

AD-A056 366

ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERD--ETC F/6 19/4
STANDARDIZATION OF TERMINAL BALLISTICS TESTING, DATA STORAGE AN--ETC(U)
MAY 78 J P LAMBERT, B E RINGERS

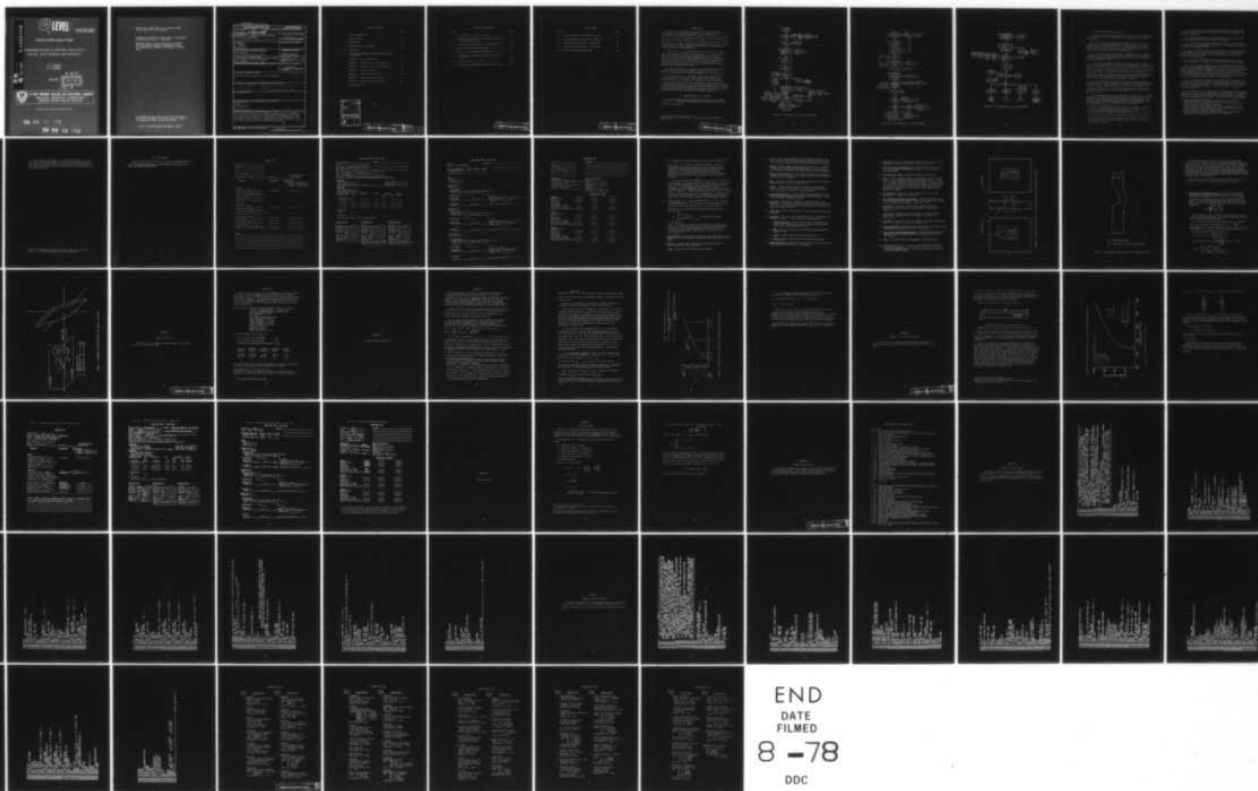
UNCLASSIFIED

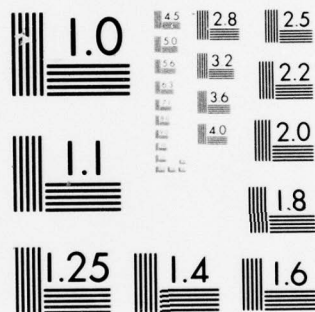
ARBRL-TR-02066

SBIE-AD-E430 062

NL

| OF |
AD
A056366





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD No. _____
DDC FILE COPY

AD A056366

(12)
SC

LEVEL

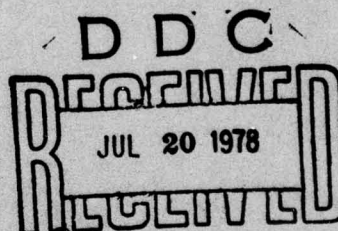
AD-E430 062

TECHNICAL REPORT ARBRL-TR-02066

STANDARDIZATION OF TERMINAL BALLISTICS
TESTING, DATA STORAGE AND RETRIEVAL

J. P. Lambert
B. E. Ringers

May 1978



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

Approved for public release; distribution unlimited.

78 06 19 150

78 06 19 150

Destroy this report when it is no longer needed.
Do not return it to the originator.

Secondary distribution of this report by originating
or sponsoring activity is prohibited.

Additional copies of this report may be obtained
from the National Technical Information Service,
U.S. Department of Commerce, Springfield, Virginia
22161.

The findings in this report are not to be construed as
an official Department of the Army position, unless
so designated by other authorized documents.

*The use of trade names or manufacturers' names in this report
does not constitute indorsement of any commercial product.*

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER BRL TECHNICAL REPORT ARBRL-TR-02066	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STANDARDIZATION OF TERMINAL BALLISTICS TESTING, DATA STORAGE AND RETRIEVAL	5. TYPE OF REPORT & PERIOD COVERED Final rept.	
7. AUTHOR(s) J. P./Lambert B. E./Ringers	6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory ATTN: DRDAR-BLT Aberdeen Proving Ground, MD 21005	8. CONTRACT OR GRANT NUMBER(s)	
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command US Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS RDT&E 1L662618AH80	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	12. REPORT DATE MAY 1978	
	13. NUMBER OF PAGES 83	
	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) SABIE AD-E434 062		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) ballistic data data base striking velocity V_s , V_r curve terminal ballistics		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (hib/lrs) The objectives of this report are to establish a systematic procedural basis for conducting terminal ballistics tests and to ascertain the data appropriate for storage in the TBD Penetrator Data Base. Chief concerns are the development of an experimental testing strategy, the definition of relevant terminal ballistics terminology, and the selection and organization of data.		

393 471

act

TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS	5
LIST OF TABLES	7
I. INTRODUCTION	9
II. PROCEDURE FOR V_s , V_r TESTING	9
III. DATA SHEETS	18
IV. DEFINITIONS OF RELEVANT BALLISTIC AND DATA BASE TERMINOLOGY	23
APPENDIX A - Query to Data Base	33
APPENDIX B - Striking Velocity Allocation	35
APPENDIX C - Example: A Test Case Considered	41
APPENDIX D - Predictive Model	51
APPENDIX E - Sample Range Checklist	55
APPENDIX F - Program Listing of "Augur"	57
APPENDIX G - Program Listing of "Impact"	67
DISTRIBUTION LIST	79

ACCESSION for	
NTIS	White Section ☒
DDC	Buff Section ☐
UNANNOUNCED	☐
JUSTIFICATION _____	
BY _____	
DISTRIBUTION/AVAILABILITY CODES	
Dist. A/A/L and/or SPECIAL	
A	-

LIST OF ILLUSTRATIONS

Figure	Page
1. Flow Chart of V_s , V_r Test Procedure	10
2. Perforated Target Plate: Front and Rear Surfaces and Sectioned Side View	26
3. Non-Perforated Target Plate: Sectioned Side View	27
4. Coordinate System Depicting Angles λ , ϕ , θ	29
5. Coordinate System Depicting Yaw Angles α , β , δ	31
B-1. Determining the Preliminary Sequence of Striking Velocities	38
C-1. Predicted V_ℓ and V_s , V_r Curve	43
C-2. Experimental Data Points and Derived V_s , V_r Curve	45

LIST OF TABLES

Table	Page
C-1. Completed Material Data Sheet for Target	46
C-2. Completed Material Data Sheet for Penetrator	47
C-3. Completed Range Data Sheet - Before Shot	48
C-4. Completed Range Data Sheet - After Shot	49
C-5. Completed Radiograph Data Sheet	50

I. INTRODUCTION

Our purpose in this report is to present a routine, effective and workable set of methods applicable to the performance and documentation of terminal ballistics testing, specifically V_s , V_r testing*. Such testing, used to determine ballistic limit velocity (V_{ℓ}) and assess dependence of residual velocity (V_r) on striking velocity (V_s) for given projectile/target setups, supplies valuable characterizations of the projectile/target situations concerned and comprises a major effort in terminal ballistics experimentation.

In order that V_s , V_r testing be efficient, approximately replicable, and attendant to quality assurance, there is a clear need for the establishment of procedural standardization in its conduct. There is an allied need to define terminology and to set conventions for data assimilation; it is intended that reasonably comprehensive standard collections of test data can be routinely inserted in a computerized storage and retrieval system so that data may be readily and selectively exploited as desired.

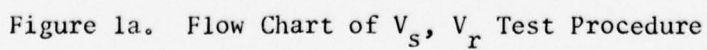
The objectives then are to suggest a structured methodology for testing, define relevant terminology, select a basic list of pertinent data and devise an organized format for its documentation.

Our treatment here is of but modest generality though amenable to expansion; by no means do we touch on all concerns that can be associated with V_s , V_r testing. For instance, the characteristics of behind-armor debris often (and increasingly) require determination and documentation though this is an area not considered here. The effort to date has primarily been concerned with long rod penetrators. Further experimentation, usage and insight will no doubt suggest necessary and desirable modifications to handle diverse impact situations.

II. PROCEDURE FOR V_s , V_r TESTING

This section describes the procedure to be followed in conducting a V_s , V_r test. A flowchart which parallels this description is shown in Figures 1a, 1b, and 1c.

*The term " V_s , V_r test" and other pertinent concepts are defined in Section IV.



