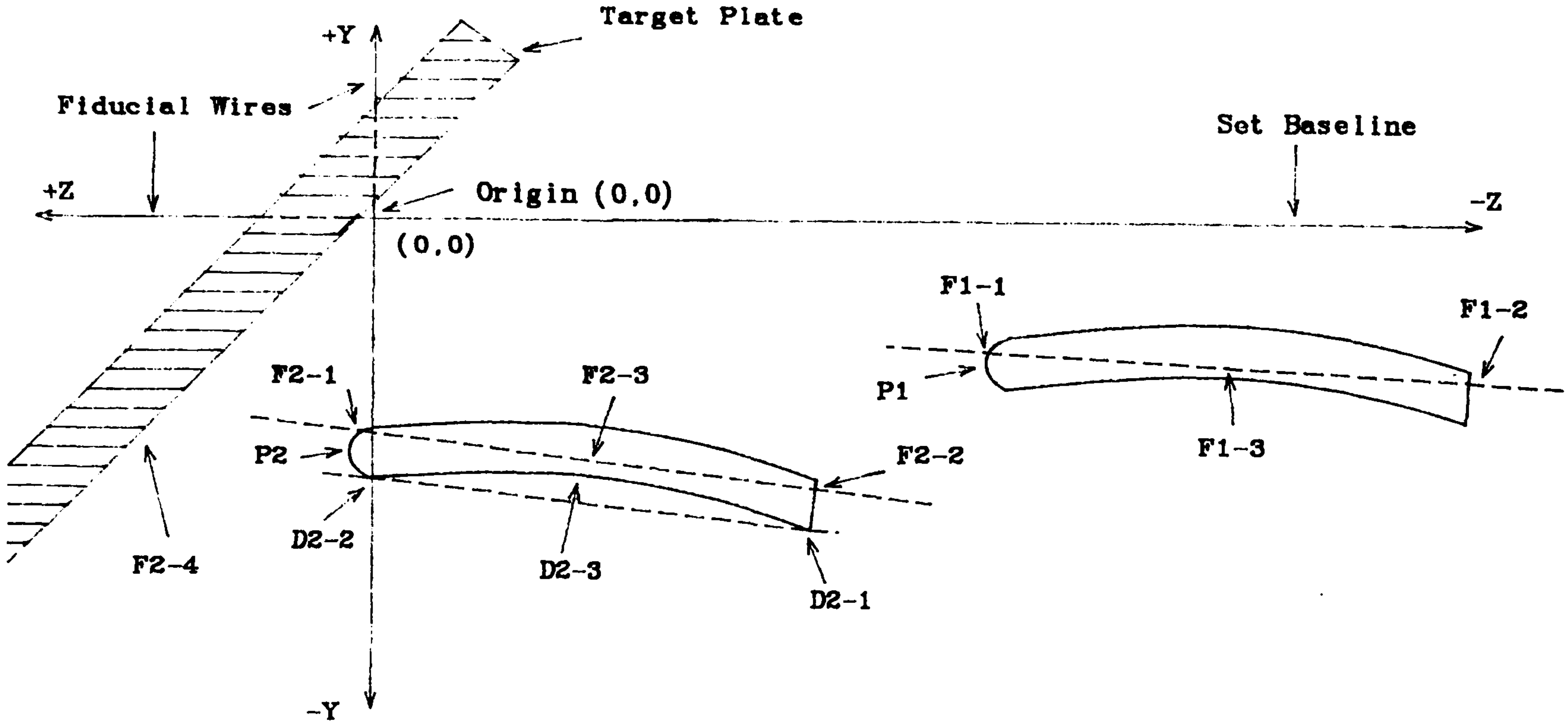


Figure A7. Digitizing Points for Between Plates in G-Range

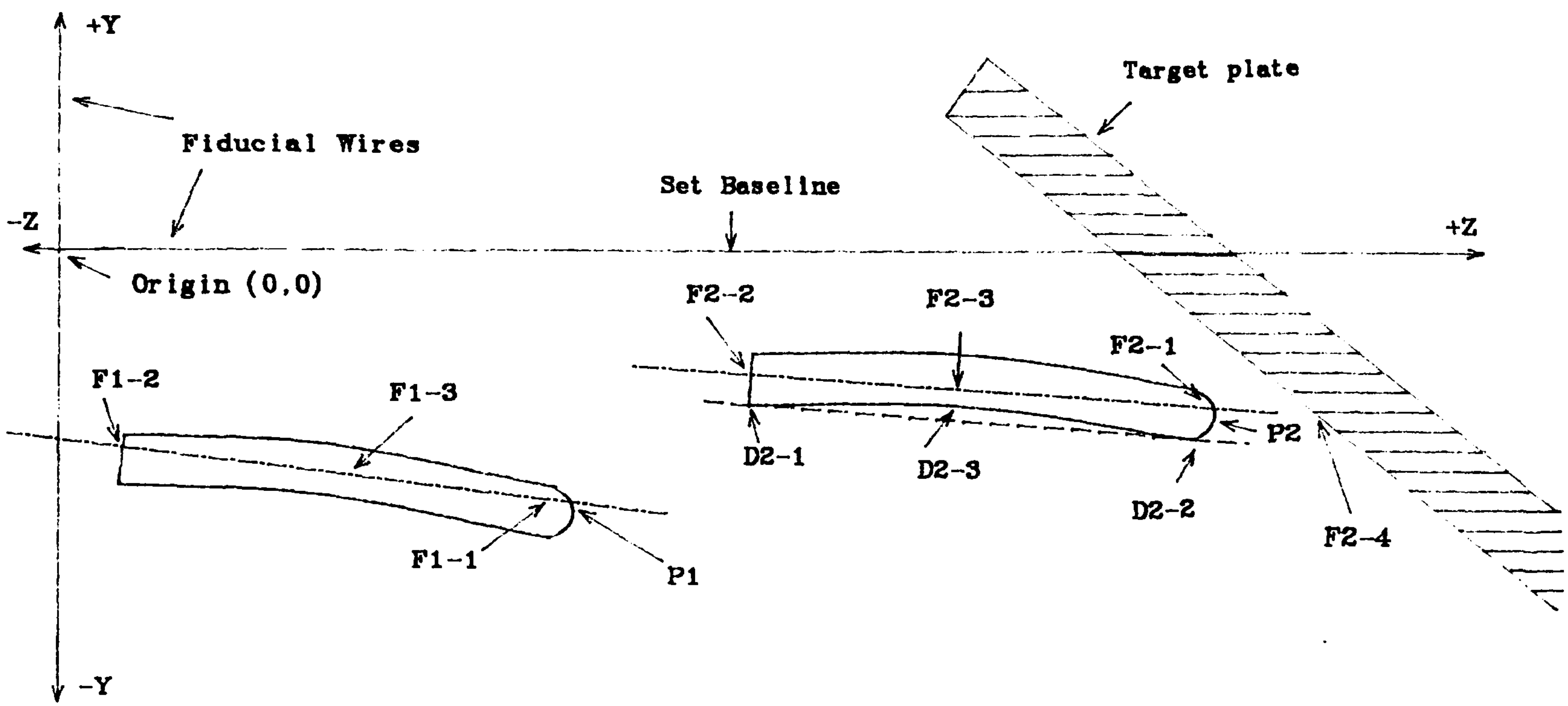


Figure A8. Digitizing Points for Between Plates in E-Range

SPEED1 COMPUTER PROMPTS AND INSTRUCTIONS FOR SINGLE TARGETS

A. Before using the digitizer, the radiographs must be correctly marked as described in the manual.

B. Place the x-ray on the light table.

Note: Be sure there is nothing between the microphones and the cursor.

C. Turn on Main Power Switch.

D. Menu will appear: Type 1 (ENTER).

Note: Push Disk in Drive B:
Hit Caps Lock Button.
Hit Num Lock Button.

E. An introduction will appear: Hit F5 to begin program.

F. Introduction prompts to set up program.

Note: F10 (system) will be displayed throughout setup process. This key will end the program and return to the MAIN menu. All data entered using the program will be lost.

1. Range: E (F1) G (F2) LARGE (F3)
2. Target Obliquity:

0	45	60	70.5	OTHER
F1	F2	F3	F4	F5

3. L/D of penetrator:

10	15	20	25	30	40	791	OTHER
F1	F2	F3	F4	F5	F6	F7	F8

4. INPUT Shot number? (a numeric value)
5. INPUT Date? (any way you please)

G. A menu will appear along with the completed processes.

Press appropriate key.
Theta is (obliquity of target).

