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ATL-TR-64-83

(U) HYPERVELOCITY IMPACT EXPERIMENTS

Technical Report No. ATL-TR-64-83
December 1964 Project No. 9650

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ABSTRACT

This final report describes the experimental results of a program conducted under Contract AF08(635)-2783, "Hypervelocity Impact Experiments," to investigate the vulnerability of multiple sheet thin target assemblies to hypervelocity projectiles impacting at both normal and oblique angles. This study of penetration, perforation and spalling was conducted using an accelerated-reservoir light-gas gun to launch projectiles to velocities ranging from 5000 fps to 25,500 fps. Projectile incident angles ranged from 90 degrees (normal) to 10 degrees.

Target damage was evaluated in terms of hole area, depth of penetration and affected area. Damage was correlated with impact velocity, impact angle, projectile variables, and target variables.

This report has been reviewed and is approved.

DAVID K. DEAN
Colonel, USAF
Chief, Weapons Division

CONTENTS

<u>Section</u>	<u>Page</u>
Abstract	i
Illustrations	iv
List of Symbols	vi
I Introduction	1
II Technical Activities and Results	5
2.1 Experimental Facility	5
2.1.1 20-mm ARLGG Gun	5
2.1.2 Surge-Tank/Flight-Range/Velocity-Chamber Complex	5
2.1.3 Impact Chamber	8
2.2 Experimental Results	8
2.2.1 Experimental Program	8
2.3 Shield Analysis	11
2.4 Target Sheet Analysis	26
2.5 Total Target Vulnerability	36
2.6 Impact Flash Phenomenon	40
III Summary	51
References	53
Appendix I - Data, Hypervelocity Impact Damage	55
Appendix II - Data, Impact Flash Phenomenon	63

ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Projectile and Shield Behavior Upon Impact of a Solid Sphere with Thin Target	2
2	Schematic of Ballistic Range 'C'	6
3a	Schematic of Spark Shadowgraph Velocity Station	7
3b	Typical Spark Shadowgraph	7
4a	Schematic of Typical Multisheet Thin Target Assembly	9
4b	Experimental Variables	9
5	Typical Shield Perforations - Effect of Varying Angle, Al - Al	12
6	Shield Damage, Al - Al ($t_s/d = 0.27$, $v = 25,000$ fps)	13
7	Shield Damage, Al - Al ($t_s/d = 0.40$, $v = 25,500$ fps)	14
8	Shield Damage, Ni - Stainless Steel ($t_s/d = 0.15$, $v = 25,000$ fps)	15
9	Shield Damage, Ni - Al ($t_s/d = 0.534$, $v = 25,000$ fps)	16
10	Typical Shield Perforation - Effect of Varying Angle	17
11	Shield Damage, Effect of Variation of Sheet Thickness, Constant Velocity	18
12	Shield Damage, $\alpha = 90^\circ$ Effect of Variation of Velocity	19
13	Shield Damage, Effect of Variation of Velocity, Constant t_s/d	20
14	Schematic of Shield Geometry	21
15	Shield Damage, $\alpha = 60^\circ$ Effect of Variation of Velocity	23
16	Shield Damage, $\alpha = 25^\circ$ Effect of Variation of Velocity	24
17	Shield Damage, Effect of Variation of Velocity, Constant t_s/d	25
18	Typical Target Spray Patterns (Shields removed), Al - Al	27
19	Typical Target Spray Patterns - Effect of Variation of Velocity	28
20	Spall and Projectile Spray Angle Variation with Velocity ($\alpha = 90^\circ$)	30

ILLUSTRATIONS (continued)

<u>Figure</u>		<u>Page</u>
21	Analysis of Spall and Projectile Spray Angles	31
22	Superposition of Spray Angles on Typical X-Ray of Projectile-Shield Impact	31
23	Typical Target Patterns - Effect of Variation of Shield Angle	33
24	Spall and Projectile Spray Angle Variation with Shield Angle - Al - Al ($t_g/d = 0.27$)	34
25	Spall and Projectile Spray Angle Variation with Shield Angle - Al - Al ($t_g/d = 0.40$)	35
26	Spall and Projectile Spray Angle Variation with Velocity ($\alpha = 60^\circ$)	37
27	Typical Target Patterns - Effect of Variation of Intersheet Spacing	38
28	Effect of Velocity on Maximum Penetration - Al - Al ($\alpha = 90^\circ$)	39
29	Vulnerability of Multisheet Thin Target Assembly, Al - Al ($t_g/d = 0.27$, $v = 25,000$ fps)	41
30	Vulnerability of Multisheet Thin Target Assembly, Al - Al ($t_g/d = 0.40$, $v = 25,500$ fps)	42
31	Typical Target Patterns - Effect of Varied Projectile and Target Assembly Materials	43
32a	Typical B/W Framing Camera Sequence of Impact Flash	44
32b	Typical Open-Shutter Camera Photograph of Impact Flash	44
32c	Typical Oscilloscope Trace Showing Intensity - Time History of Impact Flash	44
33	Reduced Data - Air and Helium Atmospheres - Variation of Peak Luminosity with Range Pressures, Velocity Constant	46
34	Variation of Peak Luminosity with Velocity	47
35	Reduced Data - Variation of Peak Luminosity with Shield Angle (Semi-Infinite and Thin Targets)	49