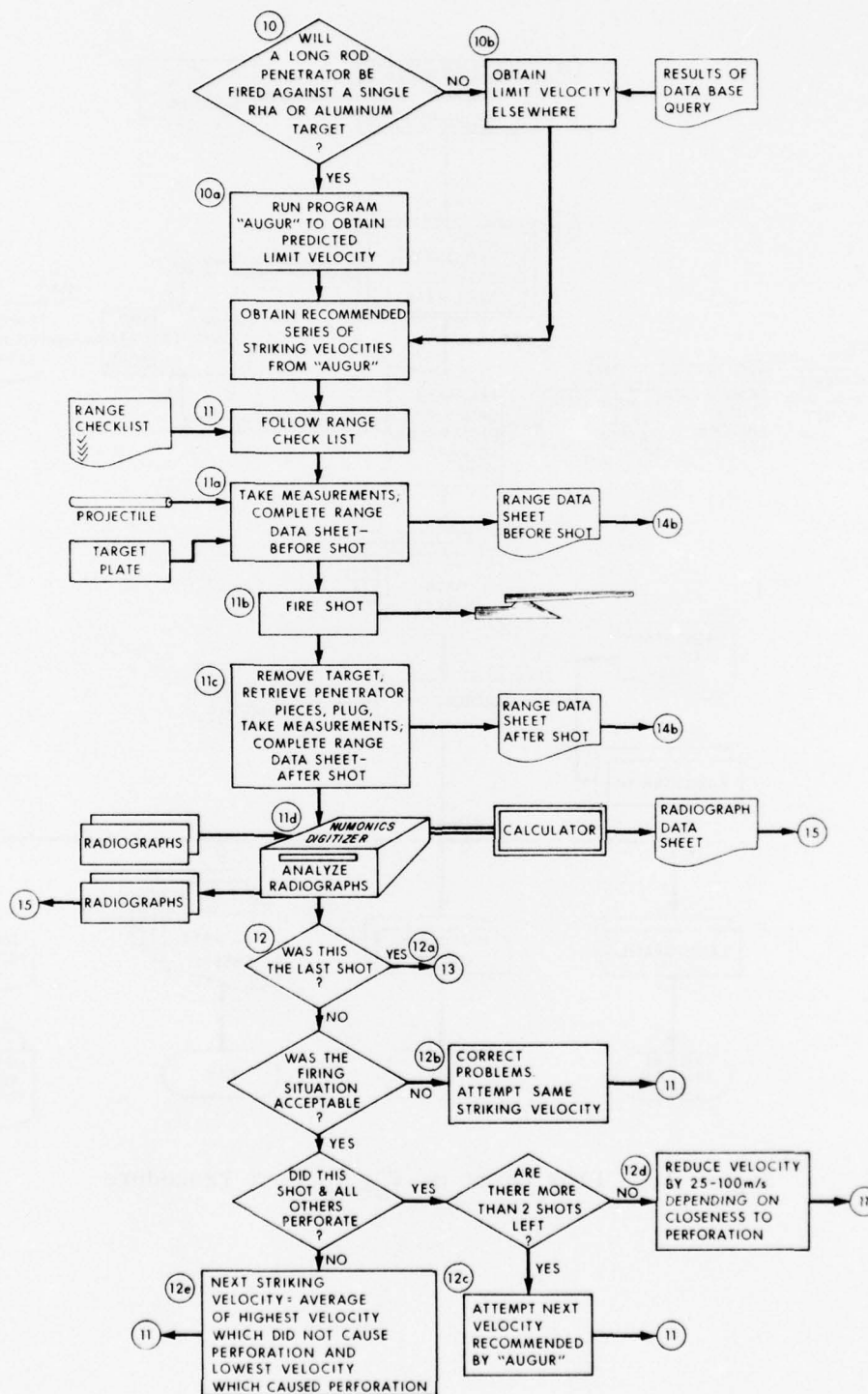


Figure 1b. Flow Chart of V_s , V_r Test Procedure

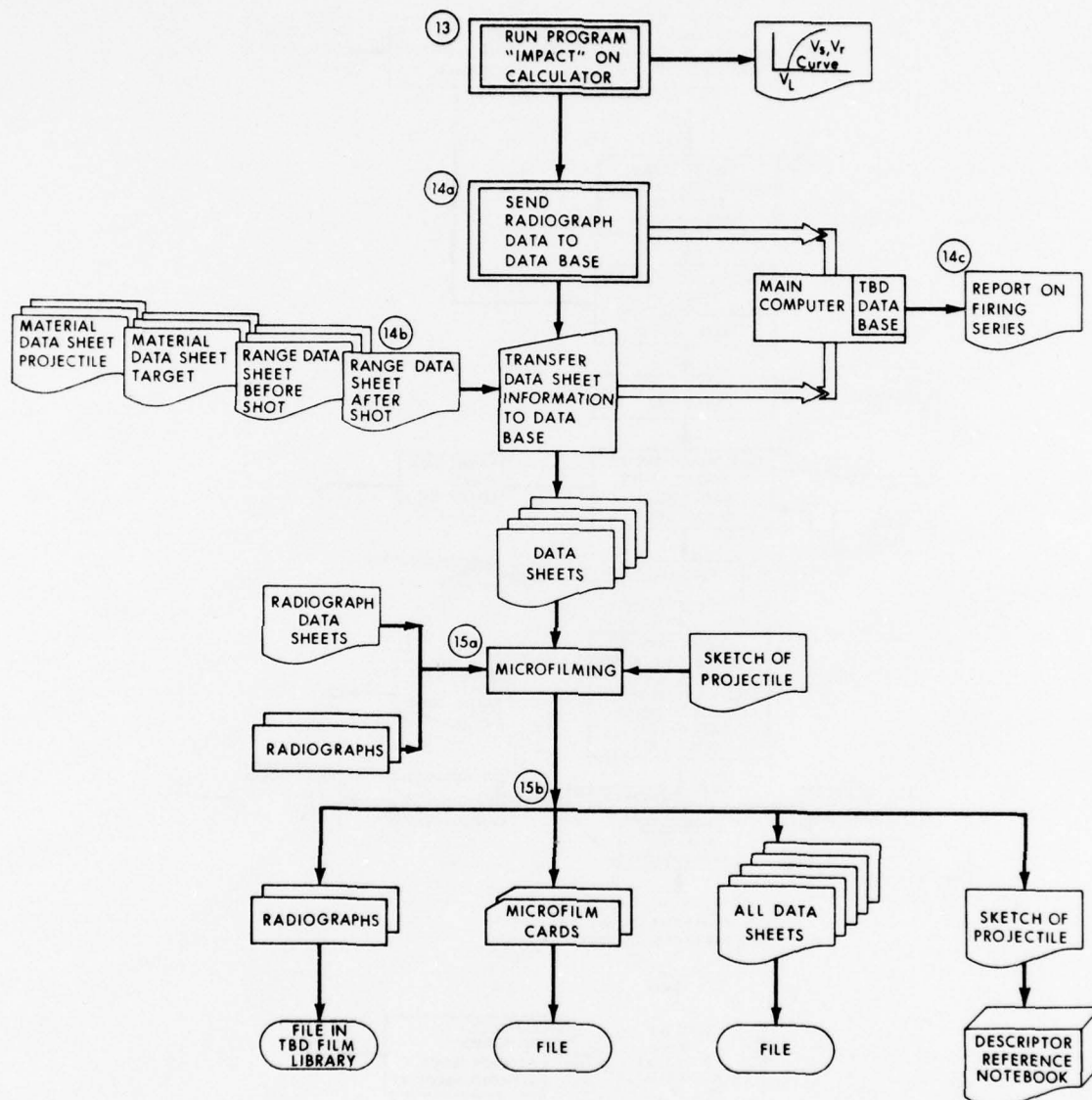


Figure 1c. Flow Chart of V_s, V_r Test Procedure

1. Delineate the purpose of the test.
2. Query the TBD Penetrator Data Base¹ to determine what information is available for this test situation (see Appendix A for an example of such a query).
- 3.a. If the data base query provides complete results for the proposed test situation the objective is met and there is no need to conduct the test. (Hopefully, this is a valid possibility in the near future when the details of every firing series conducted after 1977 will have been routinely stored in the data base.)
- 3.b. If the data base query provides incomplete results, design a projectile, make a detailed dimensioned sketch of it to be included in the Descriptor Reference Notebook* and assign the next consecutive Descriptor Reference # to it.
4. Decide on the number of rounds to be fired - always at least four. For long rod penetrators our experience suggests the frequent suitability of a six-shot V_s , V_r test (i.e., six "good" shots), which we regard as providing a high level of confidence in the limit velocity estimate and in the entire V_s , V_r curve for a broad range of situations**. In general, the number of shots to be fired will be situation dependent and, except that there should always be at least four shots, this number will be left to the discretion of the project engineer.
5. Order sufficient projectiles, targets and other experimental apparatus so there will be reasonable assurance of obtaining that number of "good" rounds. (Rounds used in V_s , V_r testing are expected to be essentially without yaw; we require that total yaw not exceed $2\frac{1}{2}^\circ$ in order for the round to be used in the derivation of a limit velocity and V_s , V_r curve).
6. Have x-rays taken of all penetrators (especially those of complex design) so that significant flaws in material or fabrication may be detected before firing and penetrators replaced as appropriate. (Such procedure further provides the possibility of correlating aspects of the radiographic image with subsequent ballistic behavior.)

¹B. Ringers, "Establishment of a KE Penetrator Data Base", to appear if this recommended standardization procedure is, indeed, adopted.

*Located in TBD Film Library (see footnote, page 17).

**Note the comparison between the predicted V_s , V_r curves and V_l 's and the derived V_s , V_r curves and V_l 's based on actual firings for four firing series noted in John P. Lambert, "The Terminal Ballistics of Certain 65 Gram Long Rod Penetrators Impacting Steel Armor Plate", Appendix E, to appear.

7.a. Fill out the top of the Material Data Sheets* (identification section) for the penetrator and target(s) and note which material tests are to be conducted.

7.b. Send labeled samples of the penetrator and target(s) and the associated Material Data Sheets to Material Testing**.

7.c. Material Testing should conduct the material tests requested and return the completed Material Data Sheets. (See Step 14b for further processing of these data sheets).

8. Send two labeled samples of the penetrator and one labeled sample of each unique target plate to a Materials Archives. These should be available for future scrutiny and it is imperative that they not be used in the firing program.

9. The remaining penetrators and target plates are to be used in the firing program. (See Step 11 for a continuation of their progress.)

10.a. If the impact situation is a long rod penetrator impacting a single rolled homogeneous armor (RHA) or aluminum (AL) target, use the program "Augur" (listed in Appendix F) to obtain a predicted limit velocity and a recommended series of striking velocities (and the anticipated corresponding residual velocities) for all but the last two shots. (For a detailed discussion of the striking velocity determination recommended for V_s , V_r testing and used in "Augur", see Appendix B).

10.b. If the impact situation is other than that described in 10a, a predicted limit velocity must be obtained elsewhere***, possibly extrapolated from the data base query. The program "Augur" is then used only to obtain a recommended series of striking velocities for all but the last two shots****.

11. For each shot in a firing series, systematically follow a range checklist to insure accurate requisition of necessary data. (A proposed checklist for the BRL Terminal Ballistics Division Ranges 110E and G is provided in Appendix E as an example.) We assume that full radiographic

*c.f., Section III for a copy of this and other data sheets.

**Material Testing is presently the mission of the Solid Mechanics Branch, Terminal Ballistics Division, BRL.

***Generalizations of the formulations given in Appendix B to cover other firing situations should be readily developed when the data base can provide sufficient empirical data.

****The anticipated residual velocities obtained will probably be meaningless until the formulation *** is developed.

coverage is available and will be used to determine pre-impact and post-perforation penetrator characteristics; for a description of the standard multi-flash x-ray system, see BRL Technical Note 1634².

The following tasks must be an integral part of any range procedure for conducting V_s , V_r tests:

a. Before the shot is fired take the necessary projectile and target measurements and complete the Range Data Sheet - Before Shot (see Step 14b for further processing of this data sheet).

b. Fire shot.

c. After the shot is fired, remove the target and retrieve the principal penetrator pieces and plug; take appropriate measurements and record them on the Range Data Sheet - After Shot. (See Step 14b for further processing of this data sheet.)

d. Analyze the radiographs using a Numonics Digitizer in tandem with a calculator (which can also communicate with the main computer). The necessary coordinates of the penetrator pieces (and plug) are digitized according to the procedure described in BRL Memorandum Report 2264³. Incorporated within the digitizer will be a program which is a modification of a FORTRAN program written by A. L. Arbuckle³. This program calculates striking and residual velocities, striking yaw, residual yaw rate, residual masses and cone and phase angles*. These calculated parameters are automatically sent to the calculator which then produces the Radiograph Data Sheet and retains the information which will later be transmitted to the main computer.

12.a. If this is the last shot in a series proceed with step 13.

12.b. If some aspect of the firing situation was unacceptable (e.g., the yaw was too high, the quality of radiographs prevented accurate analysis, the striking velocity was not close to that intended) and there is sufficient firing apparatus remaining to fire another shot, correct the problems encountered with this shot and, attempting the same striking velocity, continue at the beginning of Step 11.

²C. Grabarek and L. Herr, "X-ray Multi-Flash System for Measurement of Projectile Performance at the Target", BRLTN 1634, September 1966 (AD 3377657).

³A. L. Arbuckle, E. L. Herr, A. J. Ricchiazzi, "A Computerized Method of Obtaining Behind-the Target Data From Orthogonal Flash Radiographs", BRLMR 2264, January 1973.

*See definitions in Section IV.

12.c. If this shot (and all previous shots) perforated and there are more than two shots left, attempt the next striking velocity recommended by "Augur" and continue at the beginning of Step 11.

12.d. If this shot (and all previous shots) perforated and there are only one or two shots left, decrease the striking velocity by 25 - 100 m/s, depending on the "closeness" to non-perforation* of the previous shot. Continue at the beginning of Step 11.

12.e. If the shot did not perforate or the shot perforated and at least one previous shot did not perforate, let the next striking velocity be the average of the lowest striking velocity which caused perforation and the highest striking velocity which resulted in non-perforation**. Continue at the beginning of Step 11.

13. Use the V_s , V_r data, as determined by radiographic analysis (Step 11d) and the BASIC program "Impact" (listed in Appendix G) to extract the "standard" V_s , V_r curve and V_{ℓ} . (The procedure used in "Impact" to generate a standard V_s , V_r curve and standard V_{ℓ} estimate is described in BRL Report 1852⁴).

14.a. Prompt the calculator to send the radiograph data stored within it to the TBD Penetrator Data Base¹.

14.b. Transfer the data from the Material Data Sheets, the Range Data Sheet - Before Shot, and the Range Data Sheet - After Shot to the TBD Penetrator Data Base for each round in a series¹.

14.c. A complete report on this firing series will subsequently be generated by a computer program (to be written in FORTRAN and reside on the main computer).

15.a. Have the radiographs, all the data sheets, and the sketch of the projectile, microfilmed. This involves reproducing the radiographs, data sheets and sketch on 16mm film. The processed film is then stored on microfilm cards which are filed for future reference; the radiographs, data sheets and sketch are returned.

*Such "closeness" should be estimated from either the measured residual velocity or the target plate center hole size. The center hole diameter reduces and approaches the diameter of the penetrator as the striking velocity approaches the limit velocity.

**If the striking velocities for two successive shots are determined this way and both perforate, attempt the highest striking velocity for which there was non-perforation again.

⁴J. P. Lambert and G. H. Jonas, "Towards Standardization in Terminal Ballistics Testing: Velocity Representation", BRL Report 1852, January 1976 (AD A021289).

15.b. Store the radiographs in the TBD Film Library*, file the data sheets, and add the sketch to the Descriptor Reference Notebook. (The radiographs and data sheets are kept for five years after which time they are destroyed, their contents available and reproducible from the microfilm cards.)

**The TBD Film Library is presently located in Bldg 309, Room 102. Access to it must be arranged with the Film Librarian.*

III. DATA SHEETS

Routine characterization of the V_s , V_r test and documentation of basic information gathered in the test should be recorded on the following standard data sheets.

MATERIAL DATA

Material Ref # _____

Material _____

Source _____

Lot # _____

Plate # or Bar # _____

Material Certification # _____ and Source _____ (if different from manufacturer)

Property	Test Method	Date Source
		1. Sample of same lot #.
		2. Sample of similar material.
		3. Nominal - handbook value.
Tension		
Yield Stress (MPa) _____	_____	_____
Ultimate Stress (MPa) _____	_____	_____
Strain at the Ultimate Stress _____	_____	_____
Strain to Failure _____	_____	_____
Strain Rate (s^{-1}) _____	_____	_____
Compression		
Yield Stress (MPa) _____	_____	_____
Ultimate Stress (MPa) _____	_____	_____
Strain at the Ultimate Stress _____	_____	_____
Strain Rate (s^{-1}) _____	_____	_____
Elastic Modulus (GPa) _____	_____	_____
Poisson's Ratio _____	_____	_____
Shear Modulus (GPa) _____	_____	_____
Charpy (dyne-cm) _____	_____	_____
Hugoniot Elastic Limit (MPa) _____	_____	_____

COMMENTS: _____

RANGE DATA SHEET - BEFORE SHOT

Project Engineer _____ Comments: _____
 Project ID _____
 Range _____
 Gun Caliber _____ Smooth Bore _____ Rifling _____
 Date (month/day/yr) _____
 Round # _____ Name _____ Series _____
 Type: Experimental _____ Fielded _____
 Sabot: Discarding _____ Non-Discarding _____ None _____
 Descriptor Reference # _____
 (detailed drawing and description including stabilizer if applicable)

Projectile

Total Mass (g) _____ Launch Mass (g) _____
 Total Length (cm) _____ Powder Type _____
 Maximum Diameter (excluding stabilizer) (cm) _____ Powder Mass (g) _____

Penetrator

Nose Shape _____
 Total Length (cm) _____
 Maximum Diameter (cm) _____

Projectile Part	Mass (g)	Material	Ref. #	Hardness Value	Hardness Test	Density (g/cc)
-----------------	----------	----------	--------	----------------	---------------	----------------

A. Penetrator						
Penetrator Parts						

B. Aerodynamic
 Shell _____

C. Stabilizer _____

Rate of Spin (rps) _____ (if spin stabilized)

Target Plate 1

Material _____ Ref# _____
 Incidence Angle (deg) _____
 Mass (g) _____
 Thickness (cm) _____
 Hardness - Value _____
 - Test _____
 Density (g/cc) _____
 Type: _____ Rect _____ Cir _____
 Lgth/Dia (cm) _____
 Width (cm) _____

Target Plate 2

Material _____ Ref# _____
 Incidence Angle (deg) _____
 Mass (g) _____
 Thickness (cm) _____
 Hardness - Value _____
 - Test _____
 Density (g/cc) _____
 Type: _____ Rect _____ Cir _____
 Lgth/Dia (cm) _____
 Width (cm) _____
 Spacing between plates 1 and 2 (cm) _____

Target Plate 3

Material _____ Ref# _____
 Incidence Angle (deg) _____
 Mass (g) _____
 Thickness (cm) _____
 Hardness - Value _____
 - Test _____
 Density (g/cc) _____
 Type: _____ Rect _____ Cir _____
 Lgth/Dia (cm) _____
 Width (cm) _____
 Spacing between plates 2 and 3 (cm) _____

RANGE DATA SHEET - AFTER SHOT

Project ID _____ Comments: _____
 Round # _____ Series _____

Recovered Penetrator	Piece 1	Piece 2	Piece 3
Residual Mass (g)	_____	_____	_____
Residual Length (cm)	_____	_____	_____

Plug
 Mass (g) _____
 Length (cm) _____
 Diameter (cm) _____

Target Plate 1
 Mass (g) _____

Entrance Hole
 Minimum distance from hole to plate edge (cm) _____
 Length (cm) _____ Width (cm) _____

Perforation? Yes _____ No _____

<u>Center Hole</u>		Penetration depth (cm) _____
Length (cm) _____	Width (cm) _____	Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) _____ Width (cm) _____ Back surface fracture? Yes ___ No ___

Target Plate 2

Mass (g) _____

Entrance Hole
 Minimum distance from hole to plate edge (cm) _____
 Length (cm) _____ Width (cm) _____

Perforation? Yes _____ No _____

<u>Center Hole</u>		Penetration depth (cm) _____
Length (cm) _____	Width (cm) _____	Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) _____ Width (cm) _____ Back surface fracture? Yes ___ No ___

Target Plate 3

Mass (g) _____

Entrance Hole
 Minimum distance from hole to plate edge (cm) _____
 Length (cm) _____ Width (cm) _____

Perforation? Yes _____ No _____

<u>Center Hole</u>		Penetration depth (cm) _____
Length (cm) _____	Width (cm) _____	Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) _____ Width (cm) _____ Back surface fracture? Yes ___ No ___

RADIOGRAPH DATA

Project ID _____
 Range _____
 Gun Caliber _____
 Date (month/day/yr) _____
 Round # _____ Series _____
 File # _____

Comments: _____

Projectile
 Striking Velocity (m/s) _____
 Striking Yaw - Vertical (deg) _____
 (up: +, down: -) (α)
 Striking Yaw - Horizontal (deg) _____
 (right: +, left: -) (β)
 Total Yaw - (δ) (deg) _____

Plug (if applicable)
 Velocity (m/s) _____
 Mass (g) _____
 Length (cm) _____
 Diameter (cm) _____
 Trajectory -
 Cone Angle (λ) (deg) _____
 Phase Angle (ϕ) (deg) _____

Penetrator, Residual

<u>Plate 1</u>	<u>Piece 1</u>	<u>Piece 2</u>	<u>Piece 3</u>
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	_____	_____	_____
Phase Angle (ϕ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____
<u>Plate 2</u>			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	_____	_____	_____
Phase Angle (ϕ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____
<u>Plate 3</u>			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	_____	_____	_____
Phase Angle (ϕ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____

IV. DEFINITIONS OF RELEVANT BALLISTIC AND DATA BASE TERMINOLOGY

1. V_s, V_r Test - the firing of a number of nominally identical penetrators into as many nominally identical targets with all controlled phenomena except striking velocity being nominally invariant (i.e., a fixed "projectile-target situation"); penetrator striking and residual velocities from each shot are measured and a collection of data points (V_s, V_r) is thereby generated.