STRIKE	EXIT V	QUIT	PRINT	STORE	MENU
F1	F2	F4	F5	F6	F9

Note: Each point digitized (besides the origin) must be input TWICE; the button must be hit TWO TIMES for accuracy. Also, while digitizing, be aware of any unusual beeps; these are indications of errors.

Typical errors are:

** Switch to centimeters, or you hit the button too FAST (digitizer reads values in cms or entered too quick).

** Redo same point (the values were not valid).

** Redo same point when this disappears (the memory from the digitizer was full).

***** If digitizer does not work (no beeps), then turn the DIGITIZER off and on. No data will be lost. ********

F9 MENU - This key returns to the menu; if it fails, try hitting the digitizer button.

H. STRIKE option (Striking Velocity Calculations).

Note: Once the digitizing has started, if you hit the backspace, a note at the bottom of the screen will appear, and the entire entry must be re-entered. At this point the function keys are cleared, except the F9 (MENU) and F3 (orth).

MENU - Returns to the menu. Only the section that is being worked on will be lost. (Use this to correct a mistake during the digitizing.)

orth - Starts the digitizing for the bottom film. (Use this if side pictures were lost or to correct a mistake digitizing the bottom film.)

1. Arrows pointing the direction of the projectile will appear. (Left to Right or Right to Left)

2. If the head separation is incorrect, then press function key F1, and input correct distance?

3. Input time for striking velocity, T2 (microsec)?

4. Begin digitizing:

   Note: Be sure the digitizer is in metric (English/Metric).

Set the origin:

   Move the cursor to the MAIN MENU (upper left), and push the button (computer will not beep). Digitize the intersection of the left fiducial wires by hitting the button TWICE. Next, digitize a point along the horizontal fiducial wire, also by hitting the digitizer button TWICE.

Start digitizing the points in sequence:

1 - Fixed Point on first flash.	P1
2 - Fixed point on second flash.	P2
3 - Four points on first flash:	
a. First point is on top near the nose.	Flash 1 -1
b. Second point is on bottom near the nose.	Flash 1 -2
c. Third point is on the top near the tail.	Flash 1 -3
d. Last point is on the bottom near the rear.	Flash 1 -4
4 - The same sequence for the second flash.	Flash 2 -(1-4)

Begin orthogonal (horizontal or bottom) film:

1. How many flashes 1, 2, or 0 ? (0 if no bottom was recorded; if 0, then will ask for X value from previous shot.)

2. Set the origin for the orthogonal film, as done for side film.

3. Digitize the points:

1 - The orthogonal fixed point.	Orthogonal PT.
2 - Four points around the projectile in the same sequence, as for the side film.	YAW PT 1
	YAW PT 2
	YAW PT 3
	YAW PT 4

3 - If you have two flashes, do the same sequence for the second flash.

4 - If there were no SIDE pictures, a PROMPT for a Y-value will appear.

5 - Will be returned to the menu. "Striking velocity complete" will appear on the screen.

I. EX_Γ V - Residual Radiographs:

1. If the striking was not determined, screen will prompt for the correction factor, K.
2. Is the head separation correct, Y/N?
3. Input time between flashes (microsec)?
4. Digitize Points:

1 - Reset the origin for the residual tube heads, as done for the striking radiographs.

2 - A prompt appears asking if ALPHA (or flight characteristics of main penetrator) is desired? Y/N

A short description will	Nose point -1
appear of order to digitize	Tail point -2
the three points.	Center of mass -3

If the ALPHA is digitized, then start the sequence for the remaining fragments with the second fragment.

3 - Digitize <u>ALL</u> of the fragments in the first flash (in sequence).

Flash 3 -1
Flash 3 - # of frag.

4 - After the last is digitized, hit the digitizing button twice, <u>up high out of the range of the microphones</u>.

5 - Digitize the points <u>in sequence</u> for the second flash.

Flash 4 -1
Flash 4 - # frag.

6 - Will automatically stop after last fragment and return to the menu. "Behind-armor debris completed" will appear on the screen.

J. PRINT - Prints the Data.

1. Do you want it on Paper, Y/N?

2. The data will be printed on the paper or on the screen. If it is requested on paper, a message to turn printer on LINE appears.

K. STORE Data Storage.

1. Do you want to store the Behind-armor debris data, Y/N?

   (Will only appear if BAD was measured).

   Typically only used for full-scale testing (0.50 caliber or 25 mm).

