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DATA ANALYSIS
OF THE
REACTION BEHAVIOR OF EXPLOSIVE
MATERIALS SUBJECTED TO SUSAN TEST IMPACTS

MASTER

PREPARED FOR
UNIVERSITY OF CALIFORNIA
LAWRENCE RADIATION LABORATORY
LIVERMORE, CALIFORNIA

UNDER CONTRACT NO. 8472107

REPORT NUMBER 4500-95-11-R1

July 1970

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ABSTRACT

The experimental behavior of the AEC Susan Test MOD-1 projectile impact tests is organized and described. Threshold ignition velocities and the timing of observed explosive reactions are related to the deformation and fracture behavior of the aluminum case containing the explosive material. Explosive magnitude values (Relative Energy Release) estimated from peak pressure readings numerically are related to values estimated from transit time indications. The computer codes used in performing the study are listed and described.

ACKNOWLEDGEMENTS

1. T. E. McIlraith of William M. Brobeck & Associates performed much hard work in reading film records to be processed by Code HSPCD, and in listing Susan Test data for Code SDLST. The subject matter of this report largely is based upon this task of data acquisition.
2. A. R. Licuanan and D. E. Giroux of the Computations Department of Lawrence Radiation Laboratory assisted in the preparation of the analytical model for the Code HEMP study and performed the computer runs described in Appendix E.
3. C.N. Paoni of the Chemistry Department of Lawrence Radiation Laboratory significantly helped forward this study by his advice and assistance in setting up programming details so that a large amount of data could be handled easily in the LRL computer system.
4. K. G. Hoge of the Mechanical Engineering Department of Lawrence Radiation Laboratory performed and reported the static load tests described in Appendix F.

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1. INTRODUCTION

The subject matter of this report is a data analysis study of the experimental behavior of a large number of MOD-1 projectile, Susan Test impact rounds^{1,2,3*}. In this test an explosive containing thin wall projectile** is fired from a smooth bore gun against a steel target at velocities ranging from 50 to 1500 feet per second. The crushing behavior of the projectile and the chemical reactions thereby produced are monitored photographically with Fastax cameras; air shocks generated by the reacting explosive are monitored by an array of overpressure gages. Reference 1 is an earlier report describing this same test series. Additional information supplementing Reference 1 is presented here.

Section 2. contains a very brief description of the MOD-1 projectile, the test procedure, and the experimental instrumentation. Study results described in Section 3. are discussed and further interpreted in Section 4. The relationships between these Susan Test results and the results of other tests performed on explosive materials are discussed in Section 5. Additional experimental and analytical work is suggested in Section 6.

Two computer programs were developed to process the Susan Test data reported here. Code SDLST, used to organize and arrange the Susan Test results, is described and listed in Appendix C. Code HSPCD used to process motion versus time data from the Fastax camera records is described and listed in Appendix D.

Appendix A contains a description of a very simple numerical model of the Susan projectile impact process, derived from observed motion data as processed by Code HSPCD. The calculated timing curves used as background plots for the timing data illustrated in Section 3. are based on this model.

The explosive magnitude of any given round can be estimated from air shock arrival time information^{1,7} and also from the recorded peak overpressures. In Appendix B, explosive magnitudes estimated from peak overpressure readings are compared to equivalent values estimated from arrival time information. Explosive magnitudes based on overpressure readings plotted versus pre-impact velocity, exhibit less "scatter" than those based on arrival time estimates.

* Reference reports are indicated by superscripts, ibid page 58.

** ibid page 3.

A Code HEMP¹² model of the front end of the Susan projectile has been constructed. A study of the mechanical deformation process prior to fracture of the containment case is in process. Early study results are quoted in support of the test data analyses. Appendix E contains descriptive information concerning the Code HEMP study.

Static load tests, further described in Appendix F, were performed on Susan Test samples filled with non-reactive "mock" materials. These tests exhibited containment case distortion and fracture behavior closely corresponding to that observed in the Susan Test impact program. Such correspondance is not unreasonable since, (1) the pre-impact velocity range for threshold reactions to occur, is sufficiently low for many loading wave transits to occur during a single impact; (2) the containment case aluminum material is strain rate insensitive; and (3) the contained explosive materials easily flow, i.e., Code HEMP calculated triaxial cavity pressure is large when compared to the distortional shear required for explosive material distortion.

2.0 SUSAN TEST DESCRIPTION

The undeformed Susan Test projectile is illustrated below. It is fired from a 3.2 inch smooth-bore gun at an armor plate target. Impact is normal to the flight path of the projectile.

Figure 1 - MOD-1 Susan Projectile

The projectiles are fired down a 12 ft. range. Instrumentation used to observe the impact process are close up and long distance framing cameras, piezo-electric overpressure gages placed about 10 ft. from the point of impact, and silicon-diode light gages for timing observations. The time of impact is indicated by squib lights fired by an impact grid switch² that covers the target surface.

The Susan Test is used to rate the reaction behavior of explosive materials subjected to low velocity impact in an encased configuration. References (1) and (2) contain additional information on details of the experimental setup.

3. RESULTS

Information concerning twelve (12) individual explosive materials is illustrated. The materials selected were chosen because, (1) they are materials of current interest or, (2) they exhibit interesting kinds of behavior. Organized data on many additional explosive materials exists in the output listings of Code SDLST described in Appendix C.* The composition of the materials discussed in detail here are tabulated in Table 1. Material properties measured in other tests are tabulated in Table 2.

Susan Test records yield three kinds of test data (1) information pertaining to explosive reaction magnitude, (2) information concerning explosive reaction timing, and (3) information concerning projectile motion and the fracture behavior of the aluminum containment case. Figures 2 through 13 are plots of explosive magnitude versus pre-impact projectile velocity. Figures 14 through 25 are plots that illustrate reaction timing versus pre-impact projectile velocity. Figures 26 through 32 are plots of projectile displacement** versus time, during the impact process.

3.1 Explosive Magnitude

The scale used to display explosive magnitude is "Relative Energy Release" as described in prior reports^{1,2,3}. The MOD-1 projectile contains about 1 lb. of explosive material. The energy equivalent of one projectile load of TNT fully reacted as a point source, would register a Relative Energy Release of 70.

The explosive magnitude data presented in prior reports was based on reaction timing data that was somewhat subjective in that the time to the "start of the large reaction" (hereafter referred to as "enhancement") was a human judgment based on the rate of growth of the reaction cloud as observed on the filmed Fastax camera records. The data of this report are based directly on overpressure gage peak readings. The numerical process by which overpressure readings were substituted for timing data in making estimates of explosive magnitude is explained in Appendix B.

* Code SDLST inputs data for all AEC Susan Test impacts, currently on the order of 900 rounds.

** "Projectile displacement" is the axial displacement of the steel body of the projectile.

3.2 Reaction Timing

Time to "first observed reaction" and time to reaction "enhancement" are illustrated on Figures 14 through 24.** Notice that the plotting pattern of the reaction time data points tends to depend upon projectile displacement. The timing curves with the parameter of projectile displacement plotted in the background are based on the simple numerical model of the impacting system derived in Appendix A. This numerical model was inferred from the more or less definite "knees" observed in the curves of projectile displacement versus time obtained from the Fastax camera records processed by Code HSPCD, described in Appendix D. Figures 26 through 32 illustrate these camera records. On these timing records, the curve for the 2.5 inch displacement parameter corresponds to late "pinch" when the projectile body has reached the target wall; the explosive containing aluminum case, prior to impact, extends only 2.68 inches beyond the steel body of the projectile.*

3.3 Classifying Explosive Materials, in General

Taken all together one can classify materials with regard to their explosive magnitude and reaction timing curves. For example, PBX 9404 lights early, at a low-pre-impact velocity, and has a large magnitude reaction. At low velocities, "enhancement" occurs shortly after "first observed reaction". At higher velocities "enhancement" occurs at pinch. LX09 behaves like 9404. LX10 behaves like 9404 except that all observed "enhancements" occur shortly after "first observed reaction". LX07 lights as early as LX09. However, "enhancement" always occurs at pinch; its reaction level relatively is low. LX11 lights still later, at higher pre-impact velocities, i.e., "first observed reaction" is observed to occur very close to the pinch stage of the impact process. In general there are (1) high magnitude reaction, early lighting, low threshold pre-impact velocity materials, (2) low magnitude reaction, late lighting, high threshold pre-impact velocity materials, and (3) materials that are in between. For PBX materials, the behavior seems to be bounded by "insensitive" LX11 and "sensitive" LX10, LX09, or 9404.

3.4 Classifying Explosive Materials by Mechanical Behavior

In addition, it is useful to classify these materials according to when "knees" occur in the plots of projectile displacement versus time. See Figures 26 through 32. Impacts in which knees occur at similar levels of displacement are postulated to be impacts in which the gross mechanical interaction between the explosive filler material and the aluminum containment case is similar. Using the process model derived in Appendix A, the knee information of the motion plots is transformed into the background timing curves of Figures 14 through 25. There are three (3)

* ibid, page 3

**On Figure 25, first reaction occurred very late in the process and no "Enhancements" were noted. However, a spray of material illustrating that the case had ruptured was observed early in the process.

sets of background timing curves, corresponding to three categories (1, 2, and 3) of mechanical behavior denoted by three levels of projectile displacement (0.55", 0.75", and 1.2") to "casebreak"* On this basis, the twelve explosives have been segregated into the three (3) mechanical categories as tabulated on Table 1.

It is interesting to note that for the four (4) materials with only Viton A as the binder (LX11-0, LX04-1, LX07-2, and LX10-0), the mechanical category rating increases with binder volume. Similarly, when comparing LX09-0 with similar RX09-AG, note that the latter with a less brittle binder composition fits within a higher mechanical category.

Segregation of explosive materials into mechanical categories tends to emphasize the importance of the strength of the containment case in the Susan Test determination of ignition threshold. Also this adds to the discussion of the relationship between Susan Test results and the results of other tests performed on uncased explosive test samples such as the Skid Test, and the Hopkinson Bar impact tests. These matters are covered in the following sections of this report.

* *ibid*, page 42 and Section 4.1.2

TABLE 1

COMPOSITION OF REPORTED EXPLOSIVE MATERIALS

	<u>Mechanical*</u> <u>Category</u>	<u>Specific</u> <u>Gravity</u>	<u>Vol. %</u> <u>HMX</u>	<u>Vol. %</u> <u>Binder</u>	<u>Binder(s)</u>	<u>Binder**</u> <u>Activity</u>
LX11-0	3	1.86	79.4	20.6	Viton A	0
LX04-1	2	1.86	84.5	15.5	Viton A	0
LX07-2	1	1.86	89.7	10.3	Viton A	0
LX10-0	1	1.86	94.8	5.2	Viton A	0
LX09-0	1	1.84	91.4	5.8 2.8	DNPA FEFO	+1 +1
RX09-AG	2	1.84	93.8	3.0 3.2	DNPA FEFO	+1 +1
9404-03	1	1.84	92.4	4.2 3.5	T β CP nitrocellulose (12% N)	-1 +1
9011-02	2	1.77	85.0	15.0	Estane	-1
RX07-AA	1	1.73	61.4(RDX)	38.2 0.4	TNT anthracene	+1 -1
RX04-DJ	2	1.86	84.5	15.5	crystalline flourel	0
RX04-DS	1	1.92	82.9	9.9 7.2	Viton A aluminum	0 +1
RX08-AZ	2	1.823	77.0	19.1 3.9	FEFO AFNOL	+1

* See Section 3.4

**+1 is energy source, -1 is energy sink, 0 is neutral

DNPA is dinitropropyl acrylate

FEFO is bis (2 fluoro 2, 2 dinitroethyl) formal

T β CP is tris- β -chloroethyl phosphate

AFNOL means Airforce - Naval Ordinance Lab compound.

WILLIAM M. BROBECK & ASSOCIATES

TABLE 2
EXPLOSIVE MATERIAL MECHANICAL PROPERTIES^{*,9}

		<u>9404</u>	<u>LX041</u>	<u>9011</u>	<u>LX07</u>
Specific Gravity		1.836	1.865	1.770	
Poisson's Ratio		0.324	0.38	0.35	
Bulk Modulus	psi	1.42×10^6	1.5×10^6	1.39×10^6	
Shear Modulus	psi	$.567 \times 10^7$	$.39 \times 10^6$	$.463 \times 10^6$	
Static Shear Strength*	psi	750	485	350	
Static Tensile Strength*	psi	314	300	325	320
Static Tensile Elongation*	μin /in	2150	4150	3400	3100
Static Compressive Strength*	psi	1560	1700	1130	
Dynamic Compressive Strength**	psi	12000	13000	10000	

* at 68°F

** Hopkinson Bar Data at Approximate Strain Rate of $1000(\text{secs})^{-1}$

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR LXII-O

FIG. 2

-01-

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR LX04-1

FIG.3

FIG. 4

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR LX10-O

FIG. 5

FIG. 6

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR RX09-AG

FIG. 7

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR 9404-03

FIG.8

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR 9011-02

FIG. 9

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR RX07-AA

FIG.10

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR RX04-DS

FIG. 11

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR RX04-DJ

FIG. 12

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR RX08-AZ

FIG. 13

FIG.14

FIG. 15

FIG.16

FIG. 17

FIG. 18

FIG. 19

FIG. 20

FIG. 21

FIG. 22

FIG. 23

FIG. 24

FIG. 25

CALCULATED AND MEASURED DISPLACEMENT VERSUS TIME
PBX-9404

FIG. 26

CALCULATED AND MEASURED DISPLACEMENT VERSUS TIME
LX10-0

FIG. 27

CALCULATED AND MEASURED DISPLACEMENT VERSUS TIME

FIG. 28

CALCULATED AND MEASURED DISPLACEMENT VERSUS TIME
 RX04-DJ

FIG. 29

MEASURED DISPLACEMENT VERSUS TIME
LX07-2

FIG. 31

MEASURED DISPLACEMENT VERSUS TIME
RX09-AG

FIG. 32

4.0 DISCUSSION

4.1 General Description of Observed Impact Mechanics

To interpret the data presented here, it is useful to describe the impact process as a sequence of four mechanical events. These are named (1) impact, (2) casebreak, (3) continuing fracture, and (4) final pinch. These events are more or less identified in the motion history of the projectile by the observed "knees" in the displacement time history. When a knee occurs, it means that the forward velocity of the projectile body suddenly has slowed and that during the bounding interval of time, forward kinetic energy of the projectile body has been (1) converted into radial motion, and/or (2) dissipated in processes involving deformation, flow, and fracture. Illustrations of the approximate magnitude and shape of case deformation corresponding to these knees are illustrated on Figure 33.

It might be postulated that knees can be the result of chemical reactions. This viewpoint is not advanced here because the observed initial lighting behavior occurs at or after a knee and often is observed in a region where there is no obvious change in projectile velocity. Of course, when a large sudden chemical reaction does take place, the film record is obscured. The impact process now is discussed in terms of the four knee events. The impact event is first.

4.1.1 Impact

Several things happen shortly after impact. The rounded, lens shaped nose of the aluminum case turns inside out and flattens against the target. The case and filler begin to expand outward in radial motion. HMX crystals begin to shear and crush, and the binder must begin to deform and perhaps fracture as the impact loading builds up inside the explosive filled cavity of the projectile.