LIST OF SYMBOLS

A_1	Shield perforation or hole area
A_0	Normal projectile area, $A_0 = \frac{\pi d^2}{4}$
α	Shield angle of incidence - smallest angle measured from the shield to the projectile flight line
α_1	Shield angle below which projectile ricochet occurs and above which perforation occurs
α^*	Shield angle below which there is no subsequent damage from in-line spray particles, i. e., no target damage in the direction of the projectile flight line
β	Target sheet angle of incidence - smallest angle measured from the target to the projectile flight line
BHN	Brinell Hardness Number
γ	Projectile-spray semi-angle
θ	Spall-spray semi-angle
d	Normal projectile diameter
D	Perforation diameter in normal shield
D_{major}	Maximum length of the shield perforation
D_{minor}	Maximum width of the shield perforation
ρ_P	Projectile material density
ρ_T	Target (shield) material density
t_s	Normal sheet thickness
P	Penetration



SECTION I

INTRODUCTION

Of current interest to the Air Force in their Space Program is the investigation of non-nuclear kill mechanisms from both offensive and defensive viewpoints. Offensively, this interest has led to enhanced lethality concepts for warhead development. Defensively, it has led to advances in the science of spacecraft design. One of the problems is the vulnerability of spacecraft to impacts of hypervelocity fragments, since such a collision could result in the defeat of a mission. It is necessary, therefore, to devise means of protecting a spacecraft from these fragments while remaining aware of the penalties involved in increasing the vehicle gross weight or unduly complicating its structure.

Although many configurations of vehicle hulls have been proposed, the foremost, and one of the original concepts, is that of a thin outer shell separated from and protecting the main hull.⁽¹⁾ In theory, any meteoroid or warhead fragment that impacted this outer shell would vaporize before it could penetrate the main hull - in practice, however, this appears generally possible only at very high velocities, for the actual physical mechanism of impact that has been observed at typical encounter velocities does not include vaporization of fragments.⁽²⁾

Figure 1 is an artist's representation of the impact of a solid sphere against such a thin target, the protective outer shell. The projectile strikes the target and, because of the intense pressures developed, generates a shock wave in both projectile and target. These shocks cause the projectile to break up into a multitude of tiny fragments, producing an expanding bubble of debris with a velocity component normal to the shield that is generally less than the velocity of the original projectile. The result of these factors of fragment spread and velocity reduction is that the protected hull is subjected to less momentum and energy loading per unit area than an unprotected hull.

While it is true that this design concept should reduce the vehicle-vulnerability, the mode and magnitude of impact damage still required study. Since the number of possible target configurations is virtually unlimited, a typical multisheet thin target assembly was chosen to be subjected to impacts of specific projectiles under specific encounter conditions.