   Stores data in a file "shot number" + "BAD" on Drive B:

2. Do you want to store in the Database System, Y/N?

   a. Input T-designation (code to describe target).

   b. Input fragment number of main residual penetrator. (options will appear on screen)

   c. Input fragment number of secondary residual penetrators.

   d. Input fragment number of third residual penetrators.

   e. Input fragment number of main target plug.

   f. Input fragment number of second target plug.

   g. Data is stored in a file on drive B: as "shot number" + "DBS."

L. QUIT Ends program.

Sets the function keys to:

F1 - LIST

F2 - RUN

F3 - LOAD "

F4 - SAVE "

F7 - SYSTEM

SPEED3 COMPUTER DIGITIZING PROMPTS AND INSTRUCTIONS

A. Before using the digitizer, the radiographs must be correctly marked as described in the manual.

B. Place the x-ray on the light table.
Note: Be sure there is nothing between the microphones and the cursor.

C. Turn on Main Power switch.

D. Menu will appear. Type 3 (ENTER)
Note: Push disk in Drive B:
Hit Caps Lock Button.
Hit Num Lock Button.

E. An introduction will appear. Hit F5 to begin program.

F. Introduction prompts to set up program.
(Use Function Keys - F#)
Note: F10 (system) will be displayed throughout setup process. This key will end the program and return to the MAIN menu. All data entered using the program will be lost.

1. Range: E (F1) or G (F2)
2. L/D of penetrator:

10	15	20	25	30	40	OTHER
F1	F2	F3	F4	F5	F6	F7

3. INPUT Shot number? (a numeric value)
4. INPUT Date? (any way you please)

G. A menu will appear along with the completed processes.
Press appropriate key.

STRIKE	EXIT V	VR 1-2	QUIT	PRINT	STORE	MENU	SYSTEM
F1	F2	F3	F4	F5	F6	F9	F10

Note: Each point digitized (besides the origin) must be input TWICE; the button must be hit TWO TIMES for accuracy. Also, while digitizing, be aware of any unusual beeps; these are indications of errors. Typical errors are:

** Switch to centimeters, or you hit the button too FAST (digitizer reads values in cms, or entered too quick).

** Redo same point (the values were not valid).

** Redo same point when this disappears (the memory from the digitizer was full).

***** If Digitizer does not work (no beeps), then turn the DIGITIZER off and on. No data will be lost. **********

F9 MENU - this key will return to the menu; if it fails, try hitting the digitizer button once.

H. STRIKE option (Striking Velocity Calculations).

Note: Once the digitizing has started, if you hit the backspace, a note at the bottom of the screen will appear and the entire entry must be re-entered. At this point, the function keys are cleared except the F9 (MENU) and F3 (orth).

MENU - returns to the menu. Only the section that is being worked on will be lost. (Use this to correct a mistake during the digitizing.)

orth - Starts the digitizing for the bottom film. (Use this if side pictures were lost or to correct a mistake digitizing the bottom film.)

1. Arrows pointing the direction of the projectile will appear (left to right or right to left)

2. If the head separation is incorrect, pressing function key F1 will prompt to input correct distance?

3. Input time between the flashes (microsec)?

4. Begin digitizing:

   Note: Be sure the digitizer is in metric (English/Metric).

Set the origin.

Move the cursor to the MAIN MENU (upper left), and push the button (computer will not beep). Digitize the intersection of the left fiducial wires by hitting the button TWICE. Next, digitize a point along the horizontal fiducial wire, also by hitting the digitizer button TWICE.

Start digitizing the points in sequence:

1 - Fixed Point on first flash.	P1
2 - Fixed point on second flash.	P2
3 - Four points on first flash:	
a. First point is on top near the nose.	Flash 1 -1
b. Second point is on bottom near the nose.	Flash 1 -2
c. Third point is on the top near the tail.	Flash 1 -3
d. Last point is on the bottom near the rear.	Flash 1 -4
4 - The same sequence for the second flash.	Flash 2 -(1-4)

Begin orthogonal (horizontal or bottom) film

1. How many flashes 1, 2, or 0 ? (0 is if no bottom was recorded. If 0, then will ask for X value from previous shot.)
2. Set the origin for the orthogonal film, as was done for the side film.
3. Digitize the points:

1 - The orthogonal fixed point.	Orthogonal PT.
2 - Four points around the projectile in the same sequence, as for the side film.	YAW PT 1
	YAW PT 2
	YAW PT 3
	YAW PT 4

3 - If you have two flashes, do the same sequence for the second flash.