Appendix E describes a Code HEMP model of the front portion of the projectile. Code HEMP calculations based on this model indicate that the front lens will separate from the cylindrical cap in a circular fracture caused by radial loading at a projectile displacement on the order of 0.2 ins. At this early stage of deformation the external surface of the projectile appears to be a right circular cylinder. The internal energy, mainly flow work, added to the explosive filler material* is well distributed and equivalent to a very low maximum local temperature rise, on the

* Currently, the HEMP model assumes the filler material to be a single continuum of elastic-plastic material. See Figure 53 in Appendix E.

1. FRONT LENS SEPARATES.
2. EXPLOSIVE MATERIAL LOADS UP AND MAY FRACTURE.

IMPACT

1. HOOP LOAD FRACTURES APPEAR.
2. EXPLOSIVE MATERIAL STARTS TO FLOW RADIALY OUT THRU FRACTURE GAPS.

CASEBREAK

HOOP LOAD FRACTURES EXTEND INTO HEAVY WALL SECTION OF CASE.

CONTINUING FRACTURE

PRESSURE BUILDS IN TRAPPED EXPLOSIVE MATERIAL.

PINCH

ILLUSTRATION OF EVENTS THAT ARE ASSOCIATED WITH DISCONTINUOUS CHANGES IN PROJECTILE VELOCITY
FIG 33

order of $2.5F^0$. While a low order energy concentrating mechanism is present, i.e., the crushing and shearing of HMX crystals adjacent to the fracture radius of the separating lens, chemical reactions are not observed this early in the impact process.

The change in kinetic energy of the projectile body represented by the impact knee event, represented by the change in velocity squared, is approximately the same number for the "sensitive" materials such as 9404 and LX10. See Figure 40 of Appendix A.

$$V_o^2 - V_1^2 = 1.4 \times 10^6 (\text{in/sec})^2$$

V_1 = Projectile velocity after impact

V_o = Pre-impact velocity

When velocity after impact is set equal to zero, the calculated pre-impact velocity is on the order of 96 FPS. At velocities less than 96 FPS there is insufficient kinetic energy in the projectile body to continue the case distortion process after impact and the case will not fracture in absence of an internal chemical reaction. It is interesting to note that the earliest verifiable ignitions occur at pre-impact velocities in excess of 96 FPS. Most "sensitive" material threshold velocities occur between 100 FPS and 120 FPS.

4.1.2 Casebreak

As the projectile continues to drive in toward the target the aluminum cap mushrooms. The Code HEMP calculations show that the detail shape of the "mushroom" depends on the yield strength assumed for the filler material.* For a given axial displacement, higher yield strength filler material results in a less extreme

* To date only two (2) complete runs have been obtained from Code HEMP. More are needed to define the interaction between the case and filler. At this time, all that is clear is that the effective yield strength of the filler material, is an important process variable. Bulk modulus and the other mechanical properties also are likely to be important process variables. See Figure 55 in Appendix E, *ibid* page 117.

mushroom shape and a more widely distributed strain field within the material of the aluminum cap. Eventually the hoop loading results in longitudinal cracks in front of the aluminum case, opening up sharp edged passageways through which the explosive materials will be extruded. The rupture energy associated with this hoop loading induced case fracture process, plus additional energy required to initiate filler flow out through the fracture gaps, is postulated to be the principle factor in the early casebreak knee observed in the displacement vs. time history of the projectile.

The casebreak event is of substantial importance to the interpretation of Susan Test data since the earliest observed chemical reactions are associated with it. The several longitudinal aluminum case fractures are typical ductile fractures. The fracture plane* is inclined at 45° to the cylindrical surface. The stress concentration at the tip of the fracture is quite high so that the fracture propagates rapidly back to the axial region where the hoop strain in the case is very low, i.e., to where the case wall is thick. The axial velocity of fracture propagation** is much faster than the forward velocity of the projectile body.

After casebreak, continued projectile motion extrudes the explosive material out through the gaps opened by the longitudinal case fractures. Explosive materials are non-linear in their flow characteristics. The relationship between gap opening and flow rate will vary with the different explosive materials.

Just prior to case fracture the internal energy of the distorted explosive material calculated by Code HEMP remains low.*** However, right after the longitudinal fracture gaps open, the explosive material is forced to flow radially outwards. The shearing and crushing of HMX crystals inherent in this process is postulated to be the energy concentration mechanism that

* Test samples filled with "mock" materials have been recovered.

** A very well lighted test series using a projectile substantially similar to the MOD-1, was conducted at Site 300 at Livermore. Figure 34 is a sketch of the longitudinal crack propagation observed in adjacent Waddell camera frames of a record obtained in this Site 300 test series. Ibid page 45.

***Equivalent to a maximum local temperature rise on the order of $12F^{\circ}$ Calculated internal cavity pressure at this time is well distributed and is on the order of 50,000 psi. See Figure 54 in Appendix E, ibid page 116.

results in the observed early lighting behavior.*

If this interpretation of the mechanism for early lighting behavior is correct, then the Susan Test pre-impact threshold velocities for the "sensitive" explosives can be varied by changing the containment cap material from ductile 6061 aluminum to another ductile material with a different yield strength and rupture elongation.**

4.1.3 Continuing Fracture

On some displacement vs. time records, the knee designated continuing fracture occurs after casebreak but before final pinch. The casebreak fractures extend only into the lightly strained thick wall region of the case. As the projectile continues to advance toward the target, initially the fractured case segments can bend up with little further penetration of the early fractures. Eventually, the hoop loading at the heavy section will increase and the early fractures must open up and continue to propagate toward the steel body of the projectile; see Figures 31 and 32.

4.1.4 Pinch

The forward motion of the projectile body must slow and stop as it closely approaches the target wall*** This part of the impact process is termed pinch. After casebreak the pressure in the explosive material drops to a low level and there is little observable reduction in the velocity of the projectile body until continuing fracture or final pinch. At pinch, explosive material is trapped between the target wall and projectile body with a consequent, theoretically large increase in pressure^{4,5,6}. Thus low level reactions previously started nearly always are enhanced at pinch and materials which did not react at casebreak ultimately will react at pinch.

* At present, a very limited amount of photographic information suggests that the early reaction starts within the case and not at the surface. Reaction sustaining pressure is higher within the case. However, the region of material in close proximity to the sharp case fracture edges cannot be excluded as a potential reaction locus.

** Ibid footnote, page 56.

*** The physical character of pinch depends upon the pre-impact velocity. At velocities in excess of 500 FPS, the steel body itself begins noticeably to deform. This must be related to the explosive magnitudes attained in the late pinch reaction process.

FRAME N
TIME, $t(N)$

FRAME N+1
 $t(N) + 62 \mu S$

FRAME N+2
 $t(N+1) + 62 \mu S$

PRE-IMPACT VELOCITY = 181 FPS

ILLUSTRATION OF OBSERVED CRACK PROPAGATION
IN MOD-901 PROJECTILE TEST SERIES CONDUCTED
AT SITE 300 AT LIVERMORE.

FIG. 34

4.2 Quality of Displacement vs. Time Records

The validity of the description of Susan Test mechanics just concluded, depends upon (1) the quality of the Fastax camera records used to obtain projectile displacement versus time, and (2) reaction timing information largely related to these records. The time of impact is indicated by squib lights fired by an impact grid switch² that covers the target surface. The impact events also are monitored by silicon diodes sensitive to light intensity and piezo electric transducers to measure air shock pressure. Usually, the non-photographic reaction timing data supports the Fastax timing record. Occasionally the various sources of timing information disagree; in these cases an examination of associated test records often will allow shot data to be salvaged. Reaction timing information from the Fastax records can be obtained where, because of poor lighting or excessive debris and smoke, motion versus time data cannot.

To determine motion versus time, the Fastax film records were projected on a Recordak screen. The film reader used a set of dividers to measure the distance between the back end of the projectile and a datum. Considerable scatter is present in the individual readings primarily because the projectile edge resolution is not uniformly good. The "graininess" of the film itself is a factor. Frequently the bright impact squib light affected the edge resolution.* Smoke and debris from the gun affects the quality of the camera records. Finally, pre-impact pitching and yawing of the projectile clearly is visible in many of the lower velocity records. The deformation and fracture process subsequent to a non-axisymmetric impact is such to greatly magnify the effect of an initial impact angle with regard to the subsequent orientation of the projectile body and the resulting distortion of the aluminum cap.

The data "noise" in some displacement versus time records is so large as to preclude the observation of any knees at all. This is always the case at high pre-impact velocities, greater than 250 FPS, and frequently the case for lower pre-impact velocities. Fortunately, the knees clearly are present in most of the shots with readable records at pre-impact velocities in the region of the threshold velocity.**

The impact knee clearly is observed on the early lighting material rounds. Also, the casebreak knee clearly is present on these materials and on the less sensitive materials. In general, the impact knee cannot be observed in records of rounds with pre-impact velocities greater than 140 FPS.

* This often led to an apparent increase in projectile displacement at impact.

** The lowest pre-impact velocity at which a reaction is observed.

The casebreak knee can be observed in threshold region rounds at pre-impact velocities less than 250 FPS. The continuing fracture knee is observed infrequently. The sharpness of the casebreak knee and the presence of the continuing fracture knee should depend and probably does depend upon the degree to which a given impact is not axisymmetric.* Figures 26 and 27 illustrate the impact knee and casebreak knee. Figures 28, 29, 30 and 32 illustrate more casebreak knees. Figures 31 and 32 illustrate the continuing fracture knee.

The simplified model analysis used to calculate the background timing curves of Figures 14 through 25 assumes the existence of the impact and casebreak knees. The plotted reaction timing data is not inconsistent with this assumption. In general, the chronologically later rounds used a Fastax color camera with a framing rate of $9000(\text{secs})^{-1}$ to $12000(\text{secs})^{-1}$ or greater. The earlier rounds used a slower camera with a framing rate of $3000(\text{secs})^{-1}$ to $5000(\text{secs})^{-1}$. The uncertainty in measuring the early reaction timing due to camera framing rate is on the order of $250 \mu\text{s}$ for some of the data points on Figures 15 and 20. Otherwise it is on the order of $100 \mu\text{s}$.

4.3 Scatter in Explosive Magnitude Records

4.3.1 Due to Lack of Initial Impact Axisymmetry

The curves of explosive magnitude versus pre-impact velocity, as a group, have this characteristic. In any given pre-impact velocity regime above the threshold, most explosive magnitude data points will fit within a not too wide scatterband. An occasional data point will register an explosive magnitude some 10 to 30 points above the others; see Figures 2, 3, 7, 10, 12, and 13. Lacking additional solid experimental data, it is possible to account for these non-representative data points as "bad" data, or as being caused by chemical or manufacturing quality control variance. However, it is suggested here that this kind of behavior should be anticipated, even with representative test projectiles.

The degree to which the projectile impact initially is axisymmetric should have a considerable influence on the resulting explosive magnitude. The mushrooming action at the front of the projectile is the result of a non-linear, compressive, mechanical failure process, somewhat in the nature of column buckling. Just as comparatively small magnitudes of load eccentricity will cause a column to buckle at well below the "critical load", an initial

* Observe the variation in projectile velocity following impact for three LX10-0 rounds of approximately the same pre-impact velocity, 155 FPS, 162 FPS, and 167 FPS; see Figure 27. This variation probably relates to a degree of initial axisymmetry.

projectile impact angle will limit pressure buildup within the cavity. On the other hand, when the impact is very close to axisymmetric, then, the condition of circular symmetry will provide a self-equilibrating radial pressure field that is consistent with a much higher general pressure level within the explosive mass. Once ignited, the explosive material reaction rate increases with pressure and is self reinforcing. It is suggested that even an insensitive explosive subjected to a statistically rare, isotropic, axisymmetric Susan Test impact, could initiate to a very high level reaction.

The TNT containing material, COMP-B, is a very low explosive magnitude material, when subjected to Susan Test impacts contained inside the MOD-1 projectile. This material also has been subjected to Susan Test impacts contained inside the MOD-1A projectile. The MOD-1A projectile is longer than the MOD-1 projectile,* with a specially molded adiprene gas seal at the back of the projectile body in place of the MOD-1 commercial leather cup seal.** Figure 35 is a comparative plot of the Relative Energy Release performance inside both projectiles for COMP-B. If it is postulated that the MOD-1A projectile is more "stable" than the MOD-1 projectile by reason of its greater length and more controllable gas seal, then the definitely larger explosive magnitudes registered in the MOD-1A tests could be a partial verification of the effect of a greater degree of impact axisymmetry.

Figure 36 which is a side by side photograph of two recovered projectiles that did not react supports the above reasoning. The projectile on the bottom contains PBX 9011. It was subjected to a nearly axisymmetric impact at 121 FPS, well below its threshold velocity. Note the plug of explosive material extending well beyond the front end of the cap. Clearly, significant compression energy was present within the cavity to extrude this plug of material after termination of the compression phase of the impact.

* MOD-1A is the same weight as MOD-1. Its body length is approximately double that for the MOD-1. The all steel MOD-1 body is replaced by a composite steel and aluminum body. The explosive cavity is identical.

**Ibid page 3 , Figure 1.

On the other hand, note the projectile on the top containing PBX LX04 which contacted the target at 139 FPS. The mechanical properties of 9011 and LX04 are similar. It is obvious that this projectile was subjected to an initially off angle impact that buckled and fractured the case on one side, opening up large, pressure relieving, fracture gaps on the buckled side. There is no apparent extrusion of the explosive material within the cavity opposite the buckled side.

On the average, most Susan Test MOD-1 impacts are not axisymmetric; hence the average scatter band. Occasionally an impact occurs that is close to axisymmetric. This shot will exhibit an unusual increase in explosive magnitude, particularly when the explosive material is one classified as "insensitive."

4.3.2 Due to Variation in Material

Small differences in material formulation and processing can be a real source of variation in explosive magnitude. For example, consider the data points for differing batches of LX07 type materials plotted on Figure 4. The materials denoted LX07-2 and RX04-BA nominally meet the same material specifications. The RX04-BA was produced in a single 500 lb. batch and was pressed to a density of 1.857. The LX07-2 was produced in three smaller batches, and was pressed to a density of 1.865. The LX07-0 chemically is similar to the others, but it was processed with a slightly different mesh size mix of crystalline HMX.

-0--

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR COMP. B

FIG. 35

Recovered MOD-1 SUSAN Projectiles. Top projectile loaded with LX-04-1 and impacted at 139-FPS. Bottom projectile loaded with PBX-9011 and impacted at 121-FPS.

Fig. 36

5. RELATIONSHIP OF SUSAN TEST TO OTHER SENSITIVITY AND MECHANICAL TESTS

Explosive material behavior in the Susan Test is not inconsistent with that observed in other tests. In particular, reaction behavior observed in the Skid Test generally is in agreement with that observed in the Susan Test. In the Skid Test,^{8,11} an 11 inch uncased hemisphere of explosive material, supported by a cable suspension system, is dropped from different altitudes and is allowed to swing against a horizontal, rough (sandy) target surface. The impact angle is controlled to be either 14° or 45° from the horizontal. Skid Test explosive magnitudes are rated subjectively on a scale from one (1) to six (6). One (1) is a barely discernable reaction (scorch marks); six (6) is a large magnitude reaction. The Skid Test, "threshold" for a given impact angle, is the lowest drop height at which a reaction is observed.