The primary purpose of conducting a V_s, V_r test is to analyze the dependence of residual velocity on striking velocity (including limit velocity determination) for a specified projectile-target situation. The radiographic coverage needed for velocity measurement provides relatively easy access to further penetration mechanics analysis: frequent additional objectives in V_s, V_r testing involve, for instance, study of the dependence on striking velocity of various residual effects (e.g., residual penetrator mass; the shape, mass, and velocity of a plug or of other fragment debris).

2. Limit Velocity (V_ℓ) - value determined from a set of V_s, V_r data (as generated in a V_s, V_r test) using the computational algorithm described in BRLR 1852 (AD 20376); V_ℓ is one of a triple of values (a, p, V_ℓ) which minimizes the root mean square error when the form

$$V_r = \begin{cases} 0, & 0 \leq V_s \leq V_\ell \\ a(V_s^p - V_\ell^p)^{1/p}, & V_s > V_\ell \end{cases} \quad \text{is applied to the given}$$

V_s, V_r data set.

Note: the idealized physical notion abstracted to suggest the above form is that of an absolutely invariant projectile-target situation for which each striking velocity can yield one and only one residual velocity (and then $V_\ell = \max\{V_s : V_r = 0\} = \inf\{V_s : V_r > 0\}$).

3. Material Ref # - unique number assigned to each penetrator and target material as a cross reference between Range Data and Material Data Sheets.
4. Material - generic name of material, including specification (i.e. S7 Tool Steel, AISI 1030 Steel).
5. Source - Manufacturer of plate or bar of material.

6. Lot # - unique number assigned by manufacturer to identify the material and associated processing for a group of plates or bars, i.e., two plates from the same lot should be nominally identical.
7. Plate # - unique number assigned to a 6' x 6' or 6' x 12' plate to identify its relation to the other plates in a lot. This may be further subdivided into target plates by the experimenter.
8. Material Certification # - unique number identifying the material certificate which describes the chemical composition and processing history of the material.
9. Name - expression assigned to a group of projectiles of nominally identical design (e.g., L15, GAU 8, etc).
10. Series - unique number assigned to a group of rounds within a project; typically used to classify a group of related rounds, e.g., those within a single V_s , V_r test sequence.
11. Descriptor Reference # - unique number assigned sequentially to denote location of drawing and description pertaining to a round in the Descriptor Reference Notebook.
12. Projectile - aggregate of penetrator, aerodynamic shell, and stabilizer, (also sabot, if nondiscarding) i.e., that part of the launch mass which remains intact during flight and is expected to impact the target as a unit.
13. Launch Mass - mass of the projectile, sabot, pusher plate(s), and obturator.
14. Penetrator - that part of the projectile which is responsible for damaging the target. It may contain the following parts:
 - a. Armor-piercing Cap - piece fitted to front of penetrator to preserve body from brunt of initial impact, usually made of tough, hard, shock-absorbing material.
 - b. Body or core - principal part of penetrator responsible for damaging target.
 - c. Sheath - material which partially surrounds core.
 - d. Composite Body - body divided into forebody and aftbody.
15. Aerodynamic Shell - outer part of projectile to aid in flight only, usually made of light material like aluminum.

16. Stabilizer - means of maintaining stability during flight so that projectile strikes nose first (e.g., fins, flare, spin).
17. Incidence Angle (or Obliquity) (θ) - angle between the penetrator line of fire (path of the center of gravity) and the normal to the target plane.
18. Spacing between plates - orthogonal distance between plates.
19. Plug - a major fragment which may be punched out from the target, usually at striking velocities near the limit velocity. A plug is of roughly cylindrical shape having diameter at least as large as that of the penetrator and height (or length) no greater than the target plate thickness; front and rear ends tend to be convex and concave respectively and the lateral surface shows strong indication of shear.
20. Entrance Hole - hole made in the front surface of the target (in Figure 2., length = L_1 , width = W_1).
21. Min. distance from hole to plate edge - The minimal distance, on the front target surface plane, from the hole perimeter to the edge of the target plate (in Figure 2., min. dist. = a).
22. Perforation - passage of a penetrator completely through a target. In terms of velocity, we say there is perforation if and only if $V_r > 0$.
23. Center Hole - smallest hole in the target on neither front nor rear surface (perforation only) (in Figure 2., length = L_2 , width = W_2).
24. Exit Hole - hole made in the rear surface of the target (perforation only). (in Figure 2., length = L_3 , width = W_3).
25. Penetration Depth - target hole depth measured from the front target surface plane (nonperforation only). (see Figure 3).
26. Bulge extent from rear plate surface - maximum target material displacement from rear target surface plane (nonperforation only). (see Figure 3).
27. File # - location number of radiographs in TBD Film Library.
28. Striking Velocity (V_s) - velocity (really, speed) of penetrator at impact; determined from the position, time history of before-target radiographic images.

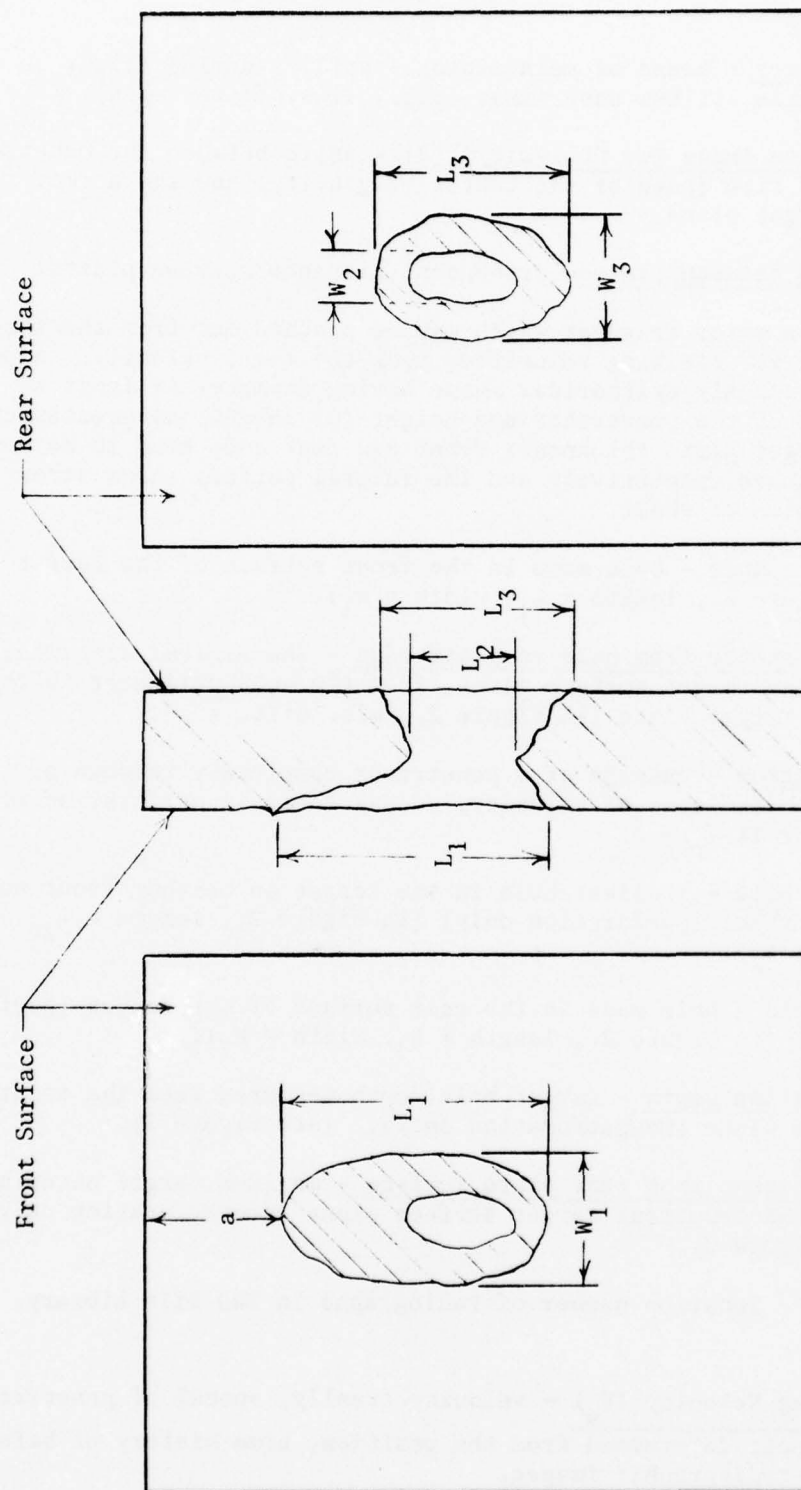
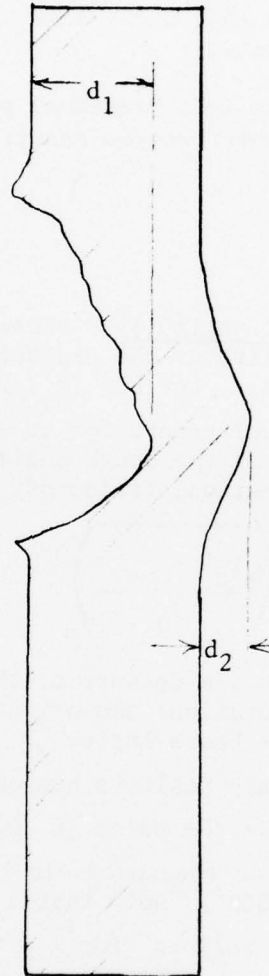


Figure 2. Perforated Target Plate: Front and Rear Surfaces and Sectioned Side View



d_1 : Penetration depth

d_2 : Bulge extent from rear plate surface

Figure 3. Non-Perforated Target Plate: Sectioned Side View

The following geometric setting will be used in describing items 29 and 30 (Figures 4 and 5). Consider a coordinate system in which the origin is on the line of fire at a point midway through the target plate, the z-axis coincides with the line of fire, and the x and y axes are respectively horizontal and vertical with respect to the test set-up. (In the context of usual experimental procedure, this means that the x-axis is parallel to and midway between the front and rear target surfaces and that the y-axis makes with these surfaces an angle equal to the obliquity.)

Note: Wherever used, the term "residual penetrator" will refer to the major (largest) post-perforation penetrator remnant,

29. Cone Angle (λ) and Phase Angle (ϕ) - these are behind-target characteristics descriptive of the trajectory of the residual penetrator (see Figure 4). Let $P = (x_o, y_o, z_o)$ be the center of gravity of the residual penetrator at some point behind the target. The Cone Angle is the acute angle between the line of fire (z-axis) and the residual trajectory (line from the origin through P):

$$\lambda = \tan^{-1} \left(\frac{\sqrt{x_o^2 + y_o^2}}{z_o} \right)$$

The Cone Angle is thus a measure of the deflection in trajectory caused by perforation; the orientation of this deflection will be provided by the Phase Angle.

Let y_1 be an arbitrary positive number; let r be the point $(0, y_1, z_o)$ and let q be the point $(0, 0, z_o)$. Then the Phase Angle is $\phi = \angle rqp$ (measured clockwise as perceived from the origin); $0^\circ \leq \phi < 360^\circ$. Note that ϕ is not defined if $\lambda = 0^\circ$.

We can specify ϕ as follows (for $\lambda \neq 0^\circ$):

- (i) If $y_o = 0$, let $\phi = \begin{cases} 90^\circ & \text{if } x_o > 0 \\ 270^\circ & \text{if } x_o < 0 \end{cases}$
- (ii) If $y_o \neq 0$, let $\psi = \tan^{-1} \left(\frac{x_o}{y_o} \right)$, $-90^\circ < \psi < 90^\circ$,

$$\text{and } \phi = \begin{cases} \psi + 180^\circ & \text{if } y_o < 0 \\ \psi & \text{if } y_o > 0 \text{ and } x_o \geq 0 \\ \psi + 360^\circ & \text{if } y_o > 0 \text{ and } x_o < 0 \end{cases} .$$

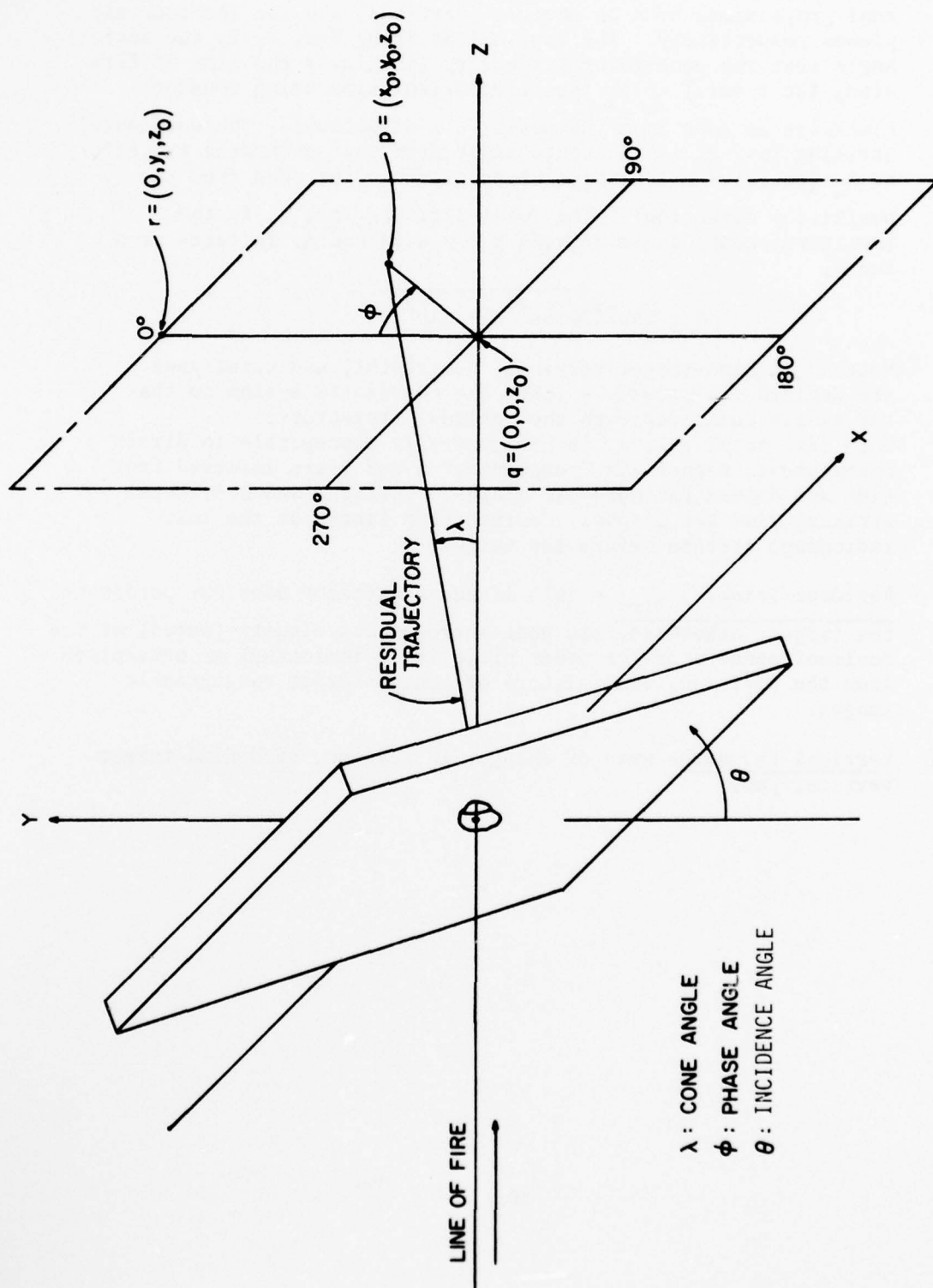


FIGURE 4. COORDINATE SYSTEM DEPICTING ANGLES λ , ϕ , AND θ .