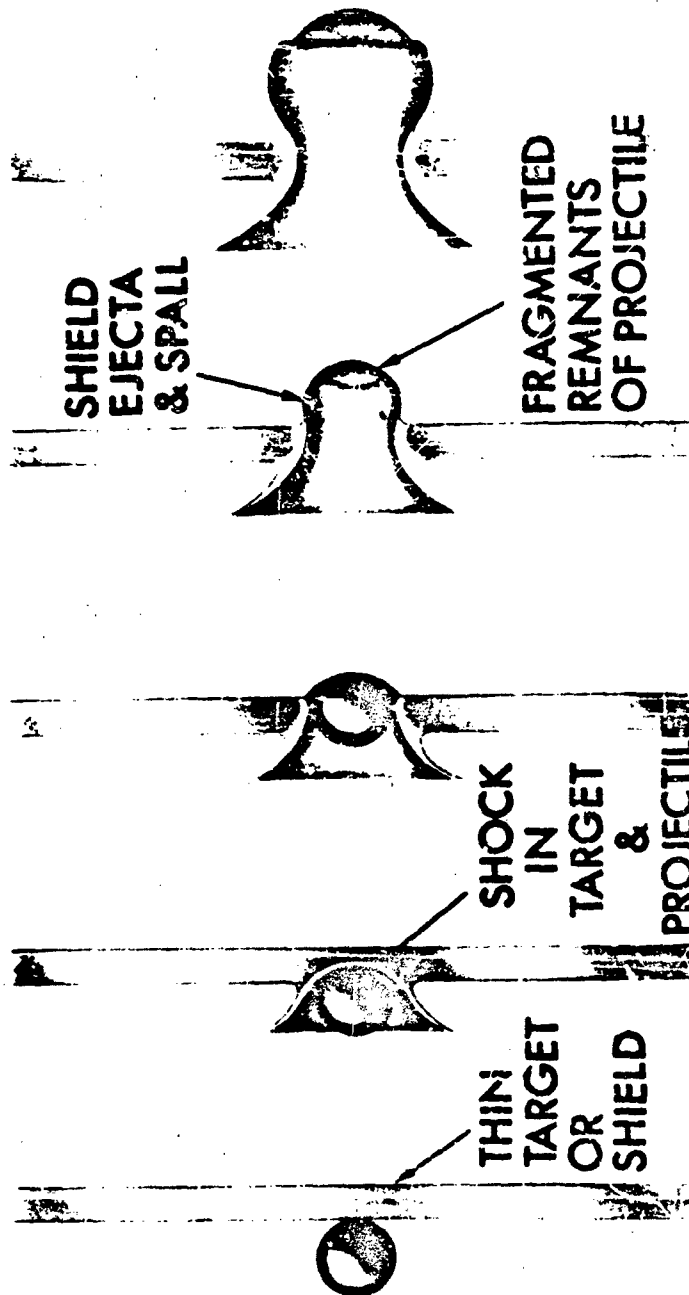


Fig. 1 Projectile and Shield Behavior Upon Impact of a Solid Sphere with Thin Target

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The basic thin target assembly consisted of two 2014-T6 aluminum sheets spaced twelve inches apart. The experimental variables were those of the projectile (material, mass, velocity, angle of impact) and those of the target assembly (material, intersheet spacing, angle of impact).

Other tests, conducted concurrently, were to investigate the phenomenon of impact flash and its potential use as a hit director and target discriminator.

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SECTION II

TECHNICAL ACTIVITIES AND RESULTS

2.1 Experimental Facility

The experiments in this program were conducted at GM Defense Research Laboratories (Ref. 3) on Ballistics Ranges 'C' and 'D'. The launchers were respectively, a .22-caliber smooth bore powder gun or a 20-mm accelerated-reservoir light-gas gun (ARLGG), and a .30-caliber ARLGG. The powder gun was used when velocities below 10,000 fps were required, and the ARLGG, guns were used for velocities above 10,000 fps. The .30-caliber ARLGG, however, was capable of launching only low weight projectiles ($m < 0.3$ gm) at velocities in excess of 25,000 fps; consequently, most of the tests were made with the 20-mm ARLGG. This gun and the associated range complex are shown schematically in Fig. 2. Following is a brief description.

2.1.1 20-mm ARLG Gun

The accelerated-reservoir light-gas gun was selected because it maintains a constant pressure at the base of the model during the launching cycle. This constant base pressure produces a constant, yet moderate, acceleration of the model throughout its travel down the barrel. Hence, the model achieves a high muzzle velocity without being loaded to the point of deformation or failure. This type of gun, then, is the logical choice for launching fragile models or sabot projectiles of high mass and high density.

2.1.2 Surge-Tank/Flight-Range/Velocity-Chamber Complex

This complex provides, in order:

- (1) Tanks that confine the muzzle blast and allow the high-pressure, high-temperature driver gas to expand and cool
- (2) Tanks that contain a controlled atmosphere in which the sabot separates from the model. The downrange end of the flight range is the sabot trap where the sabot petals are stopped, allowing the model to proceed alone.
- (3) Tanks that house spark shadowgraph instrumentation (Fig. 3a) to establish projectile velocity, orientation, and integrity during each firing. Two successive spark shadowgraph pictures of the projectile, taken along its trajectory over a distance of eighteen inches (Fig. 3b), are combined with the elapsed times obtained from chronographs to determine velocities with an accuracy of ± 1 percent. The spark shadowgraphs also show the flight orientation of the projectile, record whether it has separated properly from its sabot, and establish its trajectory.