Figure 37 is a comparison between Susan Test results and Skid Test results for 9404, LX09, LX10, LX04, and 9011. High reaction magnitude materials in the Susan Test are so identified in the Skid Test, and vice versa. Materials that clearly differ are ordered in the same sequence by either test. On the other hand, small differences in reaction timing, pre-impact velocity threshold, or drop height threshold, are not resolved reliably by either test. More or less variable factors affect the results of each test, so that the existing number of data points, statistically, are insufficient.

In addition to the standard Skid Test, Skid Test hemispherical billets have been instrumented with accelerometers and dropped vertically on a smooth surface.* Spot size is monitored. This test leads to a computed "yield" pressure which is a measure of the flow resistance of the explosive material in the spherical contact region. If a correlation exists, then materials with the same yield pressure behavior should show equivalent knee behavior in the Susan Test curves of projectile displacement versus time, i.e., be in the same mechanical category as defined in Section 3.4 Table 3 tabulates such yield pressure data and the mechanical category for several of the materials considered in this report. The "sensitive" materials, 9404, LX10, and LX09 all have comparatively high yield pressures (15000 psi to 21000 psi for 2 ft. drops) and fit within the "weak" mechanical category,** (1). The "insensitive" materials LX04 and 9011, have lower yield pressures (12000 psi to 14000 psi for 2 ft. drops,) but fit within the "stronger" mechanical category, (2).

* This test series is to be formally reported in the future.

** "Weak" means apparently low flow resistance inside the aluminum containment case.

However, note that for the 9404 billets with the "highest" yield pressure, there is no drop test data for drop heights in excess of 2 ft. because the billet breaks up. In the Susan Test, it is postulated that 9404 behaves like a weak material because it breaks up on impact and thereafter distorts with very low flow resistance.*

Hopkinson bar data⁹ relating compressive flow stress, strain, and strain rate is available for 9404, LX04, and 9011. These data show no significant differences in material flow characteristics; all three materials appear to be similar. The other continuum mechanical property information that is available⁹ tends to show that most of these materials substantially are similar.**

At this time, all that can be stated with reasonable certainty is that the Susan Test and the Skid Test order clearly different materials in the same sequence as to explosive magnitude.

* The "insensitive" new material RX08AZ is a very low yield pressure material as indicated by a very large spot size indication in the regular Skid Test. It appears to fit into stronger Susan Test mechanical category (2).

** Ibid page 8. Table 2.

TABLE 3

11" BILLET DROP TEST YIELD PRESSURE VS. MECHANICAL CATEGORY*

<u>Flow Stress (psi)</u>	<u>Drop Ht. 8 ft.</u>	<u>4ft.</u>	<u>2 ft.</u>	<u>1 ft.</u>	<u>$\frac{1}{2}$ ft.</u>	<u>Mechanical Category</u>
9404		Billet Breaks Up	20916	20188 19058	19953	1
LX10			16015	19462		1
LX09			15379 15522			1
LX07			13965 12876			1
RX04DJ		15665 15754				2
LX04	17592 17040	13180 15356	13346 12274	12604 13106		2
9011	17473 17131	13648 17055	14276 13509	14568 14023		2

* Mechanical category is defined in Section 3.4, ibid page 5.

COMPARISON BETWEEN SUSAN TEST RESULTS AND PANTEX SKID TEST RESULTS

FIG. 37

6.0 SUGGESTED ADDITIONAL WORK

6.1 As Related to Ignition Threshold and Explosive Magnitude

In Section 4.1.2 the observed threshold Susan Test early reactions are related to the rupture of the aluminum case. It can be expected that Susan Test rounds assembled with a containment cap machined from a more ductile material, or from a material with equivalent ductility but increased rupture strength, will exhibit threshold ignition at an increased level of pre-impact velocity. It is suggested that this be verified experimentally.*

In Section 4.3.1 it is inferred that the explosive magnitude of a round is affected strongly by the degree to which it is axisymmetric at the time of impact. The impact grid switch senses impact by means of an electric grid extending over the target area in the plane of the target surface. Perhaps this instrumentation could be extended to indicate initial contact position as well as impact time, since initial contact position should relate to impact normality. Also the firing of additional rounds using the MOD-1A projectile filled with a well known material such as LX04-1 could verify the effect of impact axisymmetry if the results obtained parallel those for COMP B, Figure 35.

The very large CDC Star computer, intended for 3-dimensional problem statements, will be installed at LRL. The 3-dimensional equivalent of Code HEMP** usefully could be used to perform numerical calculations relating to the degree of impact axisymmetry in the Susan Test.

The current 2-dimensional Code HEMP study can be continued to develop a more complete understanding of axisymmetric impacts with regard to the details of explosive material behavior in relation to case deformation at casebreak. Such a study can then be extended to predict changes in threshold pre-impact velocity to be expected when the continuum material properties of the case or of the explosive filler material are varied.

- * When a different configuration projectile with a very heavy copper case that did not rupture, and yielded but a small amount, was tested, pre-impact velocity threshold was lowered. Pertinent Code HEMP studies have not yet been obtained. Perhaps multiple compressive reflections inside the cavity resulted in a much higher pressure level. Also, this projectile cavity was cylindrical with an open square end; a non-axisymmetric impact should result in an initial very high local load concentration in the explosive adjacent to the case.
- ** This is now being developed. The STAR is supposed to go into operation in the Spring of 1971.

Assuming the success of the experimental and numerical studies just described, then a firm basis exists to predict the low velocity threshold ignition performance of explosive materials packaged in cases of different shapes. This would be a fact of substantial interest to designers of equipment in which explosive materials are used.

6.2 As Related to Materials Testing

As stated in Section 5, the standard mechanical property tests performed on PBX materials tend to show how similar they are in continuum mechanical behavior. These tests give little information about a potentially important mechanical difference.

The ability of a material to be "impact squeezed" from a previously static reservoir through a small hole or crack, directly pertains to the Susan Test environment. The ignition behavior as the explosive is caused to flow out through the longitudinal fracture gaps is caused by the local highly non-linear heating effects that occur during this kind of flow process. It is suggested that a standard materials test be devised to rate PBX materials as to impact flow through an orifice. To better understand the Susan Test results this property should be investigated in the absence of containment case deformation and fracture.

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APPENDIX A

SIMPLIFIED MODEL

APPENDIX A

The Susan Test is modeled by a single lumped mass system* illustrated in Figure 38. Quantised energy losses at impact and at casebreak reproduce the knee behavior illustrated in the curves of projectile displacement versus time, Figures 26 through 32, Section 3. This observed kinematic behavior of the Susan Test projectiles is the basis for the model. Its purpose is to calculate the constant displacement timing curves used as a background for the reaction time data points plotted on Figures 14 through 25, Section 3.

Table 4 and Figures 39, 40 and 41 present information obtained from the Fastax camera records as processed by Code HSPCD, see Appendix D. The timing model is based on this data.

To obtain projectile velocity after impact, the impact knee is assumed to represent a sudden change in projectile energy.

$$v_o^2 - v_1^2 = 2 \Delta E / M \quad (1)$$

The quantity calculated in equation (1) is plotted versus pre-impact velocity on Figure 40.

Projectile velocity after casebreak event is obtained by means of an equation similar to equation (1).

$$v_1^2 - v_2^2 = f(Z_{cb}) \quad (2)$$

$f(Z_{cb})$ is a function of casebreak displacement

* A more fundamental study of process mechanics, using Code HEMP, is described in Appendix E.

This quantity is plotted on Figure 40 versus pre-impact velocity. Certain points from this figure for "fully developed" casebreak behavior are plotted versus projectile displacement on Figure 41. Equation (1) is used to calculate projectile velocity after impact. Equation (2) is used to calculate projectile velocity after casebreak. For the three sets of timing curves, equation (1) and (2) become:

$$v_1^2 = v_o^2 - 1.4 \times 10^6$$

$$v_2^2 = v_1^2 - \left\{ \begin{array}{l} 1.11 \times 10^6 \text{ at } Z_{cb} = 0.55 \text{ inches} \\ 1.7 \times 10^6 \text{ at } Z_{cb} = 0.75 \text{ inches} \\ 4.15 \times 10^6 \text{ at } Z_{cb} = 1.2 \text{ inches} \end{array} \right\} \quad (3)$$

For any given pre-impact velocity, equations (3) permit the calculation of projectile velocity immediately following impact and immediately following the casebreak knee. Velocity units are inches per second.

For the time period between the impact and casebreak knee events, the resistance to projectile motion is assumed to be a constant value. The equations of motion for this time period are:

$$\ddot{Z} = - R/M$$

$$\dot{Z} = v_1 - \frac{R}{M} t \quad (4)$$

$$Z = v_1 t - \frac{R}{M} \frac{t^2}{2}$$

Solving for time in terms of displacement results in:

$$t = \frac{MV_1}{R} \left[\sqrt{1 + 2 \left(\frac{RZ}{MV_1^2} \right)} - 1 \right] \quad (5)$$

A value for R/M is obtained from Round 835, a PBX 9404 impact at a pre-impact velocity just below threshold. For this round, projectile velocity goes to zero at a displacement of 0.35 inches, 650 μ s after impact. The velocity immediately following impact is 359 inches per second.

$$\begin{aligned} Z^* &= 0.35 \text{ ins.} \\ V_o^* &= 1236 \text{ ips} \sim 103 \text{ FPS} \\ V_o^{*2} - V_1^{*2} &= 1.4 \times 10^6; V_1^* = 359 \text{ ips} \\ t^* &= 650 \times 10^{-6} \text{ secs.} \end{aligned} \quad (6)$$

From the second of equations (4), when Z goes to zero.

$$\frac{R}{M} = V_1^*/t^* \quad (7)$$

Equation (5) can be generalized by combining it with equation (7)

$$\frac{t}{t^*} = \frac{V_1}{V_1^*} \left[\sqrt{1 + \left(\frac{V_1^*}{V_1} \right)^2 \left(\frac{2Z^*}{t^* V_1^*} \right) \left(\frac{Z}{Z^*} \right)} - 1 \right] \quad (8)$$

For the limit case of Round 835 where $t = t^*$, $V_1 = V_1^*$, and $Z = Z^*$, equation (8) reduces to:

$$1 = \left[\sqrt{1 + \left(\frac{2Z^*}{t^* V_1^*} \right)} - 1 \right] \quad \text{or,} \quad \frac{2Z^*}{t^* V_1^*} = 3$$

substituting values from (6) note that,

(9)

$$\frac{2Z^*}{t^* V_1^*} = \frac{2 \times .35}{650 \times 359} \times 10^6 \approx 3.$$

Combining (6), (8), and (9) results in an expression for time after impact, t , to a projectile displacement, Z , prior to the casebreak event. Time in microseconds is,

$$t = 650 \left(\frac{V_1}{359} \right) \left[\sqrt{1 + 3 \left(\frac{359}{V_1} \right)^2 \left(\frac{Z}{.35} \right)} - 1 \right] \quad (10)$$

Additional displacement after the casebreak event is assumed to proceed at velocity, V_2 , without any velocity reduction. Projectile body motion after casebreak is assumed to take place with negligible flow resistance.

$$\Delta t = \Delta Z / V_2 \quad (11)$$

Letting subscript "cb" refer to the time and displacement at the casebreak event, then the relation between time and displacement after casebreak becomes:

$$t = 650 \left(\frac{V_1}{359} \right) \left[\sqrt{1 + 3 \left(\frac{359}{V_1} \right)^2 \left(\frac{Z_{cb}}{.35} \right)} - 1 \right] + \frac{Z - Z_{cb}}{V_2}$$

$$\text{where } V_1^2 = V_0^2 - 1.4 \times 10^6 \quad (12)$$

$$\text{and } V_2^2 = V_1^2 - f(Z_{cb})$$

Z_{cb}	0.55 ins.	0.75 ins.	1.2 ins
$f(Z_{cb})$	1.11×10^6	1.70×10^6	4.15×10^6

TABLE 4 - SHEET 1

Material		9404	9404	RX09AG	RX09AG	LX10-0	LX10-0	LX10-0	LX10-0
Round No.		835	833	711	714	858	869	868	866
Nominal Velocity	fps	103	107	140	160	120	146	163	164
HSPCD Velocity	fps	103	116	146	151	120	155	167	162
Pre-Impact Velocity	ips	1236	1393	1750	1820	1440	1865	2000	1940
Post-Impact Velocity	ips	359	910	1340	1440	815	1150	1500	1448
Post-Case-break Velocity	ips	Rebound	257		575				
Casebreak Displacement	ins	0.35	0.35		0.75	0.55			0.5
First Reaction Displacement	ins	No Reaction	0.45	0.7	No Reaction	No Reaction	0.59	0.55	0.6
$V_o^2 - V_1^2 = \frac{2\Delta E}{M} \text{ (ips)}^2$		1.4×10^6	1.114×10^6	1.38×10^6	1.335×10^6	1.41	2.157	1.75×10^6	1.67×10^6
$V_1^2 - V_2^2 = f(Z_{cb}) \text{ (ips)}^2$		0.129×10^6	0.762×10^6		1.744×10^6	0.665×10^6			

TABLE 4 - SHEET 2

Material		RX04DI	LX07-2	LX07-2	LX04-1	LX 11	RX04DH
Round No.		865	829	816	235	589	864
Nominal Velocity	fps	152	146	151	144	218	142
HSPCD Velocity	fps	146	146	167	147		
Pre-Impact Velocity	ips	1750	1751	2000	1760		
Post-Impact Velocity	ips	1140	900*	1255**	1530	2500	
Post-Case-break Velocity	ips		Rebound		800	1450	
Casebreak Displacement	ins		0.77	05-0.75**	0.75	1.2	
First Reaction Displacement	ins	0.65	0.7*	0.55	0.80	2.1	0.5
$V_o^2 - V_1^2 = \frac{2\Delta E}{M} \text{ (ips)}^2$		1.765×10^6	2.26×10^6	2.49×10^6			0.5×10^6
$V_1^2 - V_2^2 = f(Z_{cb}) \text{ (ips)}^2$					1.70×10^6	4.15×10^6	

* Assume 570 s to rebound.

** See double filtered velocity curve.

M = PROJECTILE MASS
 R = FLOW RESISTANCE, ASSUMED CONSTANT
 V_0 = PRE-IMPACT VELOCITY
 V_1 = VELOCITY IMMEDIATELY FOLLOWING IMPACT
 V_2 = VELOCITY IMMEDIATELY FOLLOWING CASEBREAK

FIG. 38

PRE-IMPACT VELOCITY IN FEET PER SECOND
CHANGE IN VELOCITY SQUARED ASSOCIATED WITH IMPACT KNEE
FIG. 40

PRE-IMPACT VELOCITY IN FEET PER SECOND
CHANGE IN VELOCITY SQUARED ASSOCIATED WITH CASEBREAK KNEE
FIG. 39

CHANGE IN VELOCITY SQUARED ASSOCIATED WITH CASEBREAK KNEE
VERSUS
PROJECTILE DISPLACEMENT WHEN CASEBREAK OCCURS
FIG. 41

APPENDIX B

EXPLOSIVENESS RELATIONSHIPS

APPENDIX B

The measure of explosive magnitude, Relative Energy Release, is the same as defined in Reference 1, 2 and 3. It is a quantity that can be calculated from pressure records or from transit time indications. Experimentally pressure records are obtained from four (4) piezoelectric transducers, placed at different distances and orientations in relation to the explosive reaction location. Transit time is estimated from the pressure gage records, and also from silicon diode records and the Fastax camera records.