4 - If there were no SIDE pictures, a PROMPT for a Y-value will appear.

5 - Will be returned to the menu. "Striking velocity complete" will appear on the screen.

I. EXIT V - Residual Radiographs:

1. If the striking was not determined, the screen will give a prompt for the X value or a prompt to digitize just the bottom film to determine the X value, if the bottom film was not lost.
2. Is the head separation correct, Y/N?
3. Input time between flashes (microsec)?
4. Digitize Points:

   1 - Reset the origin for the residual tube heads, as done for the striking radiographs.

   2 - Digitize the points <u>in sequence for the first flash</u>. Flash 3 -1

   Flash 3 - # of frag.

   3 - After the last is digitized, hit the digitizing button twice, <u>up high out of the range of the microphones</u>.

   4 - Digitize the points <u>in sequence for the second flash</u>.

   Flash 4 -1

   Flash 4 - # frag.

   5 - Will automatically stop after last fragment and return to the menu. "Behind-armor debris completed" will appear on the screen.

J. VR 1-2 Between-Plate Calculations

1. Input VR1 or VR2 for between first plates or second plates.

   Note: For a <u>double target</u> use just VR1.

2. If the striking was not determined, a prompt for the X value or a prompt to digitize just the bottom film to determine the X value, if the bottom film was not lost.

3. If the head separation is incorrect, then use function key F1.

4. Input time between flashes (microsec)?

5. Digitize Points:

   1 - Reset the origin, as done for the striking pictures.

Set the origin.

Move the cursor to the MAIN MENU (upper left), and push the button computer will not beep). Digitize the intersection of the left fiducial wires by hitting the button TWICE. Next, digitize a point along the horizontal fiducial wire, also by hitting the digitizer button TWICE.

2 - Digitize the points in sequence.

a. Fixed point on the first flash.	P1
b. Fixed point on second flash.	P2
c. Centerline point at the nose.	YAW point 1 -1
d. Centerline point at the tail.	YAW point 1 -2
e. Center-of-mass point.	YAW point 1 -3
f. Repeat c-d for second flash.	YAW point 2 - (1-3)
g. Point on target.	point 2 -4

3 - FOR VR2 The screen shows a prompt to "Digitize the Bend" Y/N?

a. If Y, then digitize three points:

1 Tail section on edge.	Deflection pt 1
2 Nose section on edge.	Deflection pt 2
3 Point of max deflection.	Deflection pt 3

4 - Will return to the menu. "First (second) residual completed"

K. PRINT - Prints the Data

1. Do you want it on Paper, Y/N?
2. The data will be printed on the paper or on the screen. If it is requested on paper, a step to be sure printer is on LINE is included.

L. STORE - Data Storage

1. Do you want to store the Behind-armor debris data, Y/N?

   (Will only appear if BAD was measured)

   Note: BAD is usually only stored for LRP or SLAP programs.

   Stores data in a file on drive B: as the "shot number" + "BAD"

2. Do you want to store in the Database System, Y/N?

a. Input T-designation (code assigning the target)

Note: Codes describing the following inputs will appear on the screen as the input is requested.

b. Input fragment number of main residual piece?

c. Input fragment number of secondary residual piece?

d. Input fragment number of main target plug?

e. Input number of pieces after first plate?

f. Input number of pieces after second plate?

g. Input category for pieces after first plate?

h. Input category for pieces after second plate?

i. Input the Month (1-12 for Jan-Dec)?

j. Input the Year (1990)?

k. Input if it is a USH3/4, (Y/N)?
If N, then input the thickness and obliquity.

l. Program will automatically store the file in a preset format on drive B as "*shot number*" + "DBS".

M. QUIT - Ends the Program

Sets the function keys to:

F1 - LIST

F2 - RUN

F3 - LOAD "

F4 - SAVE "

F7 - SYSTEM

Use the SYSTEM key (F7) to return to the MAIN MENU. The other keys are only used to manipulate the program.

Documentation for DBS-STR Program

Note: This program is used to add masses, target measures, or any other pertinent information to the data files. Once this program has been completed, no more additions are necessary to the files, except the limit velocity calculation prior to being transferred to the MAIN database system on the Bernuolli hard drives. The program will access SINGLE, TRIPLE, or DOUBLE target data.