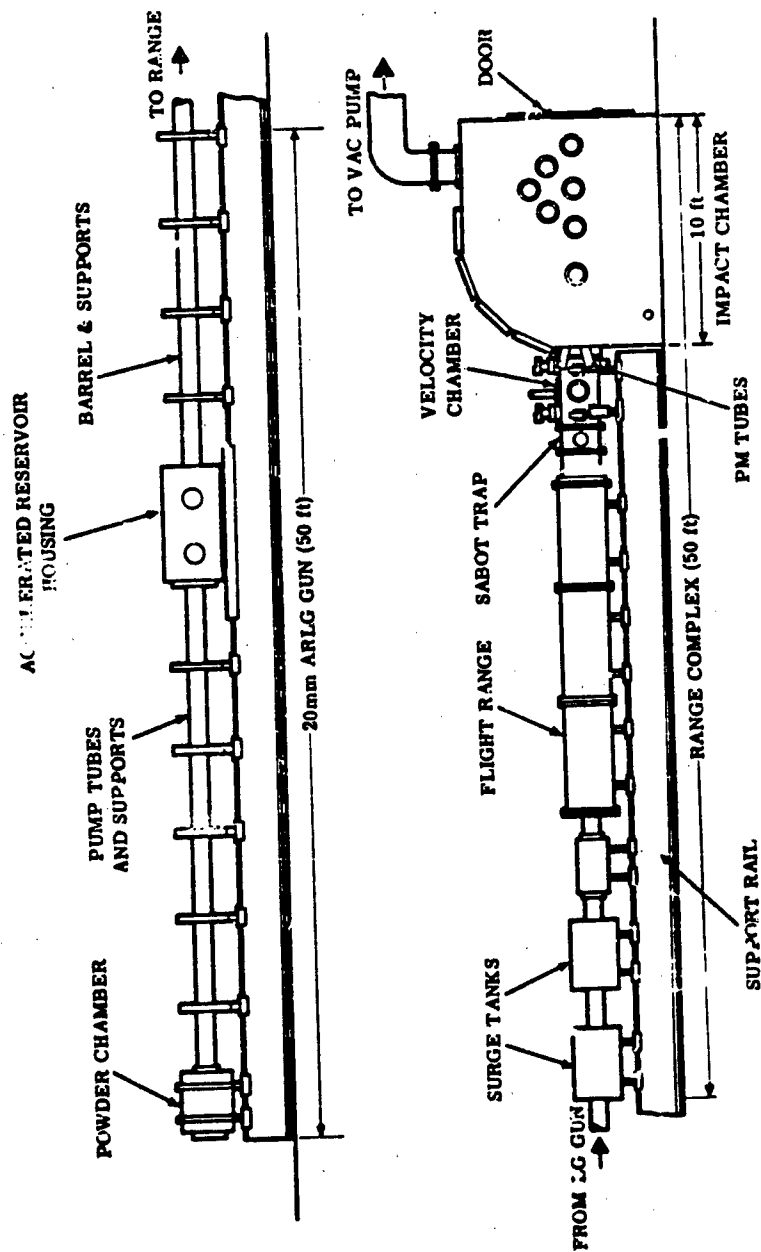


Fig. 2 Schematic of Ballistic Range 'C'

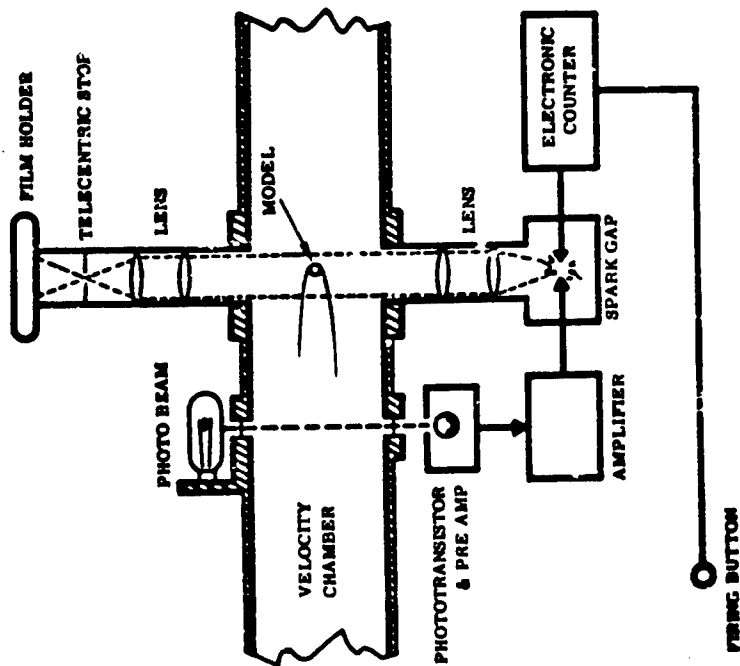


Fig. 3a Schematic of Spark Shadowgraph Velocity Station

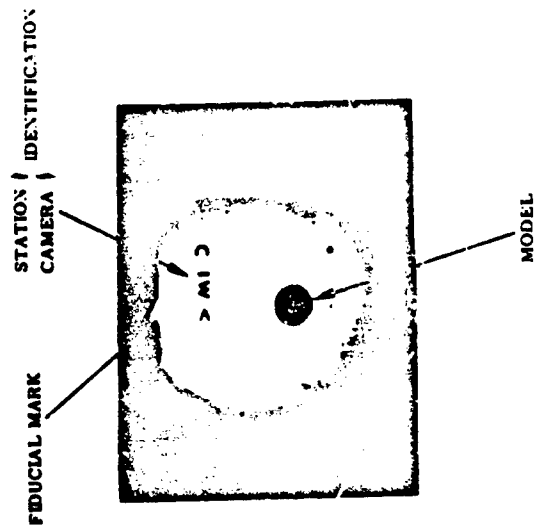


Fig. 3b Typical Spark Shadowgraph

2.1.3 Impact Chamber

This chamber was specially constructed to house the large target sheets needed to study spray distributions when the distance between shield and target is large. The impact chamber has numerous viewing ports to accommodate the instrumentation, and the rear wall of the chamber is a full-size door to allow easy installation and removal of the targets. The targets are held by a mount attached to the floor and walls. The surge-tank/flight-range/velocity-chamber/impact-chamber assembly is vacuum-sealed and can be evacuated to pressures of less than 10^{-3} torr, equivalent to a pressure-altitude of approximately 300,000 feet.