Actual impact test explosions are not clean, geometrically symmetric events. For any single shot the four pressure records vary in shape with time and in magnitude. The experimental range initially was calibrated using static charge detonations. For these static calibration rounds, the use of timing data resulted in less scatter in the calculated values of Relative Energy Release. Thus transit time estimates of explosive magnitude were considered to be more accurate than equivalent estimates based upon peak pressure readings. Accordingly, transit time data has been the preferred basis for calculation of explosive magnitude.^{1,2,3}

This study is based on records* from nearly 900 Susan Test rounds. In processing this data, it was discovered that when averaged over many rounds of approximately the same Relative Energy Release**, that:

- (1) The multiple of peak gage pressure and gage distance varied slowly with gage distance, and,
- (2) For any given pattern of the four (4) pressure gages, any particular gage position recorded peak pressures that were in approximately a constant ratio to those recorded at the three (3) other gage positions.

Consequently, Relative Energy Release numerically was related to a function of the weighted average of the multiple of gage distance and peak pressure.

The individual gage multipliers used in obtaining the weighted average just described, vary with gage pattern. Chronologically, the current existing gage pattern was employed for all rounds subsequent to Round No. 293. Three other gage patterns were used for the prior rounds. Gage multipliers were determined independantly for each gage pattern. The function used to relate Relative Energy Release to the weighted average multiple of peak pressure and gage distance, is the same for all patterns and is the "S" shaped solid line plot on Figure 42.

* See Appendix C, in which Code SDLST is described.

** Previously estimated from transit time data.

Instantaneous energy release, peak pressure, distance, and transit time are interdependent and have been related theoretically by Brode⁷ for point source detonations. At a given distance, energy release is related to the cube of peak pressure. This theoretical behavior is illustrated by the dotted line plot on Figure 42. The experimental "S" shaped relationship is preferred over the theoretical cubic relationship since the near-in pressure gage records and the high energy release records clearly do not approximate the instantaneous detonation behavior theoretically analyzed. Actual energy release takes place in time. Flat top and double peaked pressure records often are observed. Only so much total energy can be packaged inside the Susan sample cavity so that the observed "S" shaped flattening at the higher values of Relative Energy Release is not unreasonable.

Also, experimental peak pressures diverge from theoretical behavior in another way. Theoretically, a 7 ft. gage should record a peak pressure 20% to 30% higher than a 10 ft. gage. Experimentally, this variation appears to be on the order of 10%. It is postulated that this discrepancy is related to differences in shape between theoretical and actual records of pressure versus time, and to differences in spatial distribution in energy release.

In any event, the calculation of Relative Energy Release from peak pressure readings apparently has reduced the scatter in the calculated data points. For example, compare Figures 43 and 44 of this Appendix with Figures 2 and 3 located in Section 3.0. The data of Figures 2 and 3 are based on peak pressures while the data of Figures 43 and 44 are based on transit time estimates. Equivalent reductions in data scatter are observed whenever the numbers of data points for a particular class of explosive are increased by adding together the data for several slightly different but similar materials.*

There is a reason why peak pressure readings should be a better basis for estimates of Relative Energy Release. Considerable time and care is required of a person making a transit time estimate. The selection of which pressure record event or diode record event, or which Fastax camera frame represents the "start of the large reaction" can be a very subjective operation.** On the other hand, reading peak pressure from a pressure trace is a fast easy thing to do.

Actual blast pressure levels and pressure velocities vary spatially in an arbitrary fashion from shot to shot because any given shot randomly is not axisymmetric. The averaging of the four (4) pressure records*** is a simple direct integration in space that smooths the calculated result. When relative energy release is estimated from transit time indications, these also are averaged in space.

* *ibid*, Figures 46 and 47, Appendix C, pages 95 and 96.

** See Reference 1, pages 16 and 17 for discussion of spatial energy variations, and for parallel comments concerning subjective element in the determination of the "start of the large reaction".

*** The averaging of two or more peak pressure readings appears to give reasonably good estimates for Relative Energy Release.

Since good timing information was not obtained on most of the earlier rounds, making use of the pressure gage data has salvaged many shots and significantly has increased the total number of Relative Energy Release data points.

FIG. 42

EXPLOSIVE MAGNITUDE VS PRE-IMPACT VELOCITY FOR LXII-O

FIG. 43

FIG.44

APPENDIX C

CODE SDLST

APPENDIX C

Code SDLST was devised to organize the Susan Test data and to ease the process of finding, computing, and plotting correlations that may exist within the listed data. Data from approximately 900 rounds is listed. For each round 18 quantities of numerical significance are keypunched as input; currently 8 additional quantities are calculated. These 26 quantities are keyed to identifiers for round number, type of material, type of projectile, manufacturing lot, projectile serial numbers, etc.

Three fixed point numbers are basic to the SDLST organization process. These are:

IM - Round Number

JM - Material Designation Number

LM - Projectile Designation Number

Each explosive material tested is associated with a unique number, JM. While this study has been concerned with only the "MOD-1" projectile, the entire Susan Test program has been involved with several kinds of projectiles, each of which is associated with a unique number, LM. Each round number, IM, is sequenced in chronological order.

Verbal names and serial numbers are associated with IM, JM, and LM. These are KM, AM, AP, and AS as defined on comment cards in the program listing. Numerical data is stored in the X(IM, K) array where IM is round No. and K designates the particular variable of interest. The quantity X(IM, 1), pre-impact velocity, also is used as a listing order variable. The X(IM, K) array is defined on comment cards in the program listing.

Code SDLST outputs three (3) listings on command. (1) First, it will list all information in chronological round number order. (2) It then segregates the information by material number, projectile number, and lists the result in order of increasing pre-impact velocity. (3) The user then has the option of combining data for several differing materials and differing kinds of projectiles. SDLST performs the combinations by reassigning one material number to represent several to be combined and one projectile number to represent several to be combined. More than one such combined data set can be processed in a single computer run. SDLST then outputs the combined listing organized by material, projectile type, and pre-impact velocity.

In addition to the basic organization capability just described, SDLST will plot several vertical axis variables from the X(IM,K) data array against any selected horizontal axis variable also from the X(IM,K) array, for both individual materials and projectiles and for combined materials and projectiles. A given set of vertical axis variables versus the same horizontal axis variable is called a plot family. Several plot families can be obtained in a single computer run.

The source program listing is included here for record purposes, followed by portions of a sample graphical output. A detailed report for code SDLST will be issued in the future, including complete verified Susan Test data lists. The sample output includes the important data definitions with units, and three (3) explosive magnitude, combined material plots for a family of six (6) LX07 type materials, Figures 45 through 48. The selected plots* show Relative Energy Release (1) estimated from transit time data, (2) estimated from peak pressure data, and (3) the standard 10 ft. overpressure estimated from the peak pressure data.

* ibid pages 94, 95 96 and 97

```

*ID 3260GB
* CONTROLLEE(0,SDLST)
* DUMP(OCT,DEC)
* LIST 8
* FORTRAN STORE
SUBROUTINE STORE

C
CLICHE STOP

C
PARAMETER( J1=1000 , J2 = 30 , J3 = 150 , J4 = 30 , J5 = 200 ,
1 J6 = 10 , J7 = 5 , J8 = 50 , J9 = 10 , J10 = 3 , J11 = 5 )

C
COMMON/NAM1/ JM(J1),KM(J1),LM(J1),AM(J1),AP(J1),X(J1,J2),MJ(J3),
1 ML(J4),JN(J5),NJ(J5),IV( J4,J5 ) ,IM(J1),NK(J5),TITLE(12),
2 MJ2(J6,J3),ML2(J7,J4),JM3(J6),NJK(J6),JM4(J6),LM3(J7),
3 NJL(J7),LM4(J7),XP(J5),YP(J5),NP(J5),JP(J8),LP(J9),NX(J10),
4 NY(J10,J11),NN3(J10),XQ(J5),YQ(J5,2),AS(J1),INFILE(512),XNAM(12),
5 NT,NTQ,JJ3,LL3,JP1,JP2,JP3,KX,KY,XMIN,XMAX,YMIN,YMAX

C
C J1 = TOTAL NO. OF ROUNDS
C J2 = NO. OF NUMERICAL STORAGE ARRAYS PER ROUND
C J3 = NO. OF DIFFERENT MATERIAL DESIGNATIONS
C J4 = NO. OF DIFFERENT PROJECTILE DESIGNATIONS
C J5 = NO. OF ROUNDS PER COMBINED MATL + PROJ DESIGNATIONS
C J6 = NO. OF SETS OF COMBINED MATERIALS
C J7 = NO. OF SETS OF COMBINED PROJECTILES
C J8 = NO OF MATL NOS SELECTED FOR PLOTTED OUTPUT
C J9 = NO OF PROJ NOS SELECTED FOR PLOTTED OUTPUT
C J10 = NO OF FAMILIES OF CURVES FOR PLOTTED OUTPUT
C J11 = NO OF CURVES PER CURVE PLOT FAMILY
C
ENDCLICHE
USE STOP
RETURN
END
* LIST 8
* CARDS COLUMN
* FORTRAN SDLST
C
ERR = 0
CALL ODDROP(5RSDLST,LR+SDLST,ERR)
CALL ASSIGN(2,0,5RRUNAW)
CALL ASSIGN(5,0,5RSUDAT)
USE STOP
CALL ODDHWD ( 5,INTYPE,INNAME )
IF ( INTYPE ) , ,54
CALL ASSIGN ( 5,0,INNAME,-4 )
CALL ASSIGN ( 5,0,INNAME,-3,INFILE,512 )
54 CALL CRTID(2HAW,1,1)
CALL FRAME

C
C DATA INPUT ^ NOMENCLATURE
C
C NN ,NO. OF ROUNDS
C JM1 ,NO. OF MATERIAL NOS
C LM1 ,NO. OF PROJECTILE NOS
C JM2 ,NO. OF SETS OF COMBINED MATERIALS
C LM2 ,NO. OF SETS OF COMBINED PROJECTILES
C JP1 ,CALLS PLOT FOR UNCOMBINED MATL AND PROJ NOS
C JP2 ,CALLS PLOT FOR COMBINED MATL AND PROJ NOS

```

C JP3 ,NO OF CURVE FAMILIES TO BE PLOTTED
C JDW ,NON ZERO VALUE WILL SUPPRESS INITIAL DATA LIST WRITES
C MJ(K) ,ORDERED LIST OF MATERIAL DESIGNATION NO.≥S
C ML(K) ,ORDERED LIST OF PROJECTILE DESIGNATION NO.≥S
C JM3(J) ,REFERENCE MATL NO WHEN SEVERAL MATL NOS ARE COMBINED
C MJ2(J,K) ,LIST OF MATL NOS SIMILAR TO MATL NO JM3(J)
C NJK(J) ,LENGTH OF MJ2(J,K) ARRAY
C LM3(J) ,REFERENCE PROJ NO WHEN SEVERAL PROJ NOS ARE COMBINED
C ML2(J,K) ,LIST OF PROJ NOS SIMILAR TO PROJ NO LM3(J)
C NJL(J) ,LENGTH OF ML2(J,K) ARRAY
C JP(K) ,MATL NOS FOR PLOTTED OUTPUT
C LP(K) ,PROJ NOS FOR PLOTTED OUTPUT
C NX(J) ,X AXIS OUTPUT QUANTITY FOR CURVE FAMILY J
C NY(J,K) ,ARRAY OF Y AXIS OUTPUT QUANTITIES FOR CURVE FAMILY J
C NN3(J) ,LENGTH OF NY(J,K) ARRAY

C IM(N) ,ROUND NO.
C JM(IM) ,MATERIAL DESIGNATION NO.
C KM(IM) ,MATERIAL LOT NO.
C LM(IM) ,PROJECTILE DESIGNATION NO.
C AM(IM) ,MATERIAL NAME
C AP(IM) ,PROJECTILE NAME
C AS(IM) ,PROJECTILE SERIAL NO.
C X(IM,1) ,MATERIAL SPECIFIC GRAVITY DIMENSIONLESS
C X(IM,2) ,PRE-IMPACT VELOCITY FT PER SEC
C X(IM,3) ,MINIMUM ESTIMATED BLAST INTENSITY $2.2E-06 * (Q^{*3})$
C X(IM,4) ,MAXIMUM ESTIMATED BLAST INTENSITY $2.2E-06 * (Q^{*3})$
C X(IM,5) ,TIME TO INITIAL REACTION MICROSECONDS
C X(IM,6) ,TIME TO START OF LARGE REACTION MICROSECONDS
C X(IM,7) ,CLOSE UP COLOR FRAMING RATE FRAMES PER SEC
C X(IM,8) ,AMBIENT TEMPERATURE DEGREES F
C X(IM,9) ,PRESSURE GAGE NO. 1 ,PSI
C X(IM,10) ,PRESSURE GAGE NO. 2 ,PSI
C X(IM,11) ,PRESSURE GAGE NO. 3 ,PSI
C X(IM,12) ,PRESSURE GAGE NO. 4 ,PSI
C X(IM,13) ,NO. OF FRAMES TO FIRST FIRE
C X(IM,14) ,NO. OF FRAMES TO SECOND FIRE
C X(IM,15) ,DISTANCE TO PRESSURE GAGE NO. 1 ,CM
C X(IM,16) ,DISTANCE TO PRESSURE GAGE NO. 2 ,CM
C X(IM,17) ,DISTANCE TO PRESSURE GAGE NO. 3 ,CM
C X(IM,18) ,DISTANCE TO PRESSURE GAGE NO. 4 ,CM

C X(IM,19) = X(IM, 2) * X(IM, 5)
C X(IM,20) = X(IM, 2) * X(IM, 6)
C X(IM,21) = X(IM,13) / X(IM, 7) * 1000000.
C X(IM,22) = X(IM,14) / X(IM, 7) * 1000000.
C X(IM,23) = X(IM,21) * X(IM, 2)
C X(IM,24) = X(IM,22) * X(IM, 2)
C X(IM,25) = EST STD 10 FT OVERPRESSURE ,PSI
C X(IM,26) = BLAST INTENSITY RELATED TO X(IM,25)

C JN(N) ,ROUND NO.S SORTED BY MATERIAL DESIGNATION NO.
C NJ(J) ,POUND NO.S SORTED BY MATERIAL AND PROJECTILE NO.S
C IV(L,N) ,ROUND NO.S SORTED BY MAT≥L,PROJ.,AND PREIMPACT VELOCITY
C NP(N) ,ROUND NO ARRAY CORRESPONDING TO IV(L,N),FOR CURVE PLOTS
C JM4(J) ,USED IN COMBINING MATL NOS
C LM4(J) ,USED IN COMBINING PROJ NOS
C XP(N) ,SUBROUTINE PLOT,X AXIS PLOT ARRAY
C YP(N) ,SUBROUTINE PLOT,Y AXIS PLOT ARRAY
C YQ(J,1) ,MIN Y AXIS SUBJ BLAST INTENSITY ESTIMATE