30. Striking Yaw: Vertical (α), Horizontal (β), Total (δ) - (See Figure 5) for the penetrator at a point prior to impact, let A be the penetrator axis of symmetry; let A_1 and A_2 be the orthogonal projections of A on the y-z (vertical) and x-z (horizontal) planes respectively. The Vertical Striking Yaw, α , is the acute angle from the penetrator trajectory (initially the line of fire along the z axis) to A_1 (positive orientation being counter-clockwise as seen from the positive x-direction). The Horizontal Striking Yaw, β , is the acute angle from the penetrator trajectory to A_2 (positive orientation being clockwise as seen from the positive y direction). The Total Striking Yaw, δ , is the (positive) acute angle between the z-axis and A; in terms of α and β ,

$$\delta = \tan^{-1} \sqrt{\tan^2 \alpha + \tan^2 \beta}$$

Note i: behind-target vertical, horizontal, and total yaws are defined analogously - reset the coordinate system so that the z-axis coincides with the residual trajectory.

Note ii: total yaw, δ , is not generally susceptible to direct measurement; rather its "components" α and β are inferred from side and bottom radiographic images. Vertical and horizontal striking yaws are properly derived from images at the last radiograph station before the target.

31. Residual Velocity (V_r) - zero if the penetrator does not perforate the target; otherwise, the post-perforation velocity (speed) of the residual penetrator (or other piece if so indicated) as determined from the position, time history of behind-target radiographic images.
32. Vertical Yaw Rate- Rate of change, in rev/sec, of behind-target vertical yaw.

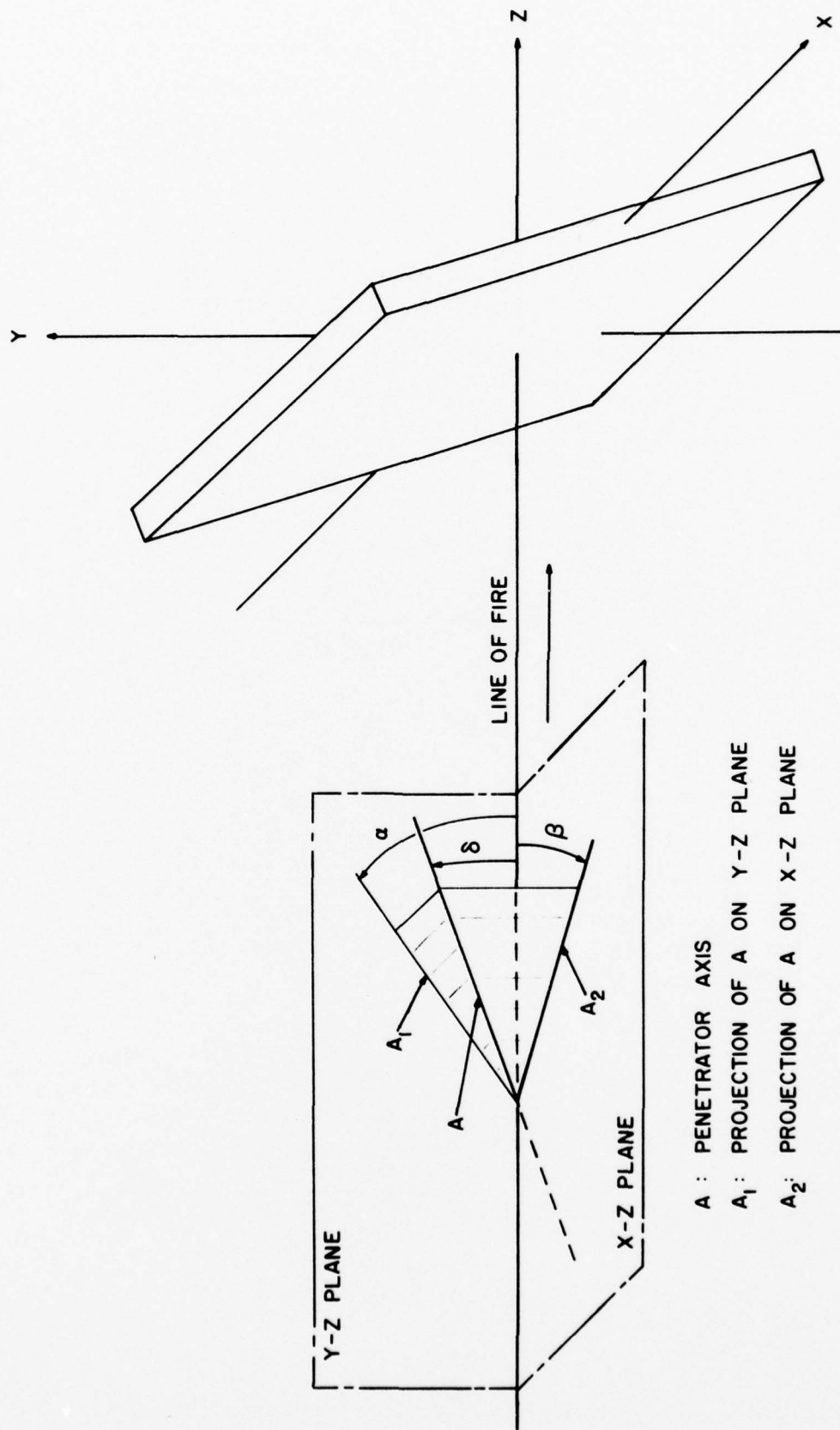


FIGURE 5. COORDINATE SYSTEM DEPICTING YAW ANGLES α , β , AND δ .

APPENDIX A

Query to Data Base

The following is a somewhat elementary example illustrating possible use of the data base.

APPENDIX A

Suppose you are interested in the performance of tungsten penetrators (65g, L/D of 10, hemispherical nose shape) against a double RHA target, 0.63cm (1/4") and 1.9cm (3/4") thick, spaced 8.26cm (3 1/4") apart at 60° obliquity. The following command to the data base¹ would produce the information available with the qualifications specified and in sorted order for easier analysis. Note: the asterisk is part of the instruction.

SORT AND PRINT: STRIKING VELOCITY, RESIDUAL VELOCITY 1, RESIDUAL VELOCITY 2, RESIDUAL MASS 1, RESIDUAL MASS 2
FOR WITH PENETRATOR MATERIAL, TUNGSTEN AND
PENETRATOR MASS, 65 AND
L/D, 10 AND
NOSE SHAPE, HEMISPHERICAL AND
TARGET MATERIAL 1, RHA AND
TARGET THICKNESS 1, .63 AND
TARGET MATERIAL 2, RHA AND
TARGET THICKNESS 2, 1.9 AND
SPACING 1, 8.26 AND
OBLIQUITY, 60 AND
TOTAL YAW, FROM 0 to 2.5*

A possible response to the query is:

NO. OF ITEMS IN QUERY RESPONSE = 50
NO. OF ITEMS IN THE DATA BANK = 500
PERCENTAGE OF RESPONSE/TOTAL DATA BASE = 10.00

STRIKING VELOCITY	RESIDUAL VELOCITY 1	RESIDUAL VELOCITY 2	RESIDUAL MASS 1	RESIDUAL MASS 2
1053 M/S	739 M/S	0 M/S	30.2 G	0.0 G
1500 M/S	1320 M/S	309 M/S	50.5 G	22.3 G
⋮	⋮	⋮	⋮	⋮

This query could also be stated more compactly in terms of the relative placement of the parameters in the data base as follows:

SORT AND PRINT: 134, 144, 162, 145, 163
FOR WITH 23, 2 AND 22, 65 AND 198, 10 AND 19, 2 AND 59, 1 AND 63,
.63 AND 70, 1 AND 74, 1.9 AND 81, 8.26 AND 61, 60 AND 137, FROM 0. TO
2.5*

The response should be the same.

APPENDIX B

Striking Velocity Allocation

APPENDIX B

The purpose here is to specify a routine for generating the (intended) striking velocities to be used in a V_s, V_r test.

In practice there will be a difference between the intended striking velocity (i.e., the velocity requested of the gun crew) and the actual realized striking velocity (i.e., the velocity measured, after the shot, from radiographic images) but this can generally be expected, on the basis of past experience, to be relatively small.

Suppose n (>4) to be the total number of rounds available for the test. For $k = 1, 2, \dots, n$, we denote by x'_k the intended striking velocity for the k th round, and by x_k and y_k respectively, the actual (measured) striking and residual velocities.

Let c be the initial estimate of limit velocity as calculated from the equations of Appendix D or the program "Augur" (which incorporates those equations) and is listed in Appendix F.* Take x'_1 to be the largest attainable (or desired) striking velocity.**

Let $n_o = n-2$. Let $q = (x'_1)^2 - c^2$. For $k = 1, 2, \dots, n_o$,

let $b_k = \frac{n_o - k}{n_o - 1}$ and let $x''_k = \sqrt{c^2 + qb_k^2}$.

This sequence of velocities ($x''_1, x''_2, \dots, x''_{n_o}$) which has been constructed before any shots are fired will serve as a preliminary guide for the first n_o shots. The intended striking velocities (x'_k) will follow this sequence (i.e., $x'_k = x''_k$) unless results significantly deviate from those anticipated. Motivation for use of this sequence is as follows: Consider the simplified partial model of the expected V_s, V_r curve:

$y = \sqrt{x^2 - c^2}$ (where x, y, c have respectively replaced V_s, V_r, V_l); the relevant corresponding range of residual velocities is then the

*In the case of multiple plate targets and for target materials other than RHA or Aluminum, the initial limit velocity estimate will need to be obtained elsewhere.

**In most V_s, V_r testing, a reasonably full V_s, V_r curve is required and it is desirable to obtain residual velocities for a wide range of striking velocities - in such cases x'_1 should be made as large as is feasible. Should interest be confined solely to limit velocity, x'_1 might be given a smaller value, the only imperative being that the corresponding shot result in perforation.

interval $[0, \sqrt{x_1'^2 - c^2}]$. This interval is partitioned into $n_0 - 1$ equal parts and the x_k'' are the n_0 corresponding images of the partition points on the x axis.

Figure B-1 is intended to be illustrative of the procedure for a situation in which it is planned to fire six shots ($n_0 = 4$).

Now the general idea is to follow the x_k'' sequence as a source of intended striking velocities until either a non-perforation ($y_k = 0$) is reached or the sequence is exhausted. In most cases we expect this part of the procedure to provide for the major portion of the testing strategy. The remaining phase (involving possible departure from the x_k'' distribution and allocation of the final two shots) is both tedious to describe and, infrequently we expect, open to the possibility of subjectivity.

A formal account of the procedure follows. x_1' , the intended striking velocity for the first shot, has already been selected. Fire the first shot*. Take x_2' , the intended striking velocity for the second shot, to be x_2'' . Fire the second shot. If the second shot perforates (and $n > 4$), take x_3' (the intended striking velocity for the third shot) to be x_3'' and fire the third shot. Continue in this manner until either a non-perforation is observed or the n_0 th shot has been fired (with all shots having perforated). We have then two possibilities:

a. The preliminary sequence of shots has been exhausted with all shots resulting in perforation. Then $y_1, y_2, \dots, y_{n_0}$ are all positive and $x_k' = x_k''$ for $k = 1, 2, \dots, n_0$.

In this case, let $x_{n_0+1}' = x_{n_0} - \delta$ where δ is 25 m/s, 50 m/s,

or 100 m/s at the discretion of the project engineer (as adjudged by the "closeness" to non-perforation of the previous shot).

Then, if $y_{n_0+1} > 0$, let $x_{n_0+2}' = x_{n_0+1} - \delta$ where δ is decided as before; if $y_{n_0+1} = 0$, let $x_n' = 1/2 (x_{n_0} + x_{n_0+1})$.

**It is essential to our development that this shot perforate, and its doing so should be a nearly inevitable consequence of the selection of x_1' .*

$c = x_4''$: Predicted limit velocity.
 $x_1' = x_1''$: Selected maximum striking velocity of interest
 (or achievable).
 $\{x_1'', x_2'', x_3'', x_4''\}$: Preliminary striking velocity
 sequence.

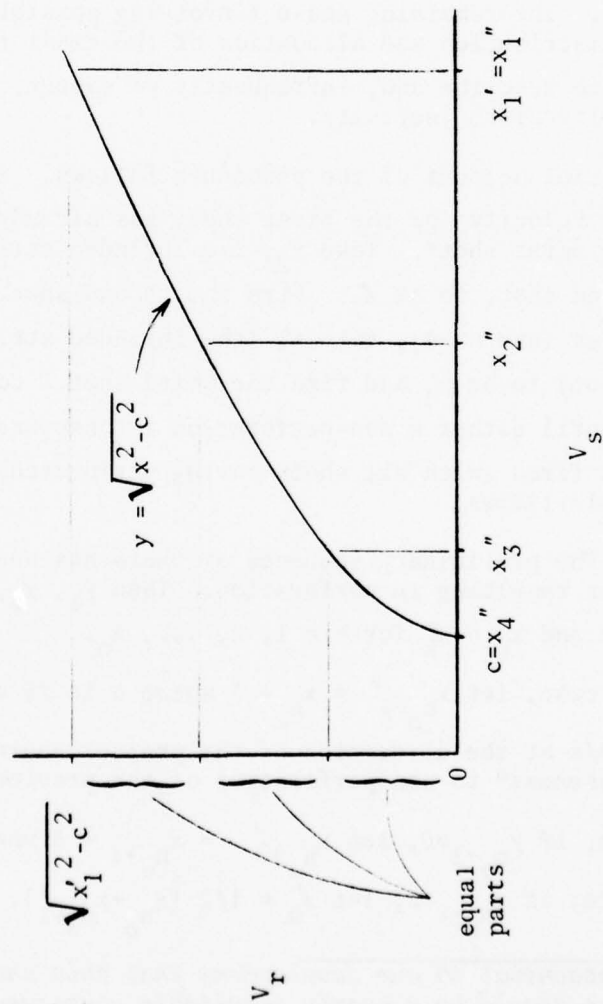


Figure B-1. Determining the Preliminary Sequence of Striking Velocities

b. the preliminary sequence must, at some point (say after the k_0 th shot) be abandoned due to a non-perforation ($y_1, y_2, \dots$,

y_{k_0-1} are positive but $y_{k_0} = 0$). In this case let

$$x_{k_0+1}' = \frac{1}{2} (x_{k_0} + x_{k_0-1}).$$

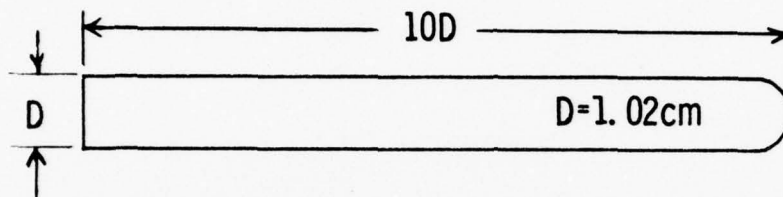
Then, for $j = k_0 + 2$ to n , let x_j' be the average of the lowest striking velocity which resulted in perforation and the highest striking velocity which resulted in non-perforation. Continue adhering to this procedure unless two successive rounds perforate; in such event, and should there be rounds remaining, try to duplicate the velocity of the k_0 th shot (i.e., use x_{k_0} as the next attempted velocity) and then, depending on whether this results in perforation or not, follow the general provisions of (a) or (b) for successive shots.