The impact of the projectile and the reaction of the target can be observed by both the 0.07-microsecond, two-channel flash radiography system and the 1.4-million-frames-per-second Beckman-Whitley framing camera. The choice of instrumentation depends upon the specific observations to be made of a given shot. The impact flash is monitored by both photomultiplier (PM) tubes and an indium-antimonide (InSb) infrared detector. The PM tubes are sensitive to the following wavelengths: (a) 1800A to 5500A, (b) 4500A to 10,000A, (c) 5940A to 10,000A. The InSb detector is sensitive to radiation in the region from 1 to 5 microns. These detectors are calibrated to measure radiation in watts per unit-solid-angle.

Preliminary firings were carried out prior to the data rounds to develop sabot designs and deflection techniques and to optimize the internal ballistics of the gun operating cycle. These firings also served as proof rounds for the impact chamber instrumentation.

2.2 Experimental Results

2.2.1 Experimental Program

The experimental program, as stated, consisted of firing specific hypervelocity projectiles into a typical multisheet target assembly under specific encounter conditions. This target assembly is shown schematically in Fig. 5 which also details the experimental variables.

A comprehensive synopsis of the raw impact data obtained during the investigation is attached to this report as Appendix I. Not included in the appendix is reduced data from a complimentary study involving hypervelocity impacts at angles of incidence ranging from 2 to 15 degrees, although this additional information has been included to extend the scope of the discussion of the experimental results. The impact flash data is attached as Appendix II. Table 1 lists typical physical and mechanical properties of the projectile and target materials.

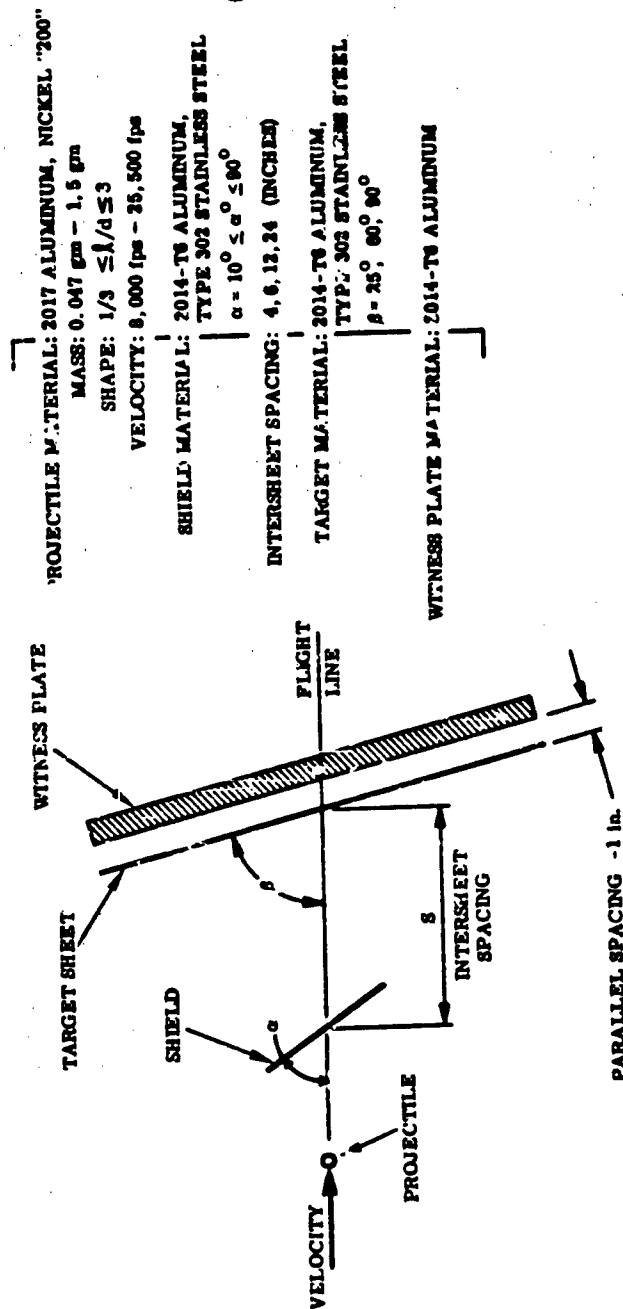


Fig. 4b Experimental Variables

Fig. 4a Schematic of Typical Multisheet Thin Target Assembly

Table 1
TYPICAL MATERIAL PROPERTIES
PHYSICAL AND MECHANICAL

	Projectile Materials				Target Materials		
	2017 Aluminum	Nickel "200"	Depleted Uranium	2014-T6 Aluminum	AISI Type 302 Stainless Steel	ASTM Type AZ31B-H24 Magnesium	
Physical properties: Density - lb/cu in. Melting Point - °F	0.101 1200	0.32 2635	0.69 2070	0.101 1200	0.29 2550 - 2590	0.064 1050 - 1170	
Mechanical properties: Tensile yield strength ksi Ultimate strength ksi Hardness	40 62 R _B 35	30 70 70 BHN	35 to 60 75 to 110 R _B 65-90	53 60 135 BHN	75 110 R _B 85	37 45 R _B 20-30	