C YQ(J,2) ,MAX Y AXIS SUBJ BLAST INTENSITY ESTIMATE
C
C

JKL = -1
510 IF(JKL) 500, ,511
TITLE = XNAM
GO TO 2
500 READ (2,1) JKL,TITLE
WRITE(3,3) TITLE
IF(JKL) 2,2,
511 IF(INTYPE) 56, ,56
CALL ASSIGN (5,0,INNAME,-4)
CALL ASSIGN (5,0,INNAME,-3)
56 CALL EXIT
2 WRITE OUTPUT TAPE 3,43
READ (2,5) JM2,LM2,JP1,JP2,JP3,JDW
WRITE(3,7) JM2,LM2,JP1,JP2,JP3,JDW

C
C INPUT INSTRUCTIONS TO COMBINE MATERIALS AND PROJECTILES
C

CALL SETCH(30.,60.,1,0,0,0,0)
WRITE (100,45) TITLE
IF(JM2) ,24,
WRITE OUTPUT TAPE 3,43
WRITE OUTPUT TAPE 3,47
CALL SETCH(10.,56.)
WRITE OUTPUT TAPE 100,47
CALL SETCH(20.,54.)
DO 48 J = 1,JM2
READ (2,5) N,JM3(J),(MJ2(J,K),K = 1,N)
WRITE(3,7) N,JM3(J),(MJ2(J,K),K = 1,N)
WRITE(100,7) N,JM3(J),(MJ2(J,K),K = 1,N)
NJK(J) = N
48 CONTINUE
24 IF(LM2) ,26,
WRITE OUTPUT TAPE 3,43
WRITE OUTPUT TAPE 3,49
CALL SETCH(10.,30.)
WRITE OUTPUT TAPE 100,49
CALL SETCH(20.,28.)
DO 50 J = 1,LM2
READ (2,5) N,LM3(J),(ML2(J,K),K = 1,N)
WRITE(3,7) N,LM3(J),(ML2(J,K),K = 1,N)
WRITE(100,7) N,LM3(J),(ML2(J,K),K = 1,N)
NJL(J) = N
50 CONTINUE
26 CONTINUE
CALL FRAME
WRITE OUTPUT TAPE 3,43

C
C INPUT INSTRUCTIONS FOR PLOTTED OUTPUT
C

CALL SETCH(30.,60.,1,0,0,0,0)
WRITE (100,45) TITLE
IF(JP1) 40, ,40
IF(JP2) ,44,
40 CALL SETCH(10.,56.)
WRITE OUTPUT TAPE 100,51
WRITE OUTPUT TAPE 3,51
READ (2,5) JJ3,(JP(K),K = 1,JJ3)

```

WRITE(3,7) JJ3,(JP(K),K = 1,JJ3)
CALL SETCH(20.,54.)
WRITE(100,7) JJ3,(JP(K),K = 1,JJ3)
WRITE OUTPUT TAPE 3,43
CALL SETCH(10.,40.)
WRITE OUTPUT TAPE 100,53
WRITE OUTPUT TAPE 3,53
READ (2,5) LL3,(LP(K),K = 1,LL3)
WRITE(3,7) LL3,(LP(K),K = 1,LL3)
CALL SETCH(20.,38.)
WRITE(100,7) LL3,(LP(K),K = 1,LL3)
WRITE OUTPUT TAPE 3,43
CALL SETCH(10.,24.)
WRITE OUTPUT TAPE 100,55
WRITE OUTPUT TAPE 3,55
CALL SETCH(20.,22.)
DO 42 J = 1,JP3
READ (2,5) N,NX(J),(NY(J,K),K = 1,N)
WRITE(3,7) N,NX(J),(NY(J,K),K = 1,N)
WRITE(100,7) N,NX(J),(NY(J,K),K = 1,N)
NN3(J) = N

```

```

42 CONTINUE
44 CONTINUE
CALL FRAME

```

C

```

CALL SETCH(30.,60.,1,0,0,0,0)
WRITE (100,45) TITLE
CALL SETCH(40.,56.)
WRITE OUTPUT TAPE 100,11
CALL SETCH(40.,54.)
WRITE OUTPUT TAPE 100,13
CALL SETCH(40.,52.)
WRITE OUTPUT TAPE 100,15
CALL SETCH(40.,50.)
WRITE OUTPUT TAPE 100,17
CALL SETCH(40.,48.)
WRITE OUTPUT TAPE 100,85
CALL SETCH( 5.,46.)
WRITE OUTPUT TAPE 100,19
CALL SETCH( 5.,44.)
WRITE OUTPUT TAPE 100,21
CALL SETCH( 5.,42.)
WRITE OUTPUT TAPE 100,23
CALL SETCH( 5.,40.)
WRITE OUTPUT TAPE 100,25
CALL SETCH( 5.,38.)
WRITE OUTPUT TAPE 100,27
CALL SETCH( 5.,36.)
WRITE OUTPUT TAPE 100,29
CALL SETCH( 5.,34.)
WRITE OUTPUT TAPE 100,31
CALL SETCH( 5.,32.)
WRITE OUTPUT TAPE 100,33
CALL SETCH( 5.,30.)
WRITE OUTPUT TAPE 100,35
CALL SETCH( 5.,28.)
WRITE OUTPUT TAPE 100,37
CALL SETCH( 5.,26.)
WRITE OUTPUT TAPE 100,57
CALL SETCH( 5.,24.)

```

```

WRITE OUTPUT TAPE 100,59
CALL SETCH( 5.,22.)
WRITE OUTPUT TAPE 100,61
CALL SETCH( 5.,20.)
WRITE OUTPUT TAPE 100,63
CALL SETCH( 5.,18.)
WRITE OUTPUT TAPE 100,65
CALL SETCH(65.,46.)
WRITE OUTPUT TAPE 100,67
CALL SETCH(65.,44.)
WRITE OUTPUT TAPE 100,69
CALL SETCH(65.,42.)
WRITE OUTPUT TAPE 100,71
CALL SETCH(65.,40.)
WRITE OUTPUT TAPE 100,73
CALL SETCH(65.,38.)
WRITE OUTPUT TAPE 100,75
CALL SETCH(65.,36.)
WRITE OUTPUT TAPE 100,77
CALL SETCH(65.,34.)
WRITE OUTPUT TAPE 100,79
CALL SETCH(65.,32.)
WRITE OUTPUT TAPE 100,81
CALL SETCH(65.,30.)
WRITE OUTPUT TAPE 100,83
CALL SETCH(65.,28.)
WRITE OUTPUT TAPE 100,93
CALL SETCH(65.,26.)
WRITE OUTPUT TAPE 100,95
CALL FRAME

```

C

```

READ (2,1) JKL,XNAM

```

C

C

C INPUT MATERIAL NOS AND PROJECTILE NOS

C

```

WRITE OUTPUT TAPE 3,43
READ (5,5) NN,JM1,LM1
WRITE(3,7) NN,JM1,LM1
WRITE OUTPUT TAPE 3,43
WRITE OUTPUT TAPE 3,87
READ (5,5) (MJ(K),K = 1,JM1)
WRITE (3,7) (MJ(K),K = 1,JM1)
WRITE OUTPUT TAPE 3,43
WRITE OUTPUT TAPE 3,89
READ (5,5) (ML(K),K = 1,LM1)
WRITE (3,7) (ML(K),K = 1,LM1)

```

C

```

WRITE OUTPUT TAPE 3,43
WRITE OUTPUT TAPE 3,11
WRITE OUTPUT TAPE 3,13
WRITE OUTPUT TAPE 3,15
WRITE OUTPUT TAPE 3,17
WRITE OUTPUT TAPE 3,85
WRITE OUTPUT TAPE 3,19
WRITE OUTPUT TAPE 3,21
WRITE OUTPUT TAPE 3,23
WRITE OUTPUT TAPE 3,25
WRITE OUTPUT TAPE 3,27
WRITE OUTPUT TAPE 3,29

```

```

WRITE OUTPUT TAPE 3,31
WRITE OUTPUT TAPE 3,33
WRITE OUTPUT TAPE 3,35
WRITE OUTPUT TAPE 3,37
WRITE OUTPUT TAPE 3,57
WRITE OUTPUT TAPE 3,59
WRITE OUTPUT TAPE 3,61
WRITE OUTPUT TAPE 3,63
WRITE OUTPUT TAPE 3,65
WRITE OUTPUT TAPE 3,67
WRITE OUTPUT TAPE 3,69
WRITE OUTPUT TAPE 3,71
WRITE OUTPUT TAPE 3,73
WRITE OUTPUT TAPE 3,75
WRITE OUTPUT TAPE 3,77
WRITE OUTPUT TAPE 3,79
WRITE OUTPUT TAPE 3,81
WRITE OUTPUT TAPE 3,83
WRITE OUTPUT TAPE 3,93
WRITE OUTPUT TAPE 3,95
WRITE OUTPUT TAPE 3,91
WRITE OUTPUT TAPE 3,39

```

```

C
C INPUT SUSAN DATA RELATED TO ROUND NO
C

```

```

DO 4 N = 1,NN
READ (5,9) I,JMIP,KMIP,LMIP,AMIP,APIP,X1IP,X2IP,X3IP,X4IP,X5IP,
1 X6IP,X7IP,X8IP,I,X9IP,X10IP,X11IP,X12IP,X13IP,X14IP,X15IP,
2 X16IP,X17IP,X18IP,ASIP
IM(N) = I
JM(I) = JMIP
KM(I) = KMIP
LM(I) = LMIP
AM(I) = AMIP
AP(I) = APIP
AS(I) = ASIP
X(I,1) = X1IP
X(I,2) = X2IP
X(I,3) = X3IP
X(I,4) = X4IP
X(I,5) = X5IP
X(I,6) = X6IP
X(I,7) = X7IP
X(I,8) = X8IP
X(I,9) = X9IP
X(I,10) = X10IP
X(I,11) = X11IP
X(I,12) = X12IP
X(I,13) = X13IP
X(I,14) = X14IP
X(I,15) = X15IP
X(I,16) = X16IP
X(I,17) = X17IP
X(I,18) = X18IP

C
C CALL CALC(I)
C
IF(JDW) 4, ,4
WRITE (3,41) N,I,JM(I),LM(I),KM(I),AM(I),AP(I),AS(I),X(I,1),X(I,2)
1 ,X(I,3),X(I,4),X(I,5),X(I,6),X(I,7),X(I,8),X(I,9),X(I,10),X(I,11)

```

```

2 ,X(I,12),X(I,13),X(I,14),X(I,15),X(I,16),X(I,17),X(I,18),X(I,19)
3 ,X(I,20),X(I,21),X(I,22),X(I,23),X(I,24),X(I,25),X(I,26)
WRITE OUTPUT TAPE 3,43
4 CONTINUE

```

```

C
C SORT BY MATERIAL NO.,PROJECTILE NO.,AND VELOCITY
C

```

```

502 CONTINUE
WRITE (3,3) TITLE
WRITE OUTPUT TAPE 3,39
DO 14 K = 1,JM1
WRITE OUTPUT TAPE 3,43
N = 0
DO 6 I = 1,NN
I1 = IM(I)
IF( JM(I1)-MJ(K) ) 6, ,6
N = N + 1
JN(N) = IM(I)
6 CONTINUE
NT = N

```

```

C
DO 12 L = 1,LM1
J = 0
DO 8 N = 1,NT
N1 = JN(N)
IF( LM(N1)-ML(L) ) 8, ,8
J = J + 1
NJ(J) = JN(N)
8 CONTINUE
JT = J
NK(L) = JT

```

```

C
C MAKE EQUAL VELOCITIES SLIGHTLY DIFFERENT FOR SORTING
DO 22 J = 1,JT
I = NJ(J)
N = 0
DO 22 M = 1,JT
M1 = NJ(M)
IF( X(I,2)-X(M1,2) ) 22, ,22
N = N + 1
X(M1,2) = X(I,2) + FLOAT(N-1)*0.0001
22 CONTINUE

```

```

C
C SORT BY VELOCITY
DO 12 J = 1,JT
I = NJ(J)
N = 0
DO 10 M = 1,JT
M1 = NJ(M)
IF( X(I,2)-X(M1,2) ) 10, ,
N = N + 1
10 CONTINUE
IV(L,N) = I
12 CONTINUE

```

```

C
C OUTPUT SORTED DATA
DO 18 L = 1,LM1
NT = NK(L)
DO 16 N = 1,NT
IF( IV(L,N) ) ,16,
I = IV(L,N)

```



```

NP(N) = IV(L,N)
IF(JDW) 52, ,52
WRITE (3,41) N,I,JM(I),LM(I),KM(I),AM(I),AP(I),AS(I),X(I,1),X(I,2)
1 ,X(I,3),X(I,4),X(I,5),X(I,6),X(I,7),X(I,8),X(I,9),X(I,10),X(I,11)
2 ,X(I,12),X(I,13),X(I,14),X(I,15),X(I,16),X(I,17),X(I,18),X(I,19)
3 ,X(I,20),X(I,21),X(I,22),X(I,23),X(I,24),X(I,25),X(I,26)
WRITE OUTPUT TAPE 3,43
52 CONTINUE
IV(L,N) = 0
16 CONTINUE
IF(JP1) 20, ,20
IF(JP2) ,18,
20 JP1 = 0
DO 46 N = 1,JJ3
IF( MJ(K)-JP(N) ) 46, ,46
DO 46 M = 1,LL3
IF( ML(L)-LP(M) ) 46, ,46
CALL PLOT
46 CONTINUE
18 CONTINUE
14 CONTINUE

```

C
C COMBINE MATERIAL NO.S AND PROJECTILE NO.S
C

```

JDW = 0
JM5 = 0
IF(JM2) ,32,
DO 28 J = 1,JM2
DO 28 K = 1,JM1
IF( MJ(K)-JM3(J) ) 28, ,28
JM4(J) = K
28 CONTINUE
DO 30 J = 1,JM2
N1 = NJK(J)
DO 30 K = 1,N1
DO 30 I = 1,NN
I1 = IM(I)
IF( JM(I1)-MJ2(J,K) ) 30, ,30
M = JM4(J)
JM(I1) = MJ(M)
30 CONTINUE
JM5 = 1
JM2 = 0
32 IF(LM2) ,38,
DO 34 J = 1,LM2
DO 34 K = 1,LM1
IF( ML(K)-LM3(J) ) 34, ,34
LM4(J) = K
34 CONTINUE
DO 36 J = 1,LM2
N1 = NJL(J)
DO 36 K = 1,N1
DO 36 I = 1,NN
I1 = IM(I)
IF( LM(I1)-ML2(J,K) ) 36, ,36
M = LM4(J)
LM(I1) = ML(M)
36 CONTINUE
JM5 = 1
LM2 = 0