APPENDIX C

Example: A Test Case Considered

The following is an example of the documentation generated in adhering to the tenets of this report during the course of a V_s , V_r test.

1. Purpose of test: To derive a V_ℓ estimate and V_s , V_r curve for L/D of 10, nominal mass of 65 grams, VIMVAR*-processed steel** rods fired into 2.54cm RHA at 60° obliquity; and to compare performance with previous results for a similar situation involving rods not VIMVAR-processed. A seven shot V_s , V_r test is planned.
2. Projectile illustration, with nominal dimensions:



VIMVAR-processed steel, finished hardness R_c 55

Nominal mass: 65 grams (average mass fired was 64.3 grams).

3. The equations of Appendix D provide the estimated parameter values: $a = 0.88$, $p = 3.4$, and $V_\ell = 1292$; the corresponding predicted V_s , V_r curve is in Figure C-1. (In practice we use the BASIC program "Augur", which incorporates the equations of Appendix D and supplies graphic capability.)
4. 1800 m/s is regarded as a reasonable maximum velocity for the experimental set-up at hand, and from the equations of Appendix B we derive the preliminary sequence of five (intended) striking velocities: 1800, 1598, 1436, 1330, and 1292. Attempting to achieve (approximately) these velocities (in the indicated order), five rounds were fired and each resulted in perforation; actual striking velocities were measured to be respectively 1800, 1647, 1489, 1360, and 1282. For the sixth shot it was then decided to attempt a velocity of 1232 m/s, a drop of 50 m/s from the (actual) fifth striking velocity; the actual striking velocity obtained was 1227 m/s and there was perforation. For the seventh (and final) shot we then opted for a velocity reduction of 25 m/s, which was exactly realized - the seventh striking velocity was 1202 m/s and there was no perforation.

*Vacuum induction melt, vacuum arc remelt.

**Which, but for the lack of molybdenum as an alloying element, would have been AISI S7 tool steel.

Prediction of Limit Velocity and V_s , V_r Curve for Steel Rods Impacting RHA

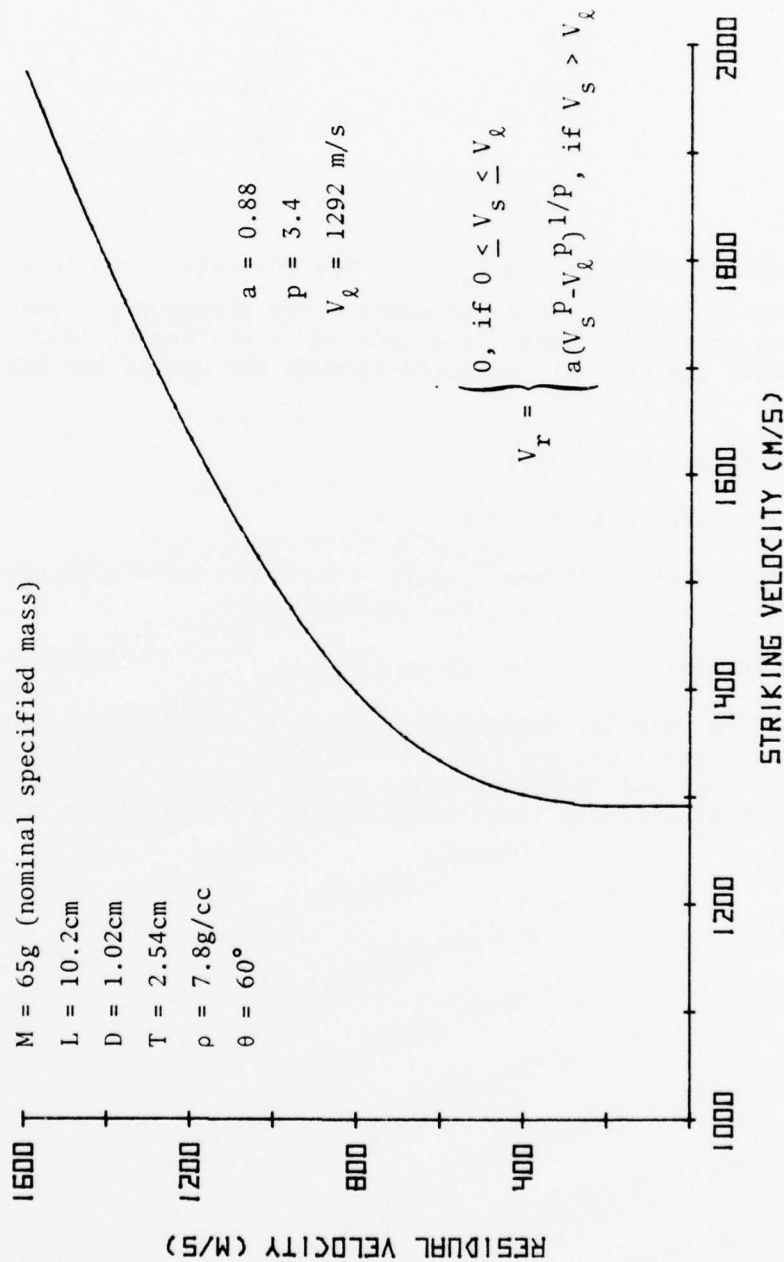


Figure C-1. Predicted V_ℓ and V_s , V_r Curve

5. The V_s , V_r data for these shots, as determined from radiographs, is:

<u>V_s</u>	<u>V_r</u>
1800	1285
1647	1145
1489	903
1360	769
1282	510
1227	203
1202	0

Figure C-2 provides the V_s , V_r curve generated from this data by the standard algorithmic procedure - the procedure, a least squares adaptation of form to data, is described in BRL Report 1852³ and is perhaps most conveniently executed through the use of the BASIC program, "Impact".

Derived parameter values are:

$$V_\ell = 1224 \text{ m/s}, a = 0.82, p = 3.0$$

S (=24 m/s) is the root mean square error associated with the fit of form to data.

6. Data Sheets:

Completed material data sheets, for target and penetrator, are provided in Tables C-1 and C-2. Tables C-3, C-4, and C-5 contain completed range and radiograph data sheets for the fourth round in the V_s , V_r test (the fourth round being chosen arbitrarily as a source for examples).

VIMVAR-Processed Steel Rods Impacting RHA

V_s, V_r Curve Derived from Experimental Data by the Standard Procedure

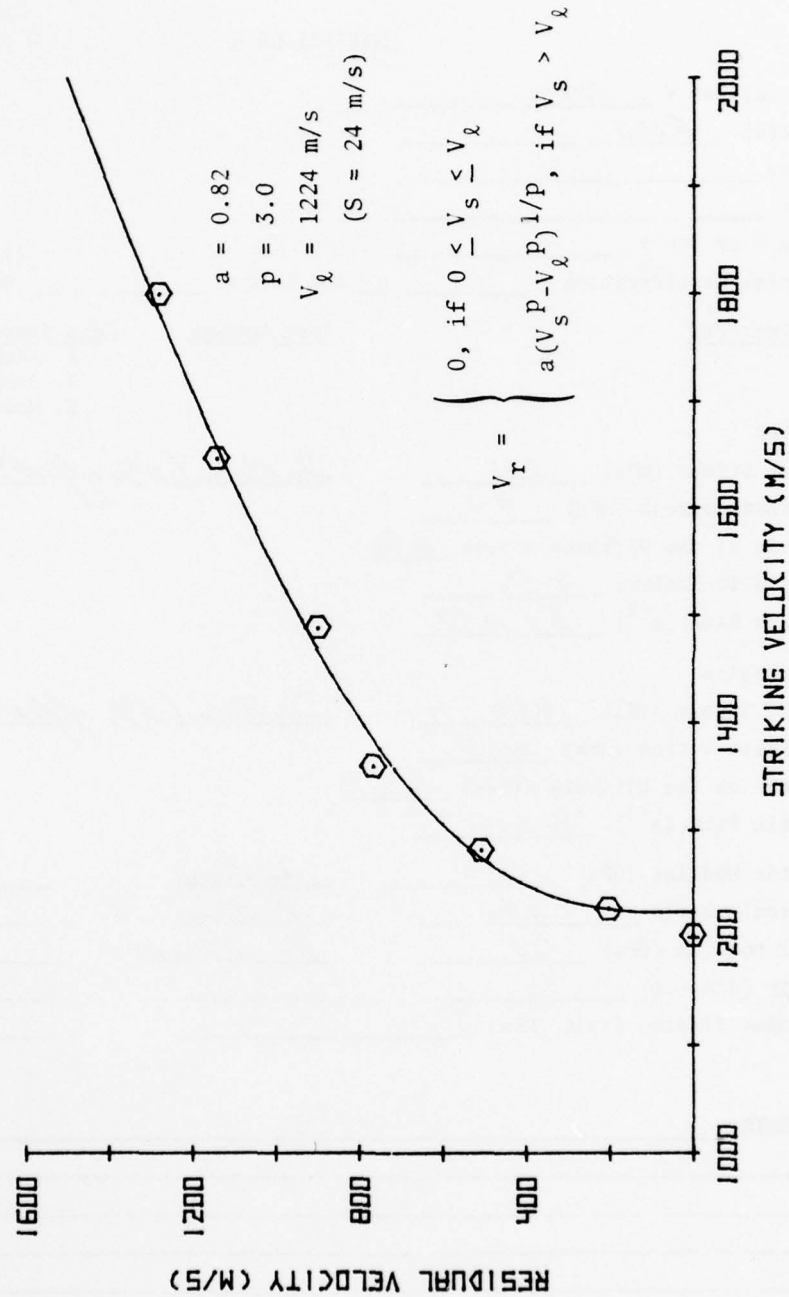


Figure C-2. Experimental Data Points and Derived V_s, V_r Curve

Table C-1. Completed Material Data Sheet for Target

MATERIAL DATA

Material Ref # 1000
 Material RHA
 Source _____
 Lot # _____
 Plate # or Bar # _____
 Material Certification # _____

and Source _____ (if different from manufacturer)

Property

Test Method

Date Source

1. Sample of same lot #.
2. Sample of similar material.
3. Nominal - handbook value.

Tension

Yield Stress (MPa) 825
 Ultimate Stress (MPa) 940
 Strain at the Ultimate Stress 6%
 Strain to Failure 18%
 Strain Rate (s^{-1}) 3×10^{-4}

Instron (.2% offset) 2

Compression

Yield Stress (MPa) 870
 Ultimate Stress (MPa) 1105
 Strain at the Ultimate Stress 5.5%
 Strain Rate (s^{-1}) 3×10^{-4}

Instron (.2% offset) 2

Elastic Modulus (GPa) 203

Instron 2

Poisson's Ratio .275

Instron 2

Shear Modulus (GPa) 79.

Elastomat 2

Charpy (dyne-cm) _____

Hugoniot Elastic Limit (MPa) _____

COMMENTS:

Table C-2. Completed Material Data Sheet for Penetrator

MATERIAL DATA

Material Ref # 10
 Material Custom Tool Steel - Vacuum Processed
 Source Carteck Corp., Reading, Pa.
 Lot # _____
 Plate # or Bar # _____
 Material Certification # _____ and Source _____ (if different from manufacturer)

<u>Property</u>	<u>Test Method</u>	<u>Date Source</u>
Tension Yield Stress (MPa) _____ Ultimate Stress (MPa) _____ Strain at the Ultimate Stress _____ Strain to Failure _____ Strain Rate (s^{-1}) _____		
Compression Yield Stress (MPa) <u>1796</u> <u>Instron (.2% offset)</u> <u>1</u> Ultimate Stress (MPa) <u>2400</u> Strain at the Ultimate Stress <u>3%</u> Strain Rate (s^{-1}) <u>4.37×10^{-5}</u> Elastic Modulus (GPa) <u>218.25</u> <u>Instron</u> <u>1</u> Poisson's Ratio <u>.286</u> <u>Elastomat</u> <u>1</u> Shear Modulus (GPa) <u>80.8</u> <u>Elastomat</u> <u>1</u> Charpy (dyne-cm) _____ Hugoniot Elastic Limit (MPa) _____		

COMMENTS: This material differs from AISI S-7 tool steel
in the (accidental) omission of Mo.

Table C-3. Completed Range Data Sheet - Before Shot

RANGE DATA SHEET - BEFORE SHOT

Project Engineer P. Lambert Comments: RECOVERY MEDIUM: 21" CELOTEX
 Project ID ACT
 Range 110 E + 20" PLYWOOD (1/2" SHEETS)
 Gun Caliber 26 Smooth Bore ☒ Rifling ☐
 Date (month/day/yr) 5/6/76
 Round # 261 Name _____ Series 19
 Type: Experimental ☒ Fielded ☐
 Sabot: Discarding ☐ Non-Discarding ☐ None ☐
 Descriptor Reference # 1
 (detailed drawing and description including stabilizer if applicable)

Projectile

Total Mass (g) 64.06 Launch Mass (g) 172.46
 Total Length (cm) 10.25 Powder Type HP-H2
 Maximum Diameter (excluding stabilizer) (cm) 1.02 Powder Mass (g) 218

Penetrator

Nose Shape HEMISPHERICAL
 Total Length (cm) 10.25
 Maximum Diameter (cm) 1.02

Projectile Part	Mass (g)	Material	Ref. #	Hardness Value	Hardness Test	Density (g/cc)
A. Penetrator	<u>64.06</u>	<u>STEEL</u>	<u>10</u>	<u>55</u>	<u>RC</u>	<u>7.83</u>
Penetrator Parts						

B. Aerodynamic Shell _____

C. Stabilizer _____

Rate of Spin (rps) _____ (if spin stabilized)

Target Plate 1

Material RHA Ref# 1000
 Incidence Angle (deg) 60
 Mass (g) 8944
 Thickness (cm) 2.53
 Hardness - Value 364
 - Test BHN
 Density (g/cc) 7.8
 Type: ☒ Rect ☐ Cir
 Lgth/Dia (cm) 30.0
 Width (cm) 15.2

Target Plate 2

Material _____ Ref# _____
 Incidence Angle (deg) _____
 Mass (g) _____
 Thickness (cm) _____
 Hardness - Value _____
 - Test _____
 Density (g/cc) _____
 Type: ☐ Rect ☐ Cir
 Lgth/Dia (cm) _____
 Width (cm) _____
 Spacing between plates 1 and 2 (cm) _____

Target Plate 3

Material _____ Ref# _____
 Incidence Angle (deg) _____
 Mass (g) _____
 Thickness (cm) _____
 Hardness - Value _____
 - Test _____
 Density (g/cc) _____
 Type: ☐ Rect ☐ Cir
 Lgth/Dia (cm) _____
 Width (cm) _____
 Spacing between plates 2 and 3 (cm) _____

Table C-4, Completed Range Data Sheet - After Shot

RANGE DATA SHEET - AFTER SHOT

Project ID ACT Comments: _____
 Round # 261 Series 19

Recovered Penetrator	Piece 1	Piece 2	Piece 3
Residual Mass (g)	<u>20.7</u>	_____	_____
Residual Length (cm)	<u>3.4</u>	_____	_____