For reference: The SPEED1 and SPEED3 programs are used to store the shot data in individual files by their shot number (i.e., 3599DBS for shot number 3599). These individual files are first combined in a file by using the DBS-STR program, and then are adjusted and corrected.

1. To begin, go to the MAIN menu on the computer.

   TYPE D (ENTER)

   It will display an introduction and ask for the filename.

   Only one file at a time can be manipulated.

   The filename being asked for is the one for a group of shots against one particular target (i.e., DUT6.FIL for Depleted Uranium against target T-designation 6).

2. Select a function. (This is the main menu for the DBS-STR program).

   1 - List -- lists the data.

   2 - Add -- add additional shots to the current file.

   3 - Create -- combine shot numbers and then create a file.

   4 - Adjust -- selects shot numbers where the masses and target measures can be added.

   5 - Quit -- ends the program.

   6 - Correct -- used to correct information in the file.

   7 - Help -- list the function of each key.

   8 - Delete a shot -- deletes a shot from the file.

   9 - Start a new file -- goes to beginning for new file.

F10 - System -- returns to the SYSTEM MAIN MENU.
Enter the number requested from above.

3. List (1 ENTER)

The program reads the file.

a. It will ASK - do you want to list the data, (Y/N)?

b. It will ASK - do you want it on paper, (Y/N)?
Usually it can be skimmed without putting it on paper.

If it is on paper, it will print the entire file.

If it is on the screen, it will show just five entries at a time; by pushing F4 (cont), the next screen will appear. At the end, the menu will reappear.

4. Add (2 ENTER)

The program reads the data currently in the file.

It will list the shot numbers already existing.

a. Prompt - Shot number to be added?
(The program reads that shot number.)

b. Prompt - Shot number to be added or (N) for none?
(The same as above, except, if N is entered, then the program will store the shot numbers added with the initial data).

c. Prompt - Do you want to list the data, (Y/N)?
(This is the same as the list section.)
TYPICALLY: it is best to adjust before listing.

5. Create (3 ENTER)

This is used the first time the shot numbers are combined into a single file. It is similar to Add; however, no file exists prior to running the section.

a. Prompt - Shot number to be added?
(The program reads that shot number.)

b. Prompt - Shot number to be added or (N) for none?
(The same as above, except, if N is entered, then the program will create a file containing the shot numbers added.)

c. Prompt - Do you want to list the data, (Y/N)?
(This is the same as the list section.)
TYPICALLY: it is best to adjust before listing.

6. Adjust (4 ENTER)

This section is used to add masses, target measures, and any other data not input via the digitizing programs.

Note: To run this section, the shot numbers to be adjusted must already be saved in the file.

a. The program will list all of the shots in the file at the top of the screen.

b. PROMPT - Which shot number is to be adjusted?
If the shot number was not found, it will return to step a.
At this point, the program lists the shot number being adjusted and the type of target (single, double, or triple)(i.e., shot number 3599 for the triple target).

c. The following prompts will vary depending on the type of target (single, triple, or double). The prompts will ask for all masses and target measures.

Note: If a value besides the nonapplicable (-0.05) already exists, it will skip that entry. Therefore, you must use the Correct section to change the values in an entry.

d. After all measures are added, a prompt will appear for another shot, (Y/N)? If yes, then the prompts will continue at (a) again.
If no, then it will store all of the adjusted values.

e. After the data are stored, a prompt for a listing appears.

7. Quit (5 ENTER)

Quit ends the program, returning to the System MAIN MENU.

8. Correct (6 ENTER)

This section will correct a particular shot number and column.

Note: You must know the column number to be corrected.

a. The program will list the shot numbers in the file.

b. Prompts for the shot number to be corrected.
Again, if it is not found, it will return to step a.

c. Prompts for column to be corrected

d. Lists the current value of the column and prompts for the new value.

e. Prompts for another correction and/or same shot number, (Y, N, or S)?

If S (same), then continues from (c) for same shot.
If Y (yes), then will start from (a).
If N (no), then will store the corrections and prompt for a listing.

9. Help (7 ENTER)

This section lists all of the menu options. By pushing the requested entry, a short explanation of that section will appear.

10. Delete a Shot Number (8 ENTER)

This section deletes a shot number from the file.

a. The program will list the shot numbers in the file.

b. It will prompt for the shot number to be deleted.
Again, if it is not found it will return to (a).

c. It will store the file, deleting the shot number requested, and prompt for a listing.

11. Start a New File (9 ENTER)

This section automatically returns to the beginning of the program with the prompt for a filename. All previous data are lost.