```

38 CONTINUE
IF(JM5) 502, ,502

GO TO 510

```
1 FORMAT(I1,12A6)
3 FORMAT(1H1,12A6)
5 FORMAT(14I5)
7 FORMAT(20I5)
9 FORMAT(I4,I3,A6,I2,2A6,F5.3,F5.0,2F5.1,3F6.0,F4.0/
1 I4,4F6.2,2F4.1,4F5.1,A6)
11 FORMAT(55H IM IS ROUND NO. )
13 FORMAT(55H JM IS MATERIAL DESIGNATION NO. )
15 FORMAT(55H KM IS MATERIAL LOT NO. )
17 FORMAT(55H LM IS PROJECTILE DESIGNATION NO. )
19 FORMAT(55H X(IM,1) IS MATERIAL SPECIFIC GRAVITY )
21 FORMAT(55H X(IM,2) IS PRE-IMPACT VELOCITY ,FT PER SEC )
23 FORMAT(55H X(IM,3) IS MIN. EST. BLAST INTENSITY ,2.2E-06Q**3)
25 FORMAT(55H X(IM,4) IS MAX. EST. BLAST INTENSITY ,2.2E-06Q**3)
27 FORMAT(55H X(IM,5) IS TIME TO INITIAL REACTION ,MICROSECS )
29 FORMAT(55H X(IM,6) IS TIME TO START OF LARGE REACTION,MICROSECS )
31 FORMAT(55H X(IM,7) IS CLOSEUP COLOR FRAMING RATE ,FRAMES/SEC )
33 FORMAT(55H X(IM,8) IS AMBIENT TEMPERATURE ,DEGREES F )
35 FORMAT(55H X(IM,9) IS PRESSURE GAGE NO. 1 ,PSI )
37 FORMAT(55H X(IM,10) IS PRESSURE GAGE NO. 2 ,PSI )
39 FORMAT(3X,1HN,4X,2HIM,3X,2HJM,3X,2HLM,5X,2HKM,7H EXPLOS,7H PROJEC,
1 7H SER NO,8H DENSITY,9H VELOCITY,25X,
2 10HX(IM,3) ,10HX(IM,4) ,10HX(IM,5) ,/70X,10HX(IM,6) ,
3 10HX(IM,7) ,10HX(IM,8) ,10HX(IM,9) ,10HX(IM,10) ,/70X,
4 10HX(IM,11) ,10HX(IM,12) ,10HX(IM,13) ,10HX(IM,14) ,
5 10HX(IM,15) ,/70X,10HX(IM,16) ,10HX(IM,17) ,10HX(IM,18) ,
6 10HX(IM,19) ,10HX(IM,20) ,/70X,10HX(IM,21) ,10HX(IM,22) ,
7 10HX(IM,23) ,10HX(IM,24) ,10HX(IM,25) ,/70X,10HX(IM,26) ,/)
41 FORMAT(I4,I6,2I5,1X,A6,1X,A6,1X,A6,1X,A6,F7.3,F8.1,26X,3F10.2/
1 (69X,5F10.2) )
43 FORMAT(/)
45 FORMAT(1X,12A6)
47 FORMAT(55H MATERIAL COMBINATIONS N,JM3(J),MJ2(J,K))
49 FORMAT(55H PROJECTILE COMBINATIONS N,LM3(J),ML2(J,K))
51 FORMAT(55H MATERIALS FOR PLOTTED OUTPUT JJ3,JP(K) )
53 FORMAT(55H PROJECTILES FOR PLOTTED OUTPUT LL3,LP(K) )
55 FORMAT(55H DESIGNATIONS OF PLOTTED VARIABLES N,NX(J),NY(J,K))
57 FORMAT(55H X(IM,11) IS PRESSURE GAGE NO. 3 ,PSI )
59 FORMAT(55H X(IM,12) IS PRESSURE GAGE NO. 4 ,PSI )
61 FORMAT(55H X(IM,13) IS NO. OF FRAMES TO FIRST FIRE )
63 FORMAT(55H X(IM,14) IS NO. OF FRAMES TO SECOND FIRE )
65 FORMAT(55H X(IM,15) IS DIST TO PRESS GAGE NO. 1 ,CM )
67 FORMAT(55H X(IM,16) IS DIST TO PRESS GAGE NO. 2 ,CM )
69 FORMAT(55H X(IM,17) IS DIST TO PRESS GAGE NO. 3 ,CM )
71 FORMAT(55H X(IM,18) IS DIST TO PRESS GAGE NO. 4 ,CM )
73 FORMAT(55H X(IM,19) = X(IM,2) * X(IM,5) )
75 FORMAT(55H X(IM,20) = X(IM,2) * X(IM,6) )
77 FORMAT(55H X(IM,21) = X(IM,13) / X(IM,7) * 1000000. )
79 FORMAT(55H X(IM,22) = X(IM,14) / X(IM,7) * 1000000. )
81 FORMAT(55H X(IM,23) = X(IM,2) * X(IM,21) )
83 FORMAT(55H X(IM,24) = X(IM,2) * X(IM,22) )
85 FORMAT(55H AS IS PROJECTILE SERIAL NO. )
87 FORMAT(55H LIST OF MATERIAL NO.S MJ(K) )
89 FORMAT(55H LIST OF PROJECTILE NO.S ML(K) )
91 FORMAT(////////)
```

```

93 FORMAT(55H X(IM,25) IS EST STD 10 FT OVERPRESSURE      ,PSI
95 FORMAT(55H X(IM,26) IS BLAST INTENSITY RELATED TO X(IM,25)

```

```

END
LIST 8
CARDS COLUMN
FORTRAN      CALC
SUBROUTINE CALC(I)

```

```

USE STOR

```

```

X(I,19) = X(I,2) * X(I,5)
X(I,20) = X(I,2) * X(I,6)
IF(X(I,7)) ,2,
X(I,21) = X(I,13) / X(I,7) * 1000000.
X(I,22) = X(I,14) / X(I,7) * 1000000.

```

```

2 CONTINUE

```

```

X(I,23) = X(I,2) * X(I,21)
X(I,24) = X(I,2) * X(I,22)

```

```

C ESTIMATE STD. 10 FT. OVERPRESSURE FROM WEIGHTED AVERAGE MULTIPLE OF
C PRESSURE GAGE DISTANCES AND READINGS.

```

```

SPD = 0.
XK = 0.
QR = 0.
DO 16 N = 1,4
L = 8 + N
M = 14 + N
IF( X(I,L) ) , ,4
PX = 0.
GO TO 6
4 PX = X(I,L)
6 IF( X(I,L)-100. ) 8, ,
PX = 0.
QR = 100.
8 DX = X(I,M)
IF( PX ) 16,16,
XK = XK + 1.
IF( I-37 ) , ,121
GO TO (120,120,140,140),N
121 IF( I-113 ) , ,122
GO TO (12,120,120,140),N
122 IF( I-232 ) , ,123
GO TO (12,12,120,120),N
123 IF( I-293 ) , ,124
GO TO (12,12,12,12),N
124 GO TO (10,12,12,14),N
120 SPD = SPD + PX*DX*1.14
GO TO 16
140 SPD = SPD + PX*DX*1.5
GO TO 16
10 SPD = SPD + PX*DX*0.9
GO TO 16
12 SPD = SPD + PX*DX
GO TO 16
14 SPD = SPD + PX*DX*1.1
16 CONTINUE
IF( XK ) 18,18,
SPD = SPD / XK

```

X(I,25) = SPD / 305.
1A CONTINUE

ESTIMATE BLAST INTENSITY FROM SPD

IF(XK-2.) ,20,20
IF(QR) 20,20,34
20 IF(SPD-1063.) ,22,24
QR = 9.57547E-06 * SPD * SPD
GO TO 34
22 QR = 10.82
GO TO 34
24 IF(SPD-1558.) 32, ,26
QR = 31.18
GO TO 34
26 IF(SPD-2621.) 32, ,28
QR = 79.1
GO TO 34
28 IF(SPD-3107.) 32, ,30
QR = 93.3
GO TO 34
30 IF(SPD-3600.) 32, ,
QR = 100.
GO TO 34
32 CONTINUE
A1 = SPD - 341.
A2 = SPD - 1063.
A3 = SPD - 1558.
A4 = SPD - 2621.
A5 = SPD - 3107.
QRT = 0.20210/A1 - 9.50678/A2 + 31.43318/A3 - 43.09922/A4
1 + 21.91897/A5
QRB = 0.18045/A1 - 0.87863/A2 + 1.00812/A3 - 0.54487/A4
1 + 0.23493/A5
QR = QRT / QRB
34 X(I,26) = QR

RETURN
END
LIST 8
CARDS COLUMN
FORTRAN PLOT
SUBROUTINE PLOT

USE STOR

NTT = NT
DO 10 I = 1,JP3
N3 = NN3(I)
KX = NX(I)
DO 2 N = 1,NT
J = NP(N)
XP(N) = X(J,KX)
2 CONTINUE
CALL AMINMX(XP,1,NT,1,XMIN,XMAX)

DO 104 M = 1,N3
NT = NTT
KY = NY(I,M)

C SET UP STORAGE ARRAYS TO PLOT RANGE WHEN BLAST SIZE IS SUBJECTIVE

IF(KY-4) 8, ,8

J = 0

K = 0

DO 14 N = 1,NT

L = NP(N)

IF(X(L,4)-X(L,3)) ,12,

J = J + 1

XQ(J) = X(L,KX)

YQ(J,1) = X(L,3)

YQ(J,2) = X(L,4)

12 CONTINUE

K = K + 1

NP(K) = L

XP(K) = X(L,KX)

YP(K) = X(L,4)

14 CONTINUE

NT = K

NTQ = J

8 CONTINUE

DO 4 N = 1,NT

J = NP(N)

YP(N) = X(J,KY)

4 CONTINUE

CALL AMINMX(YP,1,NT,1,YMIN,YMAX)

IF(KY-4) 106, ,106

YMIN = 0.

YMAX = 150.

106 CONTINUE

IF(KY-26) 108, ,108

YMIN = 0.

YMAX = 150.

108 CONTINUE

IF(KY-25) 110, ,110

YMIN = 0.

YMAX = 15.

110 CONTINUE

IF(KX-2) 6, ,6

CALL GRAV

GO TO 104

6 CALL GRAF

104 CONTINUE

10 CONTINUE

RETURN

END

LIST 8

CARDS COLUMN

FORTRAN

SUBROUTINE GRAV

GRAV

USE STOR

M = 0

N = 0

XMIN1 = XMIN

XMAX1 = XMAX

DO 4 J = 1,NT

```

      N1 = NP(J)
      IF( XP(N1)-400. ) , ,2
      N = N + 1
2    IF( XP(N1)-1000. ) , ,4
      M = M + 1
4    CONTINUE

      MQ = 0
      NQ = 0
      LQ = 0
      IF( KY-4 ) 20, ,20
      DO 14 J = 1,NTQ
      LQ = LQ + 1
      IF( XQ(J)-400. ) , ,12
      NQ = NQ + 1
12   IF( XQ(J)-1000. ) , ,14
      MQ = MQ + 1
14   CONTINUE
20   CONTINUE

      N1 = NP(1)
      N2 = NT
      N3 = LQ
      DO 10 J = 1,3
      IF( J-2 ) 8,6,
      XMIN = 0.
      XMAX = 400.
      N2 = N
      N3 = NQ
      GO TO 8
6    XMIN = 0.
      XMAX = 1000.
      N2 = M
      N3 = MQ
8    CONTINUE
      CALL SETPCH(1,0,0,0,1)
      CALL MAPG(XMIN,XMAX,YMIN,YMAX)
      CALL POINTC(1H*,XP,YP,N2,1,1)

      IF( KY-4 ) 18, ,18
      DO 16 L = 1,N3
      X1 = XQ(L)
      Y1 = YQ(L,1)
      X2 = X1
      Y2 = YQ(L,2)
      CALL LINE(X1,Y1,X2,Y2,1,0)
16   CONTINUE
18   CONTINUE

      CALL SETCH(90.,4.,1,0,0,0,0)
      WRITE (100,1) AM(N1),AP(N1),JM(N1),LN(N1)
      CALL SETCH(20.,4.)
      WRITE OUTPUT TAPE 100,5,TITLE
      CALL SETCH(60.,2.)
      WRITE (100,3) KY
      CALL FRAME
10   CONTINUE
      N2 = NT
      XMIN = XMIN1
      XMAX = XMAX1

```

```

C
1 FORMAT(1X,A6,5X,A6,2I6)
3 FORMAT(5HX(IM,,I2,27H) VERSUS PREIMPACT VELOCITY)
5 FORMAT(1X,12A6)

```

```

C
RETURN
END
*
LIST 8
*
CARDS COLUMN
*
FORTRAN          GRAF
SUBROUTINE GRAF

```

```

C
USE STOR

```

```

C
N1 = NR(1)
CALL SETPCH(1,0,0,0,1)
CALL MAPG(XMIN,XMAX,YMIN,YMAX)
CALL POINTC(1H*,XP,YP,NT,1,1)

```

```

C
IF( KY-4 ) 4, ,4
DO 2 L = 1,NTQ
X1 = XQ(L)
Y1 = YQ(L,1)
X2 = X1
Y2 = YQ(L,2)
CALL LINE(X1,Y1,X2,Y2,1,0)
2 CONTINUE
4 CONTINUE

```

```

C
CALL SETCH(90.,4.,1,0,0,0,0)
WRITE (100,1) AM(N1),AP(N1),JM(N1),LM(N1)
CALL SETCH(20.,4.)
WRITE OUTPUT TAPE 100,5,TITLE
CALL SETCH(60.,2.)
WRITE (100,3) KY,KX
CALL FRAME

```

```

C
1 FORMAT(1X,A6,5X,A6,2I6)
3 FORMAT(5HX(IM,,I2,14H) VERSUS X(IM,,I2,1H))
5 FORMAT(1X,12A6)

```

```

C
RETURN
END
*
DATA

```

LX07 FAMILY (A) , EXPLOSIVENESS AND TIMING

IM IS ROUND NO.

JM IS MATERIAL DESIGNATION NO.

KM IS MATERIAL LOT NO.

LM IS PROJECTILE DESIGNATION NO.

AS IS PROJECTILE SERIAL NO.