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2.3 Shield Analysis

Shield damage may be analyzed in many ways, and the resulting data may take many forms. (Ref. 4) For this program, however, only the gross damage has been considered; this is best represented by the perforation area or hole area, A_1 . The holes discussed in this report are those through which a collimated light beam normal to the target plane can be projected onto photosensitive paper.

Typical of the results of this program are the perforations shown in Fig. 5 to demonstrate the effect of a changing angle of incidence, α (all other variables constant). It can be seen that the hole or perforation area, A_1 , increases slowly from its normal value to a peak at an angle of approximately 35 degrees, and then decreases sharply as the angle of incidence is further decreased. It can also be seen that the hole becomes increasingly oval as α is decreased. These results are shown graphically in Fig. 6, where A_1 has been non-dimensionalized by dividing by the normal projectile area A_0 , where

$$A_0 = \frac{\pi d^2}{4} \quad (d = \text{projectile diameter})$$

The effect of hole shape has been plotted as $D_{\text{major}} / D_{\text{minor}}$, where D_{major} is the maximum length of the perforation and D_{minor} is the maximum width. Figure 7 shows the result of tests with the same combination of materials (Al-Al), but with a change in t_s/d to 0.4 (In Fig. 6, $t_s/d = 0.27$); t_s is the shield sheet thickness. It can be seen that the curve here is similar to that of Fig. 6, but it peaks at 45 degrees rather than 35 degrees. Substantial perforations were still evident at angles as low as 10 degrees, which was the final test angle of this series. Figures 8 and 9 demonstrate the effects of the impacts of nickel projectiles against stainless steel and aluminum shields, respectively. Although only three angular conditions have been tested in each case, it is felt that the curves are representative. Figure 8 is similar in shape to that of Halpern (Ref. 5); and Fig. 9 seemingly provides results similar to those of Fig. 10, which involves impacts of depleted uranium spheres against magnesium shields (from Ref. 6).

The experimental results of Al-Al impacts shown in Figs. 6 and 7 are combined in Fig. 11 to demonstrate the effect of shield thickness upon shield damage. Here it can be seen that, in the region $90^\circ < \alpha < 15^\circ$, the damage to the thicker sheet is more severe.

To consider the effect of projectile velocity on the extent of shield damage, it is necessary to refer again to the physical description of normal perforation introduced with Fig. 1. At extremely low velocities, the impact does not generate sufficient pressure to initiate the formation of shock waves, producing only elastic or shear waves. Consequently, the projectile

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SHIELD MATERIAL: 2014-T6 ALUMINUM
THICKNESS: 0.100 IN.
 $t/d: 0.27$