Plug
 Mass (g) _____
 Length (cm) _____
 Diameter (cm) _____

Target Plate 1
 Mass (g) 8848

Entrance Hole
 Minimum distance from hole to plate edge (cm) 6.5
 Length (cm) 5.5 Width (cm) 3.0

Perforation? Yes ☒ No ☐

Center Hole
 Length (cm) 2.81 Width (cm) 1.59 Penetration depth (cm) _____
 Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) 2.5 Width (cm) 2.5 Back surface fracture? Yes ☐ No ☐

Target Plate 2
 Mass (g) _____

Entrance Hole
 Minimum distance from hole to plate edge (cm) _____
 Length (cm) _____ Width (cm) _____

Perforation? Yes ☐ No ☐

Center Hole
 Length (cm) _____ Width (cm) _____ Penetration depth (cm) _____
 Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) _____ Width (cm) _____ Back surface fracture? Yes ☐ No ☐

Target Plate 3
 Mass (g) _____

Entrance Hole
 Minimum distance from hole to plate edge (cm) _____
 Length (cm) _____ Width (cm) _____

Perforation? Yes ☐ No ☐

Center Hole
 Length (cm) _____ Width (cm) _____ Penetration depth (cm) _____
 Bulge extent, from rear plate surface (cm) _____

Exit Hole
 Length (cm) _____ Width (cm) _____ Back surface fracture? Yes ☐ No ☐

Table C-5. Completed Radiograph Data Sheet

RADIOGRAPH DATA

Project ID ACT
 Range 110-E
 Gun Caliber 26
 Date (month/day/yr) 5/6/76
 Round # 261 Series 19
 File # 504-29-50

Comments: _____

Projectile
 Striking Velocity (m/s) 1360.
 Striking Yaw - Vertical (deg) +0.4
 (up: +, down: -) (α)
 Striking Yaw - Horizontal (deg) +0.7
 (right: +, left: -) (β)
 Total Yaw - (δ) (deg) 0.8

Plug (if applicable)
 Velocity (m/s) _____
 Mass (g) _____
 Length (cm) _____
 Diameter (cm) _____
 Trajectory - _____
 Cone Angle (λ) (deg) _____
 Phase Angle (ϕ) (deg) _____

Penetrator, Residual

	Piece 1	Piece 2	Piece 3
Plate 1			
Velocity (m/s)	<u>769</u>	_____	_____
Mass (g)	<u>23.4*</u>	_____	_____
Length (cm)	<u>3.6*</u>	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	<u>23</u>	_____	_____
Phase Angle (ϕ) (deg)	<u>1</u>	_____	_____
Vertical Yaw Rate (rev/sec)	<u>902</u>	_____	_____
Plate 2			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	_____	_____	_____
Phase Angle (ϕ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____
Plate 3			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle (λ) (deg)	_____	_____	_____
Phase Angle (ϕ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____

*The discrepancies between the actual mass and length of the recovered penetrator (in Table C-4) and the calculated mass and length measured on the radiograph are due primarily to the deformed condition of a residual penetrator whose jagged ends yield different lengths.

APPENDIX D

Predictive Model

APPENDIX D

Predictive Model

A method is provided for predicting the limit velocity and V_s , V_r relationship for situations involving the impact of "long-rod" penetrators* on single plate targets of rolled homogeneous armor (RHA) or aluminum (Al). An elaboration of these formulations will be forthcoming⁵.

Input parameters; it is assumed that the following values are known:

- M - penetrator mass, in grams
- L - penetrator length, in centimeters
- D - penetrator diameter, in centimeters
- T - target thickness, in centimeters
- ρ - target material density, in g/cm³
- θ - incidence angle

$$\text{Now let: } z = \frac{T}{D} (\sec \theta)^{3/4}$$

$$f(z) = z + e^{-z} - 1 \quad \left(= \sum_{k=2}^{\infty} \frac{(-z)^k}{k!} \right)$$

$$m = \frac{\rho}{4} \pi D^3 z$$

$$a = \frac{M}{M + m/3}$$

$$p = 2 + z/3$$

$$u = \begin{cases} 4,000 \text{ RHA target} \\ 1750, \text{ Al target} \end{cases} \quad (u^2 \text{ has the dimension of stress})$$

⁵J. P. Lambert, "A Residual Velocity Predictive Model for Long Rod Penetrators", to appear.

*We have in mind penetrators which are essentially cylindrical solids with length to diameter ratio in excess of 4.

The predicted limit velocity, in meters per second, is then:

$$V_{\ell} = u \left(\frac{L}{D} \right)^{.15} \sqrt{f(z) \cdot \frac{D^3}{M}}$$

and the anticipated V_s , V_r curve is specified by:

$$V_r = \begin{cases} 0, & 0 \leq V_s \leq V_{\ell} \\ a(V_s^p - V_{\ell}^p)^{1/p}, & V_s > V_{\ell} \end{cases}$$

Remark: With less assurance (because of little experience to date) we propose these formulae might also be used to describe the penetration of fragments into RHA or aluminum. Supposing the material density of the fragment to be ρ_0 g/cc and its presented area (the known or expected area projected by the fragment along the line of flight into the target surface at impact) to be A (cm²), let

$$D = 2\sqrt{A/\pi} \quad \text{and} \quad L = \frac{M}{A\rho_0},$$

and predict according to the preceding equations.

APPENDIX E

Sample Range Checklist

We strongly recommend that a complete set of range instructions be available and utilized. As an example, the following is a checklist for the BRL Terminal Ballistics Division Ranges 110E and 110G. We are grateful to Mr. Giglio-Tos of TBD for its compilation.

RANGE PROCEDURE FOR RANGES 110E & G

Before Shot:

- ___ 1. Fill out RANGE DATA SHEET BEFORE SHOT.
- ___ 2. Draw diagram of range setup if this is first shot in program or if setup has changed.
- ___ 3. Turn on delayed trigger amplifiers.
- ___ 4. Turn on counters.
- ___ 5. Turn on Thyatron trigger.
- ___ 6. Install target.
- ___ 7. Install trigger break screen.
- ___ 8. Install sabot stripper.
- ___ 9. Install film cassettes, add protective covers.
- ___ 10. Replace fiducial wires if necessary and make other repairs.
- ___ 11. Attach leaded numbers indicating stations used.
- ___ 12. Set up and number fragment recovery materials as appropriate.
- ___ 13. Assemble projectile and sabot, load at bottom of forcing cone.
- ___ 14. Insert correct amount of delay time in delayed trigger amplifiers. Record times on RANGE WORK SHEET.
- ___ 15. Turn on trigger screen voltage.
- ___ 16. Close target room door and blast room door.
- ___ 17. Weigh appropriate powder charge, put powder in case and load gun.
- ___ 18. Perform static timing test and record times on RANGE WORK SHEET
- ___ 19. Close breech.
- ___ 20. Connect firing line.
- ___ 21. Close gun room door.
- ___ 22. Close heat ducts.
- ___ 23. Connect safety interlock (red light above door should light up).
- ___ 24. Connect 110 VAC.
- ___ 25. Turn on firing power supply switch.
- ___ 26. Blow siren 3 times.
- ___ 27. Fire gun.

After Shot:

- ___ 28. Record actual time delays from delayed trigger amplifier counters on RANGE WORK SHEET.
- ___ 29. Blow siren once (1) for all clear.
- ___ 30. Disconnect safety interlock.
- ___ 31. Turn off firing power supply.
- ___ 32. Disconnect 110 VAC.
- ___ 33. Disconnect firing line and lock line in safety box.
- ___ 34. Open gun room door.
- ___ 35. Turn on exhaust fan.
- ___ 36. Clear gun (remove firing mechanism and firing plug).
- ___ 37. Open blast room and target room doors.
- ___ 38. Turn off trigger screen voltage (90V battery).
- ___ 39. Remove target and record measurements on RANGE DATA SHEET AFTER SHOT.
- ___ 40. Save at least one target plate/program.
- ___ 41. Remove films, punch project ID and round number into films.
- ___ 42. Record film measurements on RANGE WORK SHEET.
- ___ 43. Recover principal penetrator pieces and possible plug.
- ___ 44. Record their measurements on RANGE DATA SHEET AFTER SHOT.
- ___ 45. Recover other fragments if applicable.
- ___ 46. Clean range.
- ___ 47. Clean gun.
- ___ 48. Read film to determine correct powder charge for next shot to conform to V_s , V_r curve.

APPENDIX F

Program Listing of "Augur"

A program, in BASIC, to predict (and represent graphically) limit velocity and the V_s , V_r relationship for situations involving the impact of "long rod" penetrators into single RHA or aluminum plates; the test sequence of preliminary striking velocities can be generated as an option.

```

10 REM----- AUGUR -----
20 REM THE PROGRAM GENERATES PREDICTED VALUES FOR THE PARAMETERS A, P, VL
30 REM (OF THE "STANDARD" US,UR FORM) AND THE US,UR CURVE IF DESIRED.
40 REM (THE CURVE ALONE CAN BE GENERATED IF A,P,VL ARE ALREADY KNOWN).
50 REM IT IS SUPPOSED THAT THE SITUATION INVOLVES THE IMPACT OF A "LONG ROD"
60 REM PENETRATOR (L/D>4.5) HAVING HEMISPHERICAL NOSE ONTO A SINGLE RHA OR
70 REM ALUMINUM TARGET PLATE.
80 REM THE PREDICTIVE SCHEME REQUIRES AS INPUT THE TARGET THICKNESS (CM),
90 REM INCIDENCE ANGLE (DEG), PENETRATOR DIAMETER (CM) & TWO OF THE FOLLOWING:
100 REM PENETRATOR MASS (G), L/D, AVERAGE PENETRATOR DENSITY (G/CC).
110 REM THE "AUTOMATIC SCALING" OPTION PROVIDES REASONABLE PLOTTING DISPLAY
120 REM IN MOST SITUATIONS ANTICIPATED.
130 REM----- OPERATIVE EQUATIONS:
140 REM LET  $Z = T / (DX(COS(IA))^{.75})$ ,  $F(Z) = Z + EXP(-Z) - 1$ ,  $M' = R \times \pi \times D^2 \times Z / 4$  (GRAMS)
150 REM  $A = M' / (M + M' / 3)$ ,  $P = 2 + Z / 3$ ,  $VL = C \times K \times (L/D)^{.15} \times SQR(F(Z) \times D^{.3} / M)$  (M/S),
160 REM WHERE, FOR RHA: R=7.8 & K=4000, FOR ALUMINUM: R=2.74 & K=1750.
170 REM THEN, FOR  $0 < US < VL$ : UR=0; FOR  $US > VL$ : UR=AX(US-UL)^{(1/P)} (M/S).
180 REM-----
190 DEG
200 B=4000
210 B5=7.8
220 J=0:N=0
230 DIM MC[31,2],A$[80]
240 DISP "A,P,VL TO BE PREDICTED (Y OR N)";
250 INPUT A$
260 IF A$="Y" THEN 300
270 DISP "THEN A,P,VL ARE KNOWN:ENTER THEM";
280 INPUT A,P,C
290 GOTO 630
300 DISP "RHA OR AL. TARGET (R OR A) ";
310 INPUT A$
320 IF A$="R" THEN 350

```

```

330 B=1750
340 B5=2.74
350 DISP = DIAMETER (CM) ";
360 INPUT N2
370 DISP =PEN. MASS (G), (0 IF UNKNOWN) ";
380 INPUT N1
390 IF N1 THEN 420
400 DISP = L/D = ";
410 INPUT N5
420 DISP = TARGET THICKNESS (CM) ";
430 INPUT N3
440 DISP = INCIDENCE ANGLE ";
450 INPUT N4
460 IF N1=0 THEN 510
470 DISP = L/D = (0 IF UNKNOWN) ";
480 INPUT N5
490 N6=4*N1/(PI*N2^3*(N5-1/6))
500 IF N5 THEN 570
510 DISP = PENETRATOR DENSITY (G/CC) ";
520 INPUT N6
530 IF N1 THEN 560
540 N1=PI*N2^3*N6*(N5-1/6)/4
550 GOTO 570
560 N5=4*N1/(PI*N2^3*N6)+1/6
570 Q=N3/N2*(COSN4)^(-0.75)
580 A=N1/(N1+PI*N2^3*Q*B5/12)
590 P=2+Q/3
600 C=B*N5^0.15*SQR(N2^3/N1*(Q-1+EXP(-G)))
610 WRITE (15,1980)N1,N2,N3,N4,N5,
620 WRITE (15,1990)N6
630 WRITE (15,2000)A,P,C
640 P1=1/3
650 C1=C^P

```

```

660 DISP " PLOT ( Y OR N ) ";
670 INPUT AS
680 IF AS="N" THEN 1550
690 J=U-1
700 DISP " AUTOMATIC SCALING ( Y OR N ) ";
710 INPUT AS
720 IF AS="Y" THEN 780
730 U=0
740 DISP " DRAW & LABEL AXES ( Y OR N ) ";
750 INPUT AS
760 DISP " MIN ON US AXIS ( <"INTC" ) ";
770 INPUT X3
780 DISP " MAX ON US AXIS ( >"1+INTC" ) ";
790 INPUT X4
800 Z=AX(X4^P-C1)^P1
810 IF AS="N" THEN 860
820 O=1
830 IF U THEN 920
840 DISP " INTERVAL SPACING ON US AXIS ";
850 INPUT D
860 DISP " MAX ON UR AXIS ( >"INTZ" ) ";
870 INPUT Y1
880 IF O=0 THEN 970
890 DISP " INTERVAL SPACING ON UR AXIS ";
900 INPUT E
910 GOTO 970
920 D=50+50X((X4-C)>200)+100X((X4-C)>400)
930 E=2XD
940 Q=D*INT(C/D)
950 X3=Q-((C-Q)<50)*D/2
960 Y1=E+X*INT(Z/E)
970 Q=X4-X3
980 M1=X3-Q/4

```

```

990 M2=X4+Q/8
1000 M3=-Y1/3
1010 M4=1.25*Y1
1020 M5=100/(M2-M1)
1030 M6=70/(M4-M3)
1040 X9=-Q/30
1050 SCALE M1,M2,M3,M4
1060 LABEL (X,1.6,1.7,0,0.7)
1070 IF 0=0 THEN 1260
1080 LABEL (X,1.6,1.7,90,0.7)
1090 PLOT X3-Q/9,0.22*Y1,1
1100 LABEL (X)*RESIDUAL VELOCITY (M/S)*
1110 YAXIS X3,E/2,0,Y1
1120 XAXIS 0,D/2,X3,X4
1130 LABEL (X,1.6,1.7,0,0.7)
1140 FOR I=X3 TO X4 STEP D
1150 PLOT I,0,1
1160 CPLOT -2.5,-1.5
1170 LABEL (X)I
1180 NEXT I
1190 PLOT X3+Q/3,-0.133*Y1,1
1200 LABEL (X)*STRIKING VELOCITY (M/S)*
1210 FOR I=E TO Y1 STEP E
1220 PLOT X3-Q/11,I,1
1230 CPLOT 0,-0.3
1240 LABEL (2020)I
1250 NEXT I
1260 Z=AX(X4^P-C1)^P1
1270 Z0=Y1+(Z-Y1)*(Z<Y1)
1280 E0=Z0/40
1290 FOR I=0 TO Z0 STEP E0
1300 PLOT ((I/A)^P+C1)^P1,I
1310 NEXT I