X(IIM,1) IS MATERIAL SPECIFIC GRAVITY		X(IIM,16) IS DIST TO PRESS GAGE NO. 2	,CM
X(IIM,2) IS PRE-IMPACT VELOCITY	,FT PER SEC	X(IIM,17) IS DIST TO PRESS GAGE NO. 3	,CM
X(IIM,3) IS MIN. EST. BLAST INTENSITY	,2.2E-060±3	X(IIM,18) IS DIST TO PRESS GAGE NO. 4	,CM
X(IIM,4) IS MAX. EST. BLAST INTENSITY	,2.2E-060±3	X(IIM,19) = X(IIM, 2) * X(IIM, 5)	
X(IIM,5) IS TIME TO INITIAL REACTION	,MICROSECS	X(IIM,20) = X(IIM, 2) * X(IIM, 6)	
X(IIM,6) IS TIME TO START OF LARGE REACTION,MICROSECS		X(IIM,21) = X(IIM,13) / X(IIM, 7) * 1000000.	
X(IIM,7) IS CLOSEUP COLOR FRAMING RATE	,FRAMES/SEC	X(IIM,22) = X(IIM,14) / X(IIM, 7) * 1000000.	
X(IIM,8) IS AMBIENT TEMPERATURE	,DEGREES F	X(IIM,23) = X(IIM, 2) * X(IIM,21)	
X(IIM, 9) IS PRESSURE GAGE NO. 1	,PSI	X(IIM,24) = X(IIM, 2) * X(IIM,22)	
X(IIM,10) IS PRESSURE GAGE NO. 2	,PSI	X(IIM,25) IS EST STD 10 FT OVERPRESSURE	,PSI
X(IIM,11) IS PRESSURE GAGE NO. 3	,PSI	X(IIM,26) IS BLAST INTENSITY RELATED TO X(IIM,25)	
X(IIM,12) IS PRESSURE GAGE NO. 4	,PSI		
X(IIM,13) IS NO. OF FRAMES TO FIRST FIRE			
X(IIM,14) IS NO. OF FRAMES TO SECOND FIRE			
X(IIM,15) IS DIST TO PRESS GAGE NO. 1	,CM		

FIGURE 45

SDLST OUTPUT VARIABLE DEFINITIONS

RELATIVE ENERGY RELEASE VS. PRE-IMPACT VELOCITY
ESTIMATED FROM TRANSIT TIME DATA
FOR A FAMILY OF SIX LX07 TYPE MATERIALS

FIGURE 46

RELATIVE ENERGY RELEASE VS. PRE-IMPACT VELOCITY
ESTIMATED FROM PEAK OVERPRESSURE READINGS
FOR A FAMILY OF SIX LX07 TYPE MATERIALS

FIGURE 47

FIGURE 48

STANDARD 10 FT. OVERPRESSURE VS. PRE-IMPACT VELOCITY
ESTIMATED FROM PEAK OVERPRESSURE READINGS
FOR A FAMILY OF SIX LX07 TYPE MATERIALS

APPENDIX D

CODE HSPCD

APPENDIX D

Code HSPCD was written to process the Fastax camera records of projectile body motion versus time. Two methods were used to read the film. First the picture was projected against the wall. This gave a large image with indistinct edges. The film reader used a ruler to track the frame by frame motion of the projectile. Second, the picture was projected on a Recordak screen. This gave a fairly small, brighter image with sharper appearing edges. Here, the film reader used a set of dividers to track the frame by frame motion of the projectile body. The Recordak screen approach proved to be a faster process.

With either approach, the quality of the record was affected by the background lighting level at the test range, by variations in lighting level resulting from the impact indicating squib lights, miscellaneous shot debris tending to obscure the picture, and by the graininess of the film itself. The "as read" record by either process, in most instances was "noisy". A total of 52 separate records were read. Many of these were high velocity impact records in which the data resolution was too poor to show anything other than the level of impact velocity. Figures 26 through 32 illustrate the noise level in several lower velocity useful records*.

To compensate for the data noise, HSPCD performed three operations on the original displacement-time data points. (1) Straight line least squares fits were performed before impact and on the five points following impact, including the impact point. Two numerical averaging or "filtering" schemes were employed to smooth the data points. (2) The first order filter performed a continuing weighted average of three successive points. (3) The second order filter performed a continuing, weighted average of six successive points. As explained in Reference 10, these averaging processes are equivalent to Fourier analysis smoothing techniques in which higher frequency behavior including the data sampling frequency is greatly suppressed. In effect these numerical filters operate as though the data points were converted into electrical signals and were then processed through electrical filtering circuits.

HSPCD also performed a numerical differentiation operation on both sets of filtered points to obtain filtered velocity. The nature of the filtering process is such to round out discontinuous changes in "real" projectile velocity. However, the filtered values of velocity in between the discontinuous changes tend to be accurate. In analysing the records leading to the data tabulated in Table 4 of Appendix A, both displacement and velocity records were considered. The data points* plotted on Figures 26 through 32 of Section 3, are the original measured data points prior to smoothing.

* ibid pages 33 through 39

The listing of Code HSPCD is next included followed by the plotted records for displacement and velocity versus time for Round 833. These are Figures 49, 50, 51 and 52.*

* ibid, pages 108. 109 110 and 111

```

*ID 394CG8 HSPCD WESTON 80XX94
*B EXECUTE 5 MINUTES
* XEQ
* DUMP(OCT,DEC)
* LIST 8
* FORTRAN STORE
* SUBROUTINE STORE
C
CLICHE STOR
C
PARAMETER( J1 = 100 )
C
COMMON/NAM2 / Y(J1),X(J1),Y1(J1),X1(J1),Y2(J1),X2(J1),Y3(J1),
1 X3(J1),SL(J1),YL(J1),XL(J1),G(J1),S(J1),H(J1),SH(J1),W(J1),
2 COMENT(12),COMEN2(12),TITLE(12)
C
COMMON JJ,JV0,JAI,NI,NR
C
ENDCLICHE
USE STOR
RETURN
END
* LIST 8
* FORTRAN HSPCD
C
USE STOP
C
C JJ IS TOTAL LENGTH OF ARRAY
C NI IS INDEX AT IMPACT
C JV0 IS LENGTH OF ARRAY BEFORE IMPACT
C JAI IS LENGTH OF ARRAY AFTER IMPACT,INCLUDING IMPACT
C NR IS INDEX OF FIRST VISIBLE REACTION
C NE IS INDEX OF FIRST MAJOR REACTION
C FP IS CAMERA FRAMING RATE
C SF IS SCALE FACTOR USED IN DIRECT MEASUREMENTS
C Y(J1) IS READ IN ARRAY
C
CALL CRTID(2HAW,1,1)
CALL FRAME
C
2 READ (2,1) JKL,KLJ,TITLE
IF(JKL) 4,4,
CALL EXIT
4 IF(KLJ) 54,54,
READ (2,27) COMENT
READ (2,27) COMEN2
54 READ (2,3) JJ,NI,NR,NE
READ (2,5) SF,FR
READ (2,7) (Y(J),J = 1,JJ)
1 FORMAT(I1,I1,12A6)
27 FORMAT(12A6)
3 FORMAT(14I5)
5 FORMAT(F6.2,F6.0)
7 FORMAT(10F6.2)
WRITE (3,9) TITLE
WRITE (3,3) JJ,NI,NR,NE
WRITE (3,11) SF,FR
WRITE (3,13) (Y(J),J = 1,JJ)
9 FORMAT(1H1,12A6)
11 FORMAT(2F10.2)

```

13 FORMAT(10F10.2)

JAI = JJ - NI + 1
JVO = NI - 1
JJJ = JJ + 1

DTS = 1.E+06 / FR
YNI = Y(NI)
XNI = 0.
DO 6 J = 1, JJ
XK = J - NI
X(J) = XK * DTS
Y(J) = (Y(J) - YNI) / SF * 3.165
X1(J) = X(J)
Y1(J) = Y(J)

6 CONTINUE

WRITE (3,15) (J,X(J),Y(J),J = 1, JJJ)
15 FORMAT(I10,1P2E10.3)

DO 8 J = 1, NI
X2(J) = X(J)
Y2(J) = Y(J)

8 CONTINUE

DO 10 J = NI, JJJ
K = J - NI + 1
X3(K) = X(J)
Y3(K) = Y(J)

10 CONTINUE

BEST LEAST SQUARES STRAIGHT LINE FITS

CALL LINLSQ(X2,Y2,0.,JVO,A,B,C)
V02 = -A / B
BL2 = -C / B
CALL LINLSQ(X3,Y3,0.,5,A,B,C)
V03 = -A / B
BL3 = -C / B

DO 26 J = 1, JJ
X(J) = X1(J)
Y(J) = Y1(J)

26 CONTINUE

DO 14 J = 1, JJJ
IF(J-NI) , , 12
SL(J) = V02
XL(J) = X(J)
YL(J) = BL2 + V02*XL(J)
GO TO 14

12 SL(J) = V03
XL(J) = X(J-1)
YL(J) = BL3 + V03*XL(J)

14 CONTINUE

OVERALL SINGLE FILTER FIT

JJ4 = JJ - 4
JJ3 = JJ - 3
JJ2 = JJ - 2


```

JJ1 = JJ - 1
DO 16 K = 2, JJ1
J = K - 1
L = K + 1
G(K) = ( Y(J) + Y(K) + Y(L) ) / 3.
16 CONTINUE
G(1) = 2.*G(2) - G(3)
G(JJ) = 2.*G(JJ1) - G(JJ2)
DO 18 K = 2, JJ1
J = K - 1
L = K + 1
S(K) = ( G(L) - G(J) ) / 2. / DTS
18 CONTINUE
S(1) = S(2)
S(JJ) = 2.*S(JJ1) - S(JJ2)

```

C
C OVERALL DOUBLE FILTER FIT
C

```

DO 20 L = 4, JJ2
I = L - 3
J = L - 2
K = L - 1
M = L + 1
N = L + 2
H(L) = ( Y(I)+Y(N) + 2.*(Y(J)+ Y(M)) + 3.*(Y(K)+Y(L)) ) / 12.
20 CONTINUE
DO 22 L = 4, JJ3
M = L + 1
H(L) = ( H(L) + H(M) ) / 2.
22 CONTINUE
H(3) = 2.*H(4) - H(5)
H(2) = G(2)
H(1) = G(1)
H(JJ2) = 2.*H(JJ3) - H(JJ4)
H(JJ1) = G(JJ1)
H(JJ) = G(JJ)
DO 24 K = 2, JJ1
J = K - 1
L = K + 1
SH(K) = ( H(L) - H(J) ) / 2. / DTS
24 CONTINUE
SH(1) = SH(2)
SH(JJ) = 2.*SH(JJ1) - SH(JJ2)

```

C
C WRITE OUTPUT
C

```

WRITE (3,17) TITLE, (J,X(J),Y(J),G(J),H(J),S(J),SH(J),J,
1 XL(J),YL(J),SL(J),J = 1, JJJ)
17 FORMAT(1H1,19X,12A6//36H OUTPUT DISPLACEMENTS AND VELOCITIES//
1(I5,1P6E11.3,I10,3E11.3) )

```

C
C PLOT OUTPUT
C

```

CALL AMINMX(X,1,JJ,1,XMIN,XMAX)
XMAX = 1.1*XMAX
XMIN = 1.1*XMIN
CALL AMINMX(Y,1,JJ,1,YMIN,YMAX)
YMAX = 1.1*YMAX
YMIN = 1.1*YMIN
CALL MAPG(XMIN,XMAX,YMIN,YMAX)

```

```

CALL SETPCH(1,0,0,0,10)
CALL POINTC(1H*,X,Y,JJ,1,1)
CALL SETCRT(1.,1.,1,219)
CALL TRACE(XL,YL,JJJ,1,1)
CALL SETCRT(1.,1.,1,1023)
CALL TRACE(X,G,JJ,1,1)
CALL SETCH(60.,12.,1,0,0,0,0)
WRITE (100,19) TITLE
CALL SETCH(30.,16.)
IF(NR) , ,30
WRITE (100,21)
FIN
21 FORMAT(21H NO OBSERVED REACTION)
GO TO 32
30 CONTINUE
TNI = X(NR)
NR = NR - NI
WRITE (100,23) TNI,NR
23 FORMAT(20H INITIAL REACTION AT, F5.0 ,14H MICROSECONDS,,I3,20H FR
1AMES AFTER IMPACT)
32 IF(NE) 34,34,
NE = NE - NI
TNE = DTS * FLOATF(NE)
CALL SETCH(30.,18.)
WRITE (100,25) TNE,NE
25 FORMAT(20H LARGER REACTION AT, F5.0 ,14H MICROSECONDS,,I3,20H FR
1AMES AFTER IMPACT)
34 CONTINUE
IF(KLJ) 56,56,
CALL SETCH(30.,20.)
WRITE (100,19) COMENT
CALL SETCH(30.,22.)
WRITE (100,19) COMEN2
56 CONTINUE
CALL SETCH(60.,2.)
CALL CRTBCD(38H DISPLACEMENT VERSUS TIME,FIRST FILTER)
CALL FRAME
CALL MAPG(XMIN,XMAX,YMIN,YMAX)
CALL SETPCH(1,0,0,0,10)
CALL POINTC(1H*,X,Y,JJ,1,1)
CALL SETCRT(1.,1.,1,219)
CALL TRACE(XL,YL,JJJ,1,1)
CALL SETCRT(1.,1.,1,447)
CALL TRACE(X,H,JJ,1,1)
CALL SETCH(60.,12.,1,0,0,0,0)
WRITE (100,19) TITLE
CALL SETCH(30.,16.)
IF(NR) , ,36
WRITE (100,21)
FIN
GO TO 38
36 CONTINUE
WRITE (100,23) TNI,NR
38 IF(NE) 40,40,
CALL SETCH(30.,18.)
WRITE (100,25) TNE,NE
40 CONTINUE
IF(KLJ) 58,58,
CALL SETCH(30.,20.)
WRITE (100,19) COMENT

```

```

CALL SETCH(30.,22.)
WRITE (100,19) COMEN2
58 CONTINUE
CALL SETCH(60.,2.)
CALL CRTBCD(39H DISPLACEMENT VERSUS TIME,SECOND FILTER)
CALL FRAME

C
CALL AMINMX(S,1,JJ,1,SMIN,SMAX)
SMIN = 0.
SMAX = 1.1 * SMAX
CALL MAPG(XMIN,XMAX,SMIN,SMAX)
CALL SETCRT(1.,1.,1,219)
CALL TRACE(XL,SL,JJJ,1,1)
CALL SETCRT(1.,1.,1,1023)
CALL TRACE(X,S,JJ,1,1)
CALL SETCH(60.,12.,1,0,0,0,0)
WRITE (100,19) TITLE
CALL SETCH(30.,16.)
IF(NR) , ,42
WRITE (100,21)
FIN
GO TO 44
42 CONTINUE
WRITE (100,23) TNI,NR
44 IF(NE) 46,46,
CALL SETCH(30.,18.)
WRITE (100,25) TNE,NE
46 CONTINUE
IF(KLJ) 60,60,
CALL SETCH(30.,20.)
WRITE (100,19) COMENT
CALL SETCH(30.,22.)
WRITE (100,19) COMEN2
60 CONTINUE
CALL SETCH(60.,2.)
CALL CRTBCD(34H VELOCITY VERSUS TIME,FIRST FILTER)
CALL FRAME
CALL MAPG(XMIN,XMAX,SMIN,SMAX)
CALL SETCRT(1.,1.,1,219)
CALL TRACE(XL,SL,JJJ,1,1)
CALL SETCRT(1.,1.,1,447)
CALL TRACE(X,SH,JJ,1,1)
CALL SETCH(60.,12.,1,0,0,0,0)
WRITE (100,19) TITLE
19 FORMAT(1X,12A6)
CALL SETCH(30.,16.)
IF(NR) , ,48
WRITE (100,21)
FIN
GO TO 50
48 CONTINUE
WRITE (100,23) TNI,NR
50 IF(NE) 52,52,
CALL SETCH(30.,18.)
WRITE (100,25) TNE,NE
52 CONTINUE
IF(KLJ) 62,62,
CALL SETCH(30.,20.)
WRITE (100,19) COMENT
CALL SETCH(30.,22.)

```

```

WRITE (100,19) COMEN2
62 CONTINUE
CALL SETCH(60.,2.)
CALL CRTBCD(35H VELOCITY VERSUS TIME,SECOND FILTER)
CALL FRAME

```

```

C
C
ISTART = .LOC. Y
ISTOP = .LOC. TITLE(12)
LENGTH = ISTOP - ISTART + 1
DO 28 I = 1,LENGTH
Y(I) = 0.

```

```

28 CONTINUE

```

```

C
GO TO 2
END

```

```

* LIST 8

```

```

* FORTRAN LINLSQ E2.2-006

```

```

SUBROUTINE LINLSQ (X,Y,W,N, A,B,C)

```

```

CODE TO FIT THE LINEAR FUNCTION Y = M*X + BL .