12. System (F10 Function key 10)

This button returns to the system's MAIN MENU; no data are stored.

IMPORTANT: This is an executable program; therefore you cannot just edit it. The original basic program is DBS-STR.BAS on the C: drive and a back-up floppy. If changes to the program are needed, they must be performed in the basic program; it is then converted to an executable file via QuickBasic.

INTENTIONALLY LEFT BLANK.

APPENDIX B:

LISTING OF COLUMNS FOR DATA STORAGE

INTENTIONALLY LEFT BLANK.

Table B1. Column Headings and Codes for the SINGLE Files.

Column	Name	Units
1	T-designation	
2	Limit Velocity	m/s
3	Shot Number	
4	Eta	deg
5	Alpha	deg
6	Beta	deg
7	Gamma	deg
8	Striking Velocity	m/s
9	Striking Mass	grams
10	Eta Residual	deg
11	Alpha Residual	deg
12	Residual Velocity	m/s
13	Residual Mass	grams
14	Residual Mass Recovered	grams
15	Penetration Depth	cm
16	Plug Velocity	m/s
17	Plug Mass	grams
18	Plug Mass Recovered	grams
19	Plug Length	cm
21	Plug Width	cm
22	Plug Thickness	cm
23	Exit Hole Length	cm
24	Exit Hole Width	cm
25	Bulge Extent	cm
26	Residual Velocity (2nd pc)	m/s
27	Residual Mass (2nd pc)	grams
28	Residual Velocity (3rd pc)	m/s
29	Residual Mass (3rd pc)	grams
30	Delta Alpha Residual	deg
31	Delta time for Residual	micro sec
32	Entrance Hole Length	cm
33	Entrance Hole Width	cm
34	Center Hole Length	cm
35	Center Hole Width	cm
36	# pcs Residual	#
37	Maximum Res. Dia.	inches
38	Eta Plug	deg
39	Cone Angle	deg
40	Center of Frag Spray	deg
41	Weight loss	grams
42	Velocity of 2nd Plug	m/s
43	Mass of 2nd Plug	grams
44	Mass of 2nd Plug Recovered	grams

Column Headings and Codes for the SINGLE Files (Continued).

Column	Name	Units
45	Mass of 2nd residual recov.	grams
46	Bulge Length	cm
47	Bulge Width	cm
48-69	Empty	--------------
70	Code for Target	
71	Target Obliquity	deg
72	Target Thickness	inches
73	L/D	
74	Month of shot	#
75	Year of shot	#

Table B2. Column Headings and Codes for the DOUBLE Files.

Column	Name	Units
1	T-designation	
2	Limit Velocity	m/s
3	Shot Number	
4	Eta	deg
5	Alpha	deg
6	Beta	deg
7	Gamma	deg
8	Striking Velocity	m/s
9	Striking Mass	grams
10	First Plate Hardness	BHN
11	Eta first Plate	deg
12	Alpha 1	deg
13	First Residual Velocity	m/s
14	First Residual Mass	grams
15	Second Plate Hardness	BHN
16	Residual ETA	deg
17	Residual Alpha	deg
18	Residual Velocity	m/s
19	Residual Mass	grams
21	Penetration Depth	cm
22	Plug Velocity	cm
23	Plug Mass	grams
24	Recovered Plug Mass	grams
25	Plug Length	cm
26	Plug Width	cm
27	Plug Thickness	cm
28	Bulge Extent	cm
29	Rotation Rate	deg/sec
30	1st Cen H.L.	cm
31	1st Cen H.W.	cm
32	2nd Cen H.L.	cm
33	2nd Cen H.W.	cm
34	Bulge Length	cm
35	Bulge Width	cm
36	# pcs after 1st plate	#
37	# pcs after 2nd plate	#
38	Cone Angle	deg
39	Center of Frag Spray	deg
40	Eta Plug	deg
41	1st Ent. Hole Length	cm
42	1st Ent. Hole Width	cm
43	2nd Exit Hole Length	cm
44	2nd Exit Hole Width	cm

Column Headings and Codes for the DOUBLE Files (Continued).

Column	Name	Units
45	2nd Mass after 1st Plate	grams
46	3rd Mass after 1st Plate	grams
47	2nd Res. Velocity	m/s
48	2nd Res Mass	grams
49	3rd Res. Velocity	m/s
50	3rd Res Mass	grams
51-69	Empty	-------------
70	Code for Target	
71	Target Obliquity	deg
72	Target Thickness	inches
73	L/D	
74	Month of shot	#
75	Year of shot	#

Table B3. Column Headings and Codes for the TRIPLE Files.