```



```

1320 PEN
1330 DISP " DRAW ASYMPTOTE ( Y OR N ) ";
1340 INPUT AS
1350 IF AS="N" THEN 1420
1360 FOR I=X4+X9 TO X3 STEP X9
1370 Y=AXI
1380 IF Y>Y1 THEN 1410
1390 PLOT I,Y
1400 PEN
1410 NEXT I
1420 SCALE 0,100,0,70
1430 DISP " PRINT A, P, UL ( Y OR N ) ";
1440 INPUT AS
1450 IF AS="N" THEN 1550
1460 PLOT 75,25,1
1470 LABEL (2010)A,P,C
1480 CPLOT 0,0.5
1490 LABEL (X)" L"
1500 PLOT 89.5,17
1510 PLOT 89.5,28
1520 PLOT 73,28
1530 PLOT 73,17
1540 PLOT 89.5,17,-1
1550 DISP "GENERATE TEST SEQ. ( Y OR N ) ";
1560 INPUT AS
1570 IF AS="Y" THEN 2040
1580 DISP "GET POINTS ON CURVE ( Y OR N ) ";
1590 INPUT AS
1600 IF AS="N" THEN 1630
1610 WRITE (15,1960)
1620 GOSUB 1+(J-0) OF 2160,2430
1630 IF J=0 THEN 1940
1640 DISP "PLOT OTHER POINTS ( Y OR N ) ";

```

```

1650 INPUT A$
1660 IF A$="N" THEN 1690
1670 WRITE (15,1960)
1680 GOSUB 2160
1690 SCALE 0,100,0,70
1700 DISP " DRAW BORDER ( Y OR N ) ";
1710 INPUT A$
1720 IF A$="N" THEN 1780
1730 PLOT 0,0,0
1740 PLOT 0,70,2
1750 PLOT 100,70
1760 PLOT 100,0
1770 PLOT 0,0,-1
1780 DISP "UPPER TITLE, LINE 1 (N IF NONE)";
1790 INPUT A$
1800 IF A$="N" THEN 1880
1810 PLOT 50-LEN(A$)/2,66,0
1820 LABEL (X)A$
1830 DISP "UPPER TITLE, LINE 2 (N IF NONE)";
1840 INPUT A$
1850 IF A$="N" THEN 1880
1860 PLOT 50-LEN(A$)/2,63,0
1870 LABEL (X)A$
1880 DISP " LOWER TITLE (ENTER N IF NONE) ";
1890 INPUT A$
1900 IF A$="N" THEN 1930
1910 PLOT 50-LEN(A$)/2,3,0
1920 LABEL (X)A$
1930 PLOT 0,0,0
1940 WRITE (15,2030)
1950 END
1960 FORMAT /,13X,"US",8X,"UR",/,12X,4"--",6X,4"--"
1970 FORMAT F16.0,F10.0

```

```

1980 FORMAT /, "M=", F7.1, 5X, "D=", F5.2, 5X, "T=", F6.2, 5X, "IA=", F3.0, 5X, "L/D=", F5.1
1990 FORMAT 5X, "R=", F6.2, /
2000 FORMAT 20X, "A=", F5.2, "      P=", F4.1, "      UL=", F5.0, /
2010 FORMAT "A=", F5.2, /, "P=", F4.1, /, "U=", F5.0, " M/S"
2020 FORMAT F5.0
2030 FORMAT 80, /
2040 DISP "TOTAL NO. OF ROUNDS AVAILABLE ";
2050 INPUT N
2060 N8=N-2
2070 N9=N8-1
2080 DISP " MAXIMUM ATTAINABLE US ";
2090 INPUT X
2100 C0=CXC
2110 C9=XXX-C0
2120 PRINT "
2130 PRINT "
2140 PRINT "
2150 IF J=0 THEN 2720
2160 DISP "SIDES/SYMBOL (OR 0=NONE, 1=STAR)";
2170 INPUT N0
2180 Q=Q9=0
2190 Q0=90
2200 IF N0=0 THEN 2420
2210 IF N0#4 THEN 2260
2220 DISP " SQUARES OR DIAMONDS (S OR D) ";
2230 INPUT AS
2240 IF AS="D" THEN 2310
2250 Q0=45
2260 IF N0#1 THEN 2290
2270 N0=10
2280 Q9=-0.4
2290 IF N0>0 AND N0<30 THEN 2310
2300 N0=30

```

SUGGESTED STRIKING VELOCITY SEQUENCE FOR THE FIRST N8
 ROUNDS, WITH ANTICIPATED CORRESPONDING RESIDUAL VELOCITIES.
 (TWO SHOTS ARE AVAILABLE FOR POSSIBLE LATER USE) : :

```

2310 DISP " SYMBOL SIZE: L, M, OR S ";
2320 INPUT AS
2330 07-08=(POS(AS,"L")-1)+0.8*(POS(AS,"M")-1)+0.6*(POS(AS,"S")-1)
2340 N0=360/N0
2350 FOR 0=00 TO 00+370 STEP N0
2360 Q=Q+1
2370 IF Q9=0 THEN 2390
2380 08-07*(1+Q9*(-1)^Q)
2390 MEQ,13=COS0*Q8
2400 MEQ,23=SIN0*Q8
2410 NEXT Q
2420 IF N#0 THEN 2720
2430 IF J#0 THEN 2460
2440 DISP "US (E FOR END) ";
2450 GOTO 2470
2460 DISP "US (E FOR END,N FOR NEW SYMBOL)";
2470 INPUT AS
2480 IF AS="E" THEN 2700
2490 IF AS="N" THEN 2160
2500 X=VAL(AS)
2510 IF I=0 THEN 2550
2520 DISP " UR ";
2530 INPUT Y
2540 GOTO 2580
2550 Y=0
2560 IF X <= C THEN 2580
2570 Y=AX(X^P-C1)^P1
2580 WRITE (15,1970)X,Y
2590 IF N#0 THEN 2610
2600 IF J=0 THEN 2430
2610 IF J=0 THEN 2700
2620 OFFSET MSX(X-M1),M6X(Y-M3)
2630 PLOT 0,0

```

```

2640 PEN
2650 FOR K=1 TO Q
2660 PLOT M[K,1],M[K,2]
2670 NEXT K
2680 PEN
2690 IF N=0 THEN 2430
2700 RETURN
2710 END
2720 WRITE (15,1960)
2730 GOSUB 2570
2740 FOR I=2 TO N8-1
2750 X=SQR(C0+((N8-I)/N9)^2*(C9))
2760 GOSUB 2570
2770 NEXT I
2780 X=C
2790 Y=0
2800 GOSUB 2580
2810 PRINT
2820 GOTO (1+J) OF 1940,1690
2830 REM----- JPL ----- 8/1/77 ----

```


APPENDIX G

Program Listing of "Impact"

A program, in BASIC, for the derivation and graphic representation of limit velocity and the V_s , V_r relationship. Required input is a set of experimental V_s , V_r data related to a fixed penetrator/target set-up.

```

10 REM ----- IMPACT -----
20 REM FOR A GIVEN SET OF US,UR DATA THE PROGRAM GENERATES ESTIMATES FOR THE
30 REM PARAMETERS A,P,AND UL (OF THE "STANDARD" US,UR FORM) AND THE US,UR CURVE
40 REM IF DESIRED. (THE CURVE ALONE CAN BE GENERATED IF A,P,UL ARE ALREADY
50 REM KNOWN). THE PROCEDURE ADAPTS THE FORM TO EXPERIMENTAL DATA USING A
60 REM SLIGHT MODIFICATION OF THE OPTIMIZATION SCHEME DESCRIBED IN BRLR 1852.
70 REM COMPLETE SETS OF US,UR DATA SHOULD BE USED (INCLUDING NON-PERFOR-
80 REM ATIONS, FOR WHICH UR=0). THERE MUST BE AT LEAST 2 DATA PAIRS AND AT
90 REM LEAST ONE PERFORATION (UR>0) FOR THE PROCEDURE TO BE USED.
100 REM THE LAST VALUES PRINTED FOR A,P,C(=UL),S ARE THE DERIVED ESTIMATES
110 REM FOR THESE PARAMETERS. S IS THE RMS ERROR OF THE FIT.
120 REM TO CORRECT THE ENTRY OF A DATA PAIR, INPUT 'R' WHEN ASKED FOR US OR
130 REM UR, AND RE-ENTER VALUES AS INDICATED.
140 REM THE "AUTOMATIC SCALING" OPTION PROVIDES FOR REASONABLE PLOTTING
150 REM DISPLAY IN MOST SITUATIONS ANTICIPATED.
160 REM THERE IS AN OPTION TO DRAW "BANDS" - THESE ARE CURVES WHICH, FOR AN
170 REM INPUT X OF PARAMETER VARIATION, OUTLINE THE REGION FORMED BY ALLOWING
180 REM EACH OF THE 3 PARAMETERS (A,P,UL) TO VARY BY THE SPECIFIED PERCENTAGE.
190 REM -----
200 DEG
210 DIM VIC(201,2),MC(50,2),AS(80)
220 DISP "A,P,UL TO BE DERIVED (Y OR N) ";
230 INPUT AS
240 IF AS="Y" THEN 310
250 DISP "THEN A,P,UL ARE KNOWN:ENTER THEM ";
260 INPUT A,P,C
270 X1=X2=C
280 P1=P-1/P
290 C1=C^P
300 GOTO 1500
310 WRITE (15,1410)
320 Q2=C-G1-B1-B2-B3-B4-Y0-B-B
330 P=2
340 FOR I=1 TO 201
350 IF I>2 THEN 380

```

```

360 DISP ' US'I;
370 GOTO 390
380 DISP 'US'I'(ENTER F WHEN FINISHED)';
390 INPUT AS
400 IF AS='F' THEN 510
410 IF AS='R' THEN 440
420 I=I-1
430 GOTO 350
440 UCI,1]=VAL(AS)
450 DISP ' UR'I;
460 INPUT AS
470 IF AS='R' THEN 350
480 UCI,2]=VAL(AS)
490 WRITE (15,1420)UCI,1],UCI,2]
500 NEXT I
510 N=I-1
520 REDIM UCN,2]
530 SORT U,C,1,2
540 Q1=N
550 FOR I=1 TO N
560 Q1=Q1+(I-Q1)*X(I<Q1)*X(UCI,2]>0)
570 Q2=Q2+(I-Q2)*X(I>Q2)*X(UCI,2]>0)
580 NEXT I
590 FOR I=Q1 TO N
600 Y0=Y0+(UCI,2]>Y0)*X(UCI,2]-Y0)
610 U=UCI,1]*XUCI,1]
620 M=UCI,2]*XUCI,2]
630 B1=B1+UXU
640 B2=B2+U
650 B3=B3+M
660 B4=B4+UXM
670 NEXT I
680 R=N+1-Q1
690 WRITE (15,1430)
700 G2=UCI,1]

```

```

710 IF Q2=0 THEN 740
720 G1=V[C1,1]*Q1 <= Q2)+V[C2,1]*Q1>Q2)
730 G2=V[C1,1]*Q1 >= Q2)+V[C2,1]*Q1<Q2)
740 Z1=RXB1-B2XB2
750 IF Z1=0 THEN 810
760 U=(RXB4-B2XB3)/Z1
770 Z2=B2XU-B3
780 IF Z2 <= 0 THEN 810
790 C=INTSOR(Z2/R/U)
800 IF G1 <= C AND C <= G2 THEN 820
810 C=G1X(C/G1)+G2X(C/G2)
820 GOSUB 1180
830 WRITE (15,1440)A0,P,C,SQRABS((B3-U)/N)
840 GOSUB 1030
850 U2=U
860 GOSUB 1360
870 J=0.1+0.1X(P >= 4)
880 P=P+J
890 GOSUB 1030
900 IF U>U1 AND P<8.1 THEN 860
910 P=P-J
920 GOTO 1+(U1-U2) OF 980,940
930 GOSUB 1360
940 P=P-0.1
950 GOSUB 1030
960 IF U>U1 AND P>1 THEN 930
970 P=P+0.1
980 WRITE (15,1450)
990 DISP " PLOT DESIRED ( Y OR N ) ";
1000 INPUT AS
1010 IF AS="Y" THEN 1460
1020 END
1030 Z2=U
1040 Z1=U
1050 C=C+1
1060 GOSUB 1180

```

```

1070 IF U>Z1 THEN 1040
1080 C=C-1
1090 GOTO 1+(Z1-Z2) OF 1160,1110
1100 Z1=U
1110 IF C=0 THEN 1160
1120 C=C-1
1130 GOSUB 1180
1140 IF U>Z1 THEN 1100
1150 C=C+1
1160 U=Z1
1170 RETURN
1180 H=G-F-L=0
1190 C1=C^P
1200 P1=1/P
1210 FOR I=1 TO N
1220 IF VCI0,1J>C THEN 1280
1230 IF VCI0,2J=0 THEN 1270
1240 T=(C1-VCI0,1J^P)^P1
1250 F=F+T^T
1260 L=L-VCI0,2J^T
1270 NEXT I0
1280 FOR I=I0 TO N
1290 T=(VCI,1J^P-C1)^P1
1300 H=H+T^T
1310 G=G+VCI,2J^T
1320 NEXT I
1330 A0=(G>=H)+(G<H)*G/H
1340 U=2*AOX(G+L)-AOXAOX(H+F)
1350 RETURN
1360 U1=U
1370 A=A0
1380 S=SQABS((B3-U)/N)
1390 WRITE (15,1440)A,P,C,S
1400 RETURN
1410 FORMAT 13X,'U$',8X,'UR',/,12X,4'-'',6X,4'-'
1420 FORMAT F16.0,F10.0
1430 FORMAT /,8X,'A',9X,'P',9X,'C',13X,'S',/,6X,4'-'',7X,3'-'',6X,4'-'',9X,6'-'

```



```

1440 FORMAT F10.2,F10.1,F10.0,F15.1
1450 FORMAT 50"."/,"./,"./
1460 P1=1/P
1470 C1=C^P
1480 X1=CX(C <= UE1,1])^UE1,1])X(C)UE1,1])
1490 X2=UEN,1]
1500 IF B#0 THEN 1660
1510 DISP " AUTOMATIC SCALING ( Y OR N ) ";
1520 INPUT AS
1530 O=1
1540 IF AS="N" THEN 1660
1550 Q=X2-X1
1560 D=50+50X(Q>200)+100X(Q>400)
1570 E=2XD
1580 Q=DXINT(X1/D)
1590 X3=Q-((X1-Q)<50)XD/2
1600 X4=DXINT(X2/D)+D
1610 Z=AX(X4^P-C1)^P1
1620 Q=Z+(Y0-Z)X(Y0>Z)
1630 Y1=EXINT(Q/E)+E
1640 GOTO 1860
1650 Z=AX(X4^P-C1)^P1
1660 DISP " DRAW & LABEL AXES ( Y OR N ) ";
1670 INPUT AS
1680 O=(POS(AS,"Y")=1)
1690 DISP " MIN ON US AXIS ( <"INTX1" ) ";
1700 INPUT X3
1710 DISP " MAX ON US AXIS ( >"X2" ) ";
1720 INPUT X4
1730 IF X3>X1 OR X4<X2 THEN 1690
1740 IF O=0 THEN 1770
1750 DISP " INTERVAL SPACING ON US AXIS ";
1760 INPUT D
1770 Q=Z-AX(X4^P-C1)^P1
1780 IF B#0 THEN 1800
1790 Q=Z+(Y0-Z)X(Y0>Z)
1800 DISP " MAX ON UR AXIS ( >"INTQ" ) ";