```

```

C LEAST SQUARES FIT. (WEIGHTED IF W(1) POSITIVE.)

```

```

C OUTPUT VALUES ARE A, B, C IN  $A*X + B*Y + C = 0$ .

```

```

C IF B=0, SINGULAR SYSTEM. (VERTICAL LINE OR INCONSISTENT DATA.)

```

```

C IF B.NE.0, THEN  $M = -A/B$ ,  $BL = -C/B$ .
C

```

```

USE STOR

```

```

C
SX = 0.

```

```

SY = 0.

```

```

SXX = 0.

```

```

SXY = 0.

```

```

IF (W(1)) , ,10

```

```

C UN-WEIGHTED FIT...

```

```

1 SW = N

```

```

DO 5 I=1,N

```

```

SX = SX + X(I)

```

```

SY = SY + Y(I)

```

```

SXX = SXX + X(I)*X(I)

```

```

SXY = SXY + X(I)*Y(I)

```

```

5 CONTINUE

```

```

GO TO 20

```

```

C WEIGHTED FIT...

```

```

10 SW = 0.

```

```

DO 15 I=1,N

```

```

SW = SW + W(I)

```

```

SX = SX + X(I)*W(I)

```

```

SY = SY + Y(I)*W(I)

```

```

SXX = SXX + X(I)*X(I)*W(I)

```

```

SXY = SXY + X(I)*Y(I)*W(I)

```

```

15 CONTINUE

```

```

20 CONTINUE

```

```

A = SX*SY - SW*SXY

```

```

B = SW*SXX - SX*SX

```

```

C = SX*SXY - SY*SXX

```

```

RETURN

```

```

END

```

```

* DATA

```

```

1 833 PBX9404 107FPS SUSAN TEST DATA

```

```

ANY ARBITRARY COMMENT CAN BE MADE HERE IN A FIELD OF 72

```

```

A 2ND COMMENT MAY BE MADE HERE , ALSO IN A FIELD OF 72.

```

```

POSITION

```

```

72

```

17 8 16 18
 43.8010540.
 8.50 9.00 9.75 10.25 11.00 11.40 12.10 12.70 13.00 13.50
 13.90 14.25 14.35 14.45 14.55 14.70 14.90
 835 PBX9404 103FPS SUSAN TEST DATA
 22 10
 43.8010500.
 7.30 7.90 8.10 8.50 9.00 9.60 10.00 10.60 11.60 12.10
 12.30 12.50 12.70 13.30 13.40 13.70 13.70 13.40 13.50 13.00
 13.00 13.00
 818 PBX9404 144FPS SUSAN TEST DATA
 14 10 13 15
 43.8510000.
 5.30 5.70 6.50 7.30 8.20 9.10 9.90 10.30 11.20 12.60
 12.60 13.70 14.20 14.80
 1 235 LX04 144FPS SUSAN TEST DATA
 ORIG RUN PTS 9*10 LOOKED LIKE DUPLICATES.THEY ARE DROPPED HERE.

34 11 16 34
 64.40 8700.
 -13.15-12.35 -9.90 -9.20 -7.60 -6.60 -4.90 -4.30 -1.90 -1.30
 -0.55 1.50 2.70 3.65 4.20 4.90 5.75 6.50 6.50 7.70
 7.95 8.65 8.70 9.50 9.75 10.35 10.50 11.60 12.15 12.35
 12.75 13.35 13.85 14.35
 280 RX04AC 197FPS SUSAN TEST DATA
 22 14 15 22
 63.40 9500.
 -12.35-10.35 -8.75 -6.15 -5.30 -2.80 -1.50 -0.70 0.70 1.40
 2.80 4.35 5.65 8.00 9.35 10.90 12.10 13.10 13.50 16.15
 17.30 17.90
 590 LX04 268FPS SUSAN TEST DATA
 14 10 14
 43.4010200.
 2.50 3.70 5.20 6.40 8.10 9.10 10.60 12.20 13.60 15.00
 16.40 17.90 19.15 20.20
 587 LX04 498FPS SUSAN TEST DATA
 14 10 17
 43.4010800.
 -8.75 -6.20 -3.90 -1.35 1.20 3.50 6.50 8.35 11.40 14.10
 16.20 18.00 20.50 22.80
 1 589 RX04P1 SUSAN TEST DATA

CASE BREAK 6 FRAMES AFTER IMPACT, BALLOONED CASE 5 FRAMES AFTER IMPACT.
 SUDDEN VELOCITY CHANGE OCCURS AT CASE BALLOONING AND FRACTURE

22 9 21 23
 43.1010400.
 3.00 4.65 5.50 6.60 8.00 9.15 10.10 11.10 12.10 13.40
 14.40 15.50 16.40 17.30 18.35 18.70 18.95 19.85 20.55 21.40
 21.40 22.40
 1 END OF DATA

HSPCD DISPLACEMENT VERSUS TIME, FIRST FILTER
 ROUND 833

FIGURE 49

HSPCD DISPLACEMENT VERSUS TIME, SECOND FILTER
ROUND 833

FIGURE 51
 HSPCD VELOCITY VERSUS TIME, FIRST FILTER
 ROUND 833

FIGURE 52
HSPCD VELOCITY VERSUS TIME, SECOND FILTER
ROUND 833

APPENDIX E

CODE HEMP MODEL

APPENDIX E

A Code HEMP¹² model of the front end of the containment cap of the Susan Test projectile has been constructed, with 36 axial zones and 21 radial zones, as illustrated on Figures 53 and 59. The left hand boundary contacts an immovable target wall. The right hand boundary is caused to approach the wall at a constant velocity. To date, two code runs have been made, both with a right hand boundary velocity of 100 FPS.

The case material is 6061 aluminum. The explosive filler was taken to be an elastic-perfectly plastic material with the elastic properties of LX04. The two code runs differed in the magnitude of the assumed filler material yield strength. The first run assumed a yield strength value of 14503 psi; the second run assumed a value of 1450 psi. In comparing these two code runs note that for the same displacement of the right hand boundary, 0.348 ins., the weaker filler material resulted in a clearly mushroomed shape of case in the region adjacent to the target, Figure 55. On the other hand, front end mushroom distortion was not so marked when the stronger material was assumed. Both the Fastax camera records and recovered unreacted Susan Test samples exhibit clearly mushroomed case distortion similar to that for the assumed weaker filler material.

The front "lens" of the aluminum case adjacent to the target, separated in a circular fracture after a displacement of the right hand boundary of 0.024 ins. for the 1450 psi filler material and 0.216 ins. for the 14503 psi filler material. The criterion of fracture was a distortional shear strain in the case on the order of 0.26 ins. per inch. The static load tests reported in Appendix F support this calculated result in that a definite yielding is noted after a deformation of 0.2 inches.

Figures 53 and 54 illustrate the distribution of triaxial pressure, distortional shear stress, distortional strain, and internal energy within the cavity at a rear boundary displacement of 0.204 ins. and 0.348 ins. Internal energy is expressed as equivalent temperature rise in °F. Both these figures assume that the explosive cavity is filled with the weaker 1450 psi yield strength filler material. Note that the triaxial pressure is well distributed and that it is an order of magnitude higher than the distortional shear stress.

Finally, it is interesting to note that the maximum strain in the aluminum case, when filled with the weaker 1450 psi material, after a displacement of 0.348 ins. is due to primarily hoopwise loading and is approximately at the fracture point of the 6061 aluminum material. The displacement-time curve for a Susan Test sample filled with PBX 9404 indicates a casebreak knee at this level of deformation, see Figure 26, Section 3*. Also see Figures 56, and 58 of Appendix F which indicates longitudinal fracture of the static test samples at 0.455 ins. and 0.375 ins.**

* ibid page 33

** ibid pages 121 and 124

Obviously much more work can be accomplished with Code HEMP in defining the interrelationships between explosive material physical properties and fracture of the containment case. It is encouraging that the work to date generally supports current experimental observations.

ZONE DESIGNATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TEMP. EQ. OF INTERNAL ENERGY * °F	2.5	1.4	1.9	1.9	1.5	2.0	1.6	1.5	2.2	1.5	0.8	2.2	1.7	0.8	2.0	0.9	0.9
TRIAxIAL PRESSURE PSI	3350	3460	4150	2830	5250	3640	3500	5210	4800	4020	3450	5500	4800	3660	5050	3900	4400
DISTORTIONAL STRAIN —	.41	.14	.31		.24	.33	.27	.21	.36	.25	.16	.31	.27	.13	.35	.14	.18
DISTORTIONAL SHEAR STRESS, PSI	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683

* SPECIFIC HEAT = 0.28
SPECIFIC GRAVITY = 1.86

CALCULATED EXPLOSIVE FILLER PARAMETERS WHEN FRONT CASE "LENS" FAILS

ZONE DESIGNATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TEMP. EQ. OF INTERNAL ENERGY * °F	11.2	4.1	6.7	3.7	2.6	4.3	3.7	4.0	3.8	3.2	2.0	6.0	3.4	1.7	3.6	1.9	1.9
TRIAXIAL PRESSURE PSI	5490	5220	5980	4640	6260	5320	4870	6170	6220	5260	4820	6190	6020	5320	6260	5740	6250
DISTORTIONAL STRAIN —	1.84	.68	.78	.61	.42	.70	.61	.45	.62	.52	.32	.97	.55	.27	.58	.30	.31
DISTORTIONAL SHEAR STRESS, PSI	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683	683

* SPECIFIC HEAT = 0.28
SPECIFIC GRAVITY = 1.86

CALCULATED EXPLOSIVE FILLER PARAMETERS AT CASE BREAK

DEFORMED SURFACE SHAPES CALCULATED BY CODE HEMP FOR HIGH YIELD STRENGTH AND LOW YIELD STRENGTH EXPLOSIVE FILLER MATERIAL.

FIG.55

APPENDIX F

STATIC LOAD TESTS

APPENDIX F

Two static load tests were performed on Susan Test samples filled with non-reactive "mock" materials. The first test sample was filled with a material designated as RM08-AD. The mechanical properties of this material are unknown in detail. Unconfined it feels rubberlike and easily can be compressed or distorted by squeezing with one's fingers.

The second test sample was filled with a material designated as RM04-BF. This is a 15% viton material designed to be a mechanical mock up for LX04. When subjected to the "finger" test it seemed clearly stiffer and less deformable than RM08-AD.

The details of the two tests are included in the following two memoranda* by K.G. Hoge, the LRL engineer in charge of the tests. Compare Figures 56 and 58 that illustrate test machine load versus displacement. Note that longitudinal case fracture occurs at 0.45 inches and 0.375 inches. In both tests, the front lens of the containment case visually had separated in the same manner as in the dynamic Susan Test impacts. In Figure 56 note that the load versus displacement curve begins to turn over at a displacement of 0.2 inches. These observations are in approximate agreement with both the Susan Test dynamic behavior and with the code HEMP calculated behavior described in Appendix E.

Figure 59 shows a series of photographs of the RM04-BF test sample in the testing machine, taken at different levels of displacement. The mushroomed shape at the front of the projectile closely corresponds to the shapes visible in the Fastax camera records for actual Susan Test impacts. Photographs showing a similar mushroom shape were taken for the RM08-AD test sample.

* In Mr. Hoge's memorandum of June 5, 1970 third paragraph, he quotes a magnitude range for variation in explosive material strength versus strain rate observed in Hopkinson bar experiments performed on unconfined wafers of explosive material. When confined inside the Susan MOD-1 projectile, the apparent strain rate effect is likely to be less than this because the distortional stress field numerically is overshadowed by the triaxial pressure field due to the confinement. See Figures 53 and 54 in Appendix E.

June 5, 1970

MEMORANDUM

To: L. G. Green/A. M. Weston
From: K. G. Hoge
Subject: Slow Rate Deformation of a Susan Projectile

A Susan projectile consisting of a steel body and 6061-T6 aluminum cap filled with extruded RM-08-AD mock explosive was compressed in a 120,000 lb capacity universal test machine at a crosshead rate of 0.04 in/min. Strain gages were bonded to the cap 1/2 inch below the end of the tapered section of the cylinder. Gages were placed in both the longitudinal and hoop directions. Photographs were taken at 0, .3, .4, .5, .6, and .7 inch deflection points.

Figure 1 shows the load deflection record. A longitudinal crack was initiated just prior to 1/2 inch deflection. The load fell off sharply from about 25,000 to 15,000 pounds but recovered at about 0.6 inch deflection. Figure 2 shows strain gage data. The initial portion of the longitudinal strain trace was missed because of failure of the recorder pen to write. Photographs give a reasonably clear picture of the cap deformation during loading. The projectile and photographs have been delivered to L. Green for evaluation.

The validity of a slow rate test to predict the dynamic behavior of the Susan projectile depends mainly upon the rate sensitivity of the materials involved. Aluminum 6061-T6 is relatively insensitive to rate. However, most plastic-bonded explosives have been shown to be quite sensitive to strain rate effects. In compression their strength increases by approximately 500 per cent* as rate is increased from 10^{-3} to 10^3 sec^{-1} . Also, there are some differences in the rate sensitivity of various explosives. This difference in sensitivity is believed to be the primary cause for differences that have been noted in the failure behavior of Susan projectiles.

Since I have no data on the properties of RM-08-AD, it is impossible to say how good a mechanical mock it is. Therefore, it is recommended that another slow rate deformation test be performed on a projectile containing RM-04-BG. I have data which shows the RM-04-BG is a very good mechanical mock for LX-04-1.

K. G. Hoge

* ibid footnote page 119

FIG. 1 - LOAD DEFLECTION RECORDS
FIG. 5C

FIG. 2. STRAIN GAGE RECORDS - GAGES WERE LOCATED $\frac{1}{2}$ INCH BELOW TOP EDGE OF CYLINDER.

June 11, 1970

MEMORANDUM

To: L. G. Green/A. M. Weston
From: K. G. Hoge
Subject: Slow Rate Deformation of a Susan Projectile

In accordance with my recommendations stated in my memorandum, dated June 5, 1970, a second slow rate deformation test was performed on a Susan projectile filled with RM-04-BF mock explosive.* This mock H.E. is composed of 15% viton and 85% cyanuric acid. The test was conducted on a 120,000 pound capacity Universal test machine at a crosshead velocity of 0.02 in/sec. Photographs were taken at 0.01 inch deformation intervals (Figure 1 shows these photographs). Note that a longitudinal crack appears at a deformation of 0.4 inch. Figure 2 shows the normal load versus deformation.

K. G. Hoge

KGH/kmm

Attachment

* The RM-04-BF material mechanically is similar to the RM-04-BG material mentioned in the memorandum of June 5, 1970.

FIG.2-LOAD VERSUS DEFORMATION - PLOT FOR SUSAN PROJECTILE
FILLED WITH RM-04-BF MOCK H.E.
FIG.58

Load = 0 lbs
 Axial Deformation = 0 ins

Load = 26,300 lbs.
 Axial Deformation = 0.3 ins

Load = 27,000 lbs
 Axial Deformation = 0.2 ins

Load = 17,000 lbs
 Axial Deformation = 0.4 ins

STATIC LOAD TEST OF MOD-1 SUSAN PROJECTILE FILLED WITH MOCK EXPLOSIVE RM04BF

Fig. 59