PROJECTILE MATERIAL: 2017 ALUMINUM
DIAMETER: 0.375 IN.
VELOCITY: 25,000 fps

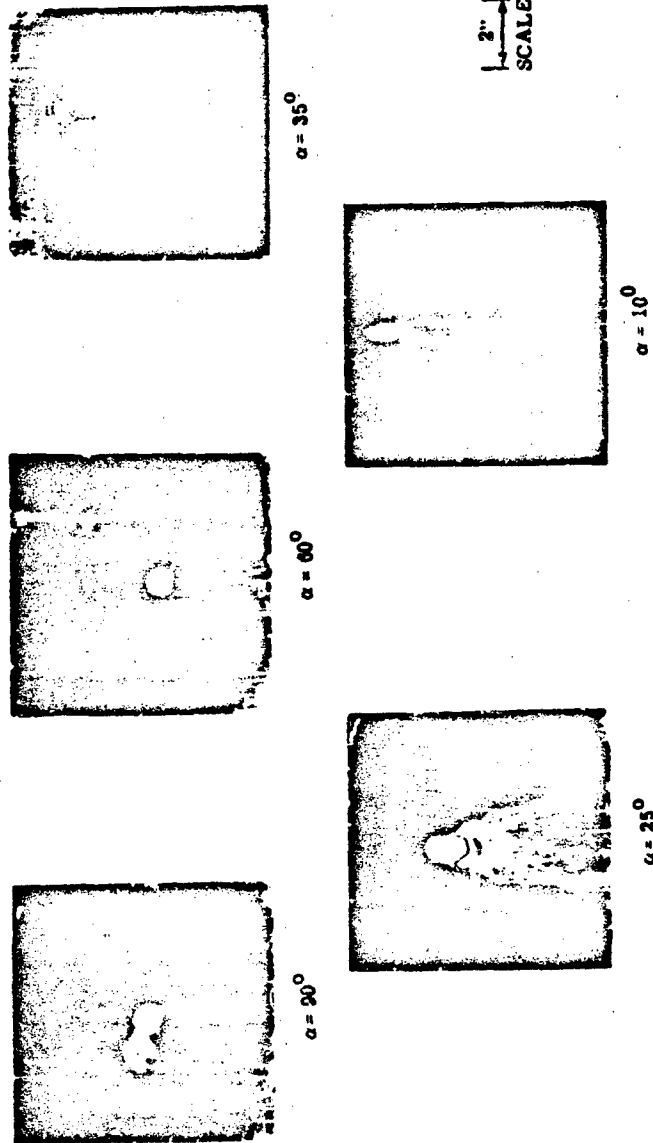


Fig. 5 Typical Shield Perforations - Effect of Varying Angle, Al - Al

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM
 DIAMETER: 0.375 IN.
 VELOCITY: 25,000 fps $t_p/d: 0.27$

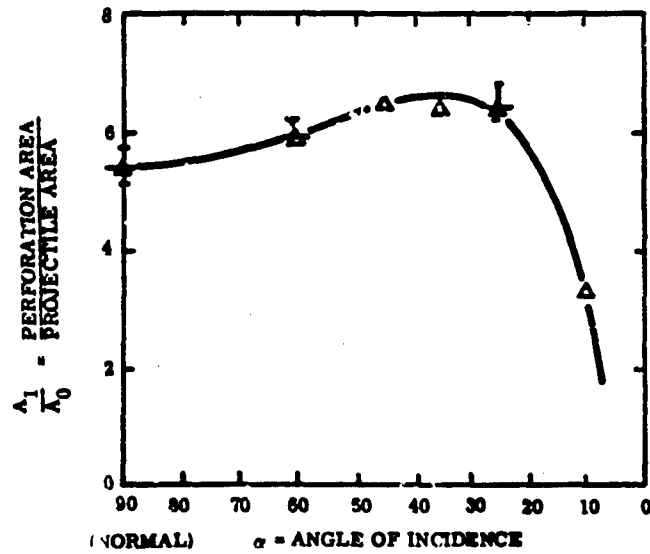


Fig. 6a Area of Perforation

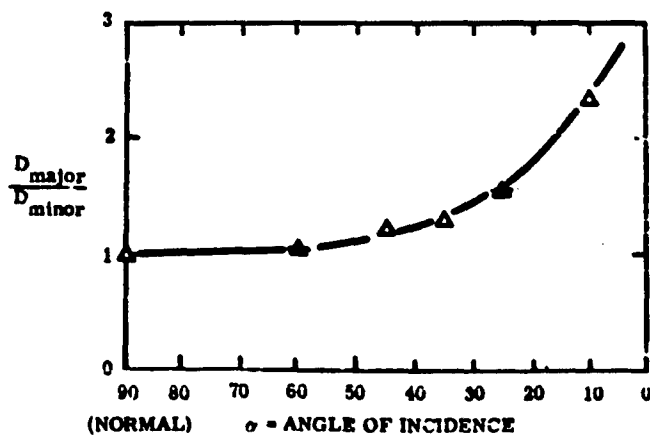


Fig. 6b Shape of Perforation

Fig. 6 Shield Damage, Al - Al ($t_p/d = 0.27$, $v = 25,000$ fps)

13

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL : 2014-75 ALUMINUM
 DIAMETER: 0.25 IN.
 VELOCITY: 25,500 fps $t_p/d : 0.40$