```

```

1810 INPUT Y1
1820 Z0=Y1
1830 IF 0=0 THEN 1860
1840 DISP " INTERVAL SPACING ON UR AXIS ";
1850 INPUT E
1860 Q=X4-X3
1870 M1=X3-Q/4
1880 M2=X4+Q/8
1890 M3=-Y1/3
1900 M4=1.25*Y1
1910 M5=100/(M2-M1)
1920 M6=70/(M4-M3)
1930 X7=X3-Q/11
1940 X9=-Q/20
1950 SCALE M1,M2,M3,M4
1960 LABEL (X,1.6,1.7,0,0.7)
1970 IF 0=0 THEN 2160
1980 LABEL (X,1.6,1.7,90,0.7)
1990 PLOT X3-Q/9,0.22*Y1,1
2000 LABEL (X)"RESIDUAL VELOCITY (M/S)"
2010 YAXIS X3,E/2,0,Y1
2020 XAXIS 0,D/2,X3,X4
2030 LABEL (X,1.6,1.7,0,0.7)
2040 FOR I=X3 TO X4 STEP D
2050 PLOT I,0,1
2060 CPLOT -2.5,-1.5
2070 LABEL (X)I
2080 NEXT I
2090 PLOT X3+Q/3,-0.13*Y1,1
2100 LABEL (X)"STRIKING VELOCITY (M/S)"
2110 FOR I=E TO Y1 STEP E
2120 PLOT X7,I,1
2130 CPLOT 0,-0.3
2140 LABEL (3160)I
2150 NEXT I
2160 IF B#0 THEN 2530
2170 DISP "SIDES/SYMBOL (OR 0=NONE,1=STAR)";

```

```

2180 INPUT N0
2190 J=09=0
2200 00=90
2210 IF N0=0 THEN 2410
2220 IF N0#4 THEN 2270
2230 DISP " SQUARES OR DIAMONDS (S OR D) ";
2240 INPUT AS
2250 IF AS="D" THEN 2310
2260 00=45
2270 IF N0#1 THEN 2300
2280 N0=10
2290 09=-0.4
2300 N0=30+(N0-30)*((N0>0) AND (N0<30))
2310 DISP " SYMBOL SIZE: L, M, OR S ";
2320 INPUT AS
2330 07=08-(POS(AS,"L")-1)+0.8*(POS(AS,"M")-1)+0.6*(POS(AS,"S")-1)
2340 FOR 0=00 TO 00+365 STEP 360/N0
2350 J=J+1
2360 IF 09=0 THEN 2380
2370 08=07*(1+09*(-1)^J)
2380 MCJ,1J=COS0*08
2390 MCJ,2J=SIN0*08
2400 NEXT 0
2410 SCALE 0,100,0,70
2420 FOR I=1 TO N
2430 OFFSET MSX(UCI,1J-M1),M6*(UCI,2J-M3)
2440 PLOT 0,0
2450 PEN
2460 FOR K=1 TO J
2470 PLOT MCK,1J,MCK,2J
2480 NEXT K
2490 PEN
2500 NEXT I
2510 SCALE M1,M2,M3,M4
2520 Z0=Y1+(Z-Y1)*(Z<Y1)
2530 Y=Z0/40
2540 J=1

```

```

2550 FOR I=0 TO 20 STEP Y
2560 U=MCJ,1J=((I/A)^P+C1)^P1
2570 MCJ,2J=I
2580 IF U>= X4 THEN 2610
2590 J=J+1
2600 NEXT I
2610 FOR I=1 TO J-1
2620 PLOT MCJ,1J,MCJ,2J
2630 NEXT I
2640 PEN
2650 DISP " DRAW ASYMPTOTE ( Y OR N ) ";
2660 INPUT AS
2670 IF AS="N" THEN 2740
2680 FOR I=X4+X9 TO X3 STEP X9
2690 Y0=AXI
2700 IF Y0>Y1 THEN 2730
2710 PLOT I,Y0
2720 PEN
2730 NEXT I
2740 SCALE 0,100,0,70
2750 IF B=0 THEN 2780
2760 DISP " PRINT A, P, UL ( Y OR N ) ";
2770 GOTO 2790
2780 DISP "PRINT A,P,UL,S ( Y OR N ) ";
2790 INPUT AS
2800 IF AS="N" THEN 2870
2810 PLOT 75,27,1
2820 LABEL (3170)A,P,C
2830 CPLOT 0,0.6
2840 LABEL (X). L
2850 IF B=0 THEN 2870
2860 LABEL (3180)S
2870 DISP " DRAW BANDS ( Y OR N ) ";
2880 INPUT AS
2890 IF AS="Y" THEN 3200
2900 SCALE 0,100,0,70
2910 DISP " DRAW BORDER ( Y OR N ) ";

```

```

2920 INPUT AS
2930 IF AS="N" THEN 2990
2940 PLOT 0,0,0
2950 PLOT 0,70,2
2960 PLOT 100,70
2970 PLOT 100,0
2980 PLOT 0,0,-1
2990 DISP "INPUT UPPER TITLE 1 (N IF NONE) ";
3000 INPUT AS
3010 IF AS="N" THEN 3090
3020 PLOT 50-0.625*LEN(AS),66,0
3030 LABEL (3470)AS
3040 DISP "INPUT UPPER TITLE 2 (N IF NONE) ";
3050 INPUT AS
3060 IF AS="N" THEN 3090
3070 PLOT 50-0.625*LEN(AS),63,0
3080 LABEL (3470)AS
3090 DISP "INPUT LOWER TITLE (N IF NONE) ";
3100 INPUT AS
3110 IF AS="N" THEN 3140
3120 PLOT 50-0.625*LEN(AS),3,0
3130 LABEL (3470)AS
3140 PLOT 0,0,0
3150 END
3160 FORMAT F5.0
3170 FORMAT " A=",F5.2,/, " P=",F4.1,/,/, "U =",F5.0, " M/S"
3180 FORMAT /, "S=",F4.0, " M/S)"
3190 DISP " PERCENT PARAMETER VARIATION ";
3200 INPUT U0
3210 U8=1+U0/100
3220 U9=2-U8
3230 Q=AXU8
3240 A0=QX(Q<1)+(Q >= 1)
3250 P0=PXU8
3260 C0=CXU9
3270 WRITE (15,3450)A0,P0,C0
3280 GOSUB 3350

```



```

3290 A0=AXU9
3300 P0=PXU9
3310 C0=CXU8
3320 WRITE (15,3460)A0,P0,C0
3330 GOSUB 3350
3340 GOTO 2860
3350 P1=1/P0
3360 C1=C0^P0
3370 SCALE M1,M2,M3,M4
3380 FOR I=0 TO 20 STEP Y
3390 X=((I/A0)^P0+C1)^P1
3400 IF X>X4 THEN 3420
3410 PLOT X,I
3420 NEXT I
3430 PEN
3440 RETURN
3450 FORMAT /,'A1=',F5.2,' P1=',F5.2,' C1=',F5.0
3460 FORMAT 'A2=',F5.2,' P2=',F5.2,' C2=',F5.0,/
3470 FORMAT F1.0
3480 REM-----JPL-----8/1/77-----

```

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
12	Commander Defense Documentation Center ATTN: DDC-TCA Cameron Station Alexandria, VA 22314	2	Commander US Army Missile Research and Development Command ATTN: DRDMI-R DRDMI-RBL Redstone Arsenal, AL 35809
1	Director Defense Nuclear Agency ATTN: MAJ Spangler Arlington, VA 22209	1	Commander US Army Tank Automotive Research & Development Cmd ATTN: DRDTA-RWL Warren, MI 48090
1	Director Defense Advanced Research Projects Agency ATTN: Tech Info 1400 Wilson Boulevard Arlington, VA 22209	1	Commander US Army Mobility Equipment Research & Development Cmd ATTN: DRDME-WC Fort Belvoir, VA 22060
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib Rock Island, IL 61299
1	Commander US Army Aviation Research and Development Command ATTN: DRSAB-E 12th and Spruce Streets St. Louis, MO 63166	2	Commander US Army Armament Research and Development Command ATTN: DRDAR-TSS (2 cys) Dover, NJ 07801
1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035	4	Commander US Army Armament Research and Development Command ATTN: Mr. V. Guadagno Mr. R. Davitt B. Knutelsky G. Demitrak Dover, NJ 07801
2	Commander US Army Electronics Command ATTN: DRSEL-HL-CT, S.Crossman DRSEL-RD Fort Monmouth, NJ 07703	1	Commander US Army Watervliet Arsenal ATTN: SARWV-RDD-SE, P.Vottis Watervliet, NY 12189

DISTRIBUTION LIST

<u>No. of</u> <u>Copies</u>	<u>Organization</u>	<u>No. of</u> <u>Copies</u>	<u>Organization</u>
1	Commander US Army Harry Diamond Labs ATTN: DRXDO-TI 2800 Powder Mill Road Adelphi, MD 20783	3	Commander Naval Air Systems Command ATTN: AIR-604 Washington, DC 20360
5	Commander US Army Materials and Mechanics Research Center ATTN: DRXMR-T, Mr. J. Bluhm DRXMR-T, Dr. D. Roylance DRXMR-T, Dr. A.F. Wilde DRXMR-T, Dr. J. Mescall DRXMR-ATL Watertown, MA 02172	3	Commander Naval Ordnance Systems Command ATTN: ORD-9132 Washington, DC 20360
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range NM 88002	2	Commander Naval Air Development Center, Johnsville Warminster, PA 18974
1	Deputy Assistant Secretary of the Army (R&D) Department of the Army Washington, DC 20310	1	Commander Naval Missile Center Point Mugu, CA 93041
1	HQDA (DAMA-ARP) Washington, DC 20310	1	Commander & Director David W. Taylor Naval Ship Research & Development Ctr Bethesda, MD 20084
1	HQDA (DAMA-MS) Washington, DC 20310	1	Commander Naval Surface Weapons Center ATTN: Code TX, Dr. W.G. Soper Dahlgren, VA 22448
1	Commander US Army Research Office ATTN: Dr. E. Saibel P. O. Box 12211 Research Triangle Park NC 27709	2	Commander Naval Surface Weapons Center Silver Spring, MD 20910
1	Chief of Naval Research ATTN: Code ONR 439 N. Perrone Washington, DC 20360	3	Commander Naval Weapons Center ATTN: Code 4057 Code 4011, Dr. E. Lundstrom Code 3813, Mr. M. Backman China Lake, CA 93555
		4	Commander Naval Research Laboratory ATTN: Mr. W. J. Ferguson Mr. J. Baker Dr. H. Pusey Dr. F. Rosenthal Washington, DC 20375

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Superintendent Naval Postgraduate School ATTN: Dir of Lib Monterey, CA 93940	1	Director Lawrence Livermore Laboratory ATTN: Dr.R.H. Toland, L-424 P. O. Box 808 Livermore, CA 94550
2	ADTC/DLJW (MAJ D. Matuska, LTC J. Osborn) Eglin AFB, FL 32542	1	Aeronautical Research Assoc. of Princeton, Inc. 50 Washington Road Princeton, NJ 08540
1	AFFDL (FDT) Wright-Patterson AFB, OH 45433	2	Aerospace Corporation ATTN: Mr. L. Rubin Mr. L. G. King 2350 E. El Segundo Blvd El Segundo, CA 90009
1	AFML (Dr. T. Nicholas) Wright-Patterson AFB, OH 45433	1	Boeing Aerospace Company ATTN: Mr. R. G. Blaisdell (M.S. 40-25) Seattle, WA 98124
3	ASD (YH/EX, John Rievley; XROT, Gerald Bennett; ENFTV, Matt Kolleck) Wright-Patterson AFB, OH 45433	1	Dupont Experimental Labs ATTN: Mr. J. Lupton Wilmington, DE 19801
1	Headquarters National Aeronautics and Space Administration Washington, DC 20546	1	Effects Technology Inc. 5383 Hollister Avenue P. O. Box 30400 Santa Barbara, CA 93105
4	Director National Aeronautics and Space Administration Langley Research Center Langley Station Hampton, VA 23365	1	Falcon R&D ATTN: Mr. R. Miller 1225 S. Huron Street Denver, CO 80223
1	Director National Aeronautics and Space Administration Manned Spacecraft Center ATTN: Lib Houston, TX 77058	2	Falcon R&D Thor Facility ATTN: Mr. D. Malick Mr. J. Wilson 696 Fairmount Avenue Baltimore, MD 21204
1	Director Jet Propulsion Laboratory ATTN: Lib (TD) 4800 Oak Grove Drive Pasadena, CA 91103		

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	FMC Corporation Ordnance Engineering Div San Jose, CA 95114	1	Pacific Technical Corp. ATTN: Dr. F. K. Feldmann 460 Ward Drive Santa Barbara, CA 93105
1	General Electric Company Armament Systems Dept Burlington, VT 05401	1	Philco-Ford Corporation Capistrano Test Facility San Juan Capistrano, CA 92675
1	President General Research Corporation ATTN: Lib McLean, VA 22101	3	Physics International Company ATTN: Dr. D. Orphal Dr. E. T. Moore Dr. M. Chawla 2700 Merced Street San Leandro, CA 94577
1	Goodyear Aerospace Corp 1210 Massillon Road Akron, OH 44315	3	Sandia Laboratories ATTN: Dr. W. Herrmann Dr. L. Bertholf Dr. J. W. Nunziato Albuquerque, NM 87115
1	H. P. White Laboratory Bel Air, MD 21014	1	Science Applications, Inc. 101 Continental Blvd, Suite 310 El Segundo, CA 90245
3	Honeywell, Inc. Government & Aerospace Products Division ATTN: Mr. J. Blackburn Dr. G. Johnson Mr. R. Simpson 600 Second Street, NE Hopkins, MN 55343	1	Science Applications, Inc. ATTN: G. Burghart 201 W. Dyer Rd (Unit B) Santa Ana, CA 92707
1	Lockheed Corporation ATTN: Dr. C. E. Vivian Department 8114 Sunnyvale, CA 94087	2	Systems, Science & Software, Inc. ATTN: Dr. R. Sedgwick Ms. L. Hageman P. O. Box 1620 La Jolla, CA 92038
1	Materials Research Lab., Inc. 1 Science Road Glenwood, IL 60427	1	US Steel Corporation Research Center 125 Jamison Lane Monroeville, PA 15146
1	McDonnell-Douglas Astronautics Company ATTN: Mail Station 21-2 Dr. J. Wall 5301 Bolsa Avenue Huntington Beach, CA 92647		

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Drexel University Dept of Mechanical Engineering ATTN: Dr. P. C. Chou 32nd and Chestnut Streets Philadelphia, PA 19104	1	University of Dayton Univ. of Dayton Research Inst ATTN: Mr. H. F. Swift Dayton, OH 45405
1	New Mexico Institute of Mining and Technology Terra Group Socorro, NM 87801	2	University of Delaware Dept of Mechanical Engineering ATTN: Prof. J. Vinson Dean I. Greenfield Newark, DE 19711
1	Forrestal Research Center Aeronautical Engineering Lab Princeton University ATTN: Dr. A. Eringen Princeton, NJ 08540	2	University of Denver Denver Research Institute ATTN: Mr. R. F. Recht Mr. T. W. Ipson 2390 S. University Boulevard Denver, CO 80210
3	Southwest Research Institute Dept of Mechanical Sciences ATTN: Dr. U. Lindholm Dr. W. Baker Dr. P. H. Francis 8500 Culebra Road San Antonio, TX 78228	2	University of Florida Dept of Engineering Science and Mechanics ATTN: Dr. C. A. Sciammarella Dr. L. Malvern Gainesville, FL 32601
1	Stanford Research Institute Poulter Laboratory 333 Ravenswood Avenue Menlo Park, CA 94025	<u>Aberdeen Proving Ground</u> Marine Corps Ln Ofc Dir, USAMSAA Cdr, USATECOM ATTN: Mr. W. Pless Mr. S. Keithley	
3	University of Arizona Civil Engineering Department ATTN: Dr. D. A. DaDeppo Dr. R. Richard Dr. R. C. Neff Tucson, AZ 85721		
4	University of California Los Alamos Scientific Lab ATTN: Dr. R. Karpp Dr. J. Dienes Dr. L. Germain Dr. B. Germain P. O. Box 808 Livermore, CA 94550		