Column	Name	Units
1	T-designation	
2	Limit Velocity	m/s
3	Shot Number	
4	Eta	deg
5	Alpha	deg
6	Beta	deg
7	Gamma	deg
8	Striking Velocity	m/s
9	Striking Mass	grams
10	Eta first Plate	deg
11	Alpha 1	deg
12	First Residual Velocity	m/s
13	First Residual Mass	grams
14	Residual ETA	deg
15	Eta second Plate	deg
16	Alpha 2	deg
17	2nd Residual Velocity	m/s
18	2nd Residual Mass	grams
19	Residual Alpha	deg
20	Residual Velocity	m/s
21	Residual Mass	grams
22	Penetration Depth	cm
23	Plug Velocity	cm
24	Plug Mass	grams
25	Bulge Extent	cm
26	2nd VR 1	m/s
27	2nd MR 1	grams
28	3rd Vr 1	m/s
29	3rd Mr 1	grams
30	2nd Vr 2	m/s
31	2nd Mr 2	grams
32	3rd Vr 2	m/s
33	3rd Mr 2	grams
34	2nd Vr 3	m/s
35	2nd Mr 3	grams
36	First Plate Hardness	BHN
37	Second Plate Hardness	BHN
38	Third Plate Hardness	BHN
39	Rotation Rate 1	deg/sec
40	Rotation Rate 2	deg/sec
41	1st Cen H.L.	cm
42	1st Cen H.W.	cm
43	2nd Cen H.L.	cm

Column Headings and Codes for the TRIPLE Files (Continued).

Column	Name	Units
44	2nd Cen H.W.	cm
45	3rd Cen H.L.	cm
46	3rd Cen H.W.	cm
47	Bulge Length	cm
48	Bulge Width	cm
49	# pcs after 1st plate	#
50	# pcs after 2nd plate	#
51-69	Empty	-------------
70	Code for Target	
71	Target Obliquity	deg
72	Target Thickness	inches
73	L/D	
74	Month of shot	#
75	Year of shot	#

Table B4. Column Headings and Codes for the Semi-Infinite Files.

Column		Name	Units
1		T-designation	
2		L/D	
3		Shot Number	
4		Density	g/cc
5		Plate Hardness	BHN
6		Gamma	deg
7		Striking Velocity	m/s
8		Striking Mass	grams
9		Original Length	inches
10		Original Diameter	inches
11		Penetration depth (Normal)	inches
12		Volume Below the Surface	cc
13		Rise Above the Surface	cm
14		Diameter of the tunnel	cm
15		Volume of the Rise	cc
16	*	Kinetic Energy of Striking	J/cc
17	*	Area (cross-section striking)	square cm
18	*	Mass/Area	g/sc
19	*	Kinetic Energy/Area	J/sc
20	*	Penetration	cm
21	*	ρ LV^2	g/sc*(m/s)^2
22	*	P/L	
23	*	Volume, Total	cc
24	*	KE/Vt	J/cc
25	*	KE/Vbs	J/cc
26	*	Dt/Dp	
27	*	Cross sectional Area Tunnel	sc
28	*	Mass/Area tunnel	r/sc
		SI at Obliquity measures	
29		Ent Hole Length	cm
30		Ent Hole Width	cm
31		Theta	deg
32		Penetration LOS	cm
33		Perp. to center (Ptc)	cm
34		LOS to center (Pc)	cm
35		Ent Hole @ Original Surface (GASH)	cm
36		Alpha	deg
37		Beta	deg
38	*	Path Deviation	deg

Column Headings and Codes for the Semi-Infinite Files (Continued).

Column	Name	Units
39-69	Empty	-------------
70	Code for Target	
71	Target Obliquity	deg
72	Target Thickness	inches
73	L/D	
74	Month of shot	#
75	Year of shot	#

* These values are calculated from the measured values

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

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

<u>Aberdeen Proving Ground</u>

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

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-3847 Date of Report JUN 90

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.)

---FOLD HERE---

DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 210[illegible]-5066

OFFICIAL BUSINESS

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

POSTAGE WILL BE PAID BY ADDRESSEE

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-9989

---FOLD HERE---