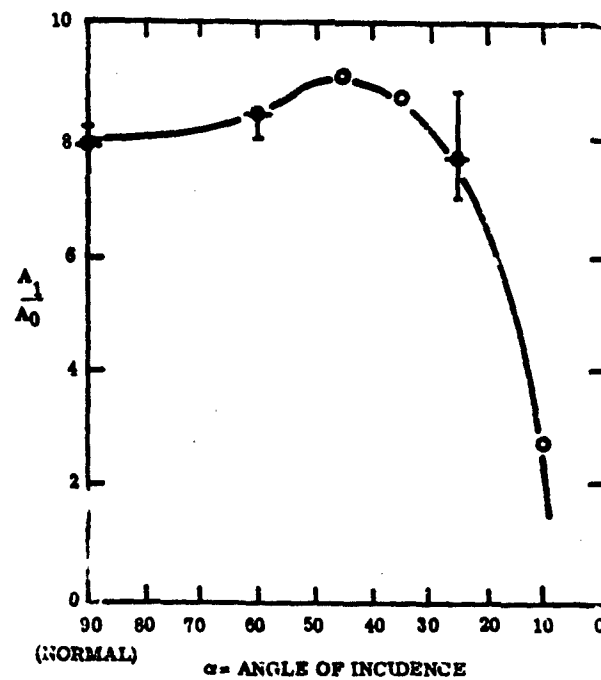


Fig. 7a Area of Perforation

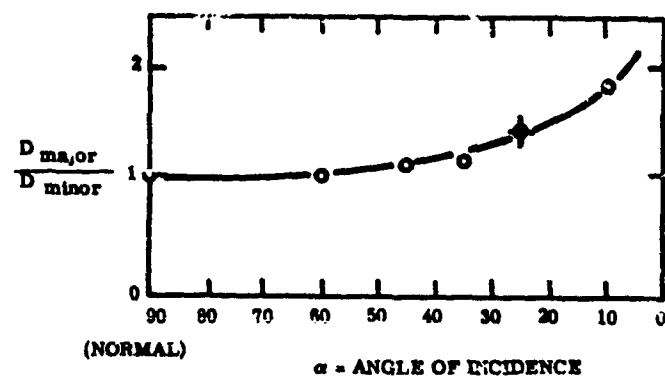


Fig. 7b Shape of Perforation

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PROJECTILE MATERIAL: NICKEL "200" SHIELD MATERIAL: TYPE 302 STAINLESS STEEL
 DIAMETER: 0.187 IN.
 VELOCITY: 25,000 fps $t_s/d : 0.150$

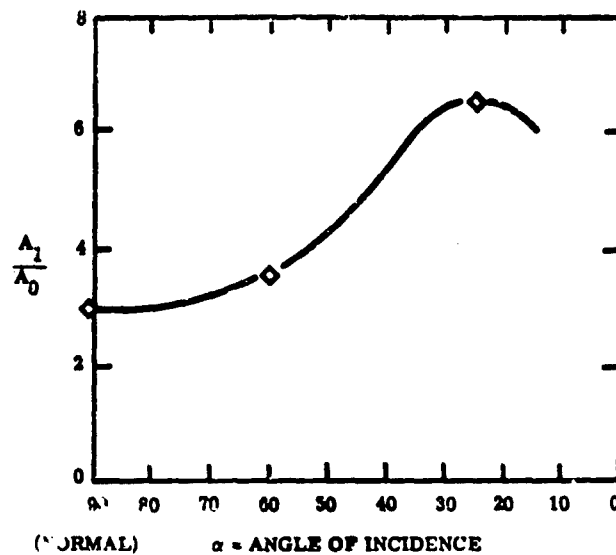


Fig. 8a Area of Perforation

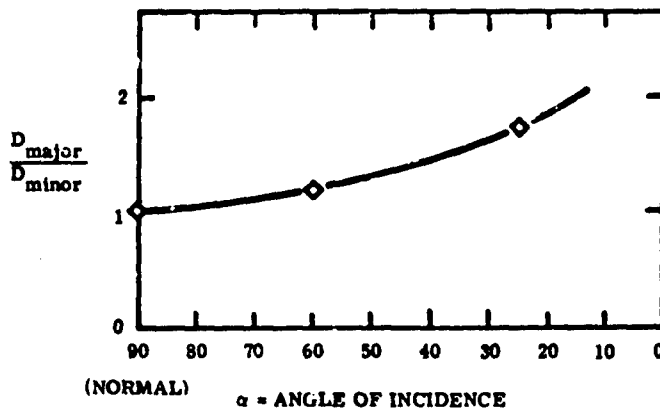


Fig. 8b Shape of Perforation

Fig. 8 Shield Damage, Ni - Stainless Steel ($t_s/d = 0.15$, $v = 25,000$ fps)

15

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PROJECTILE MATERIAL: NICKEL "700" SHIELD MATERIAL: 2014-T6 ALUMINUM
 DIAMETER: 0.187 IN. $t_g/d : 0.534$
 VELOCITY: 25,000 fps

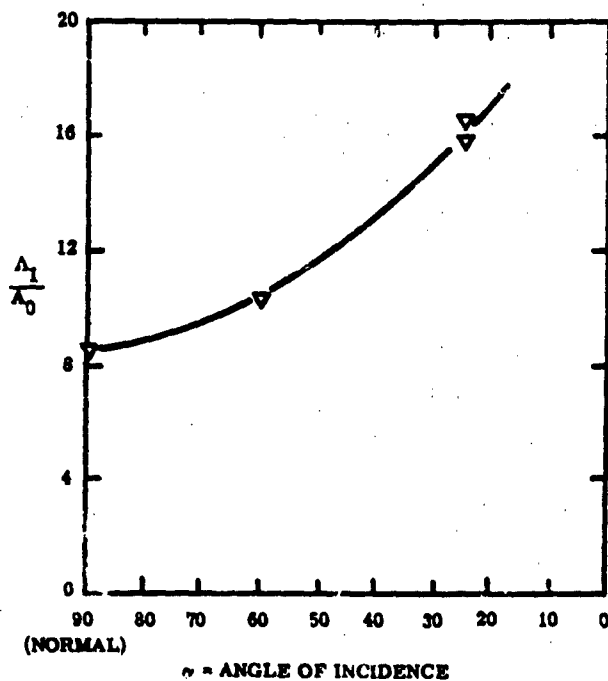


Fig. 9a Area of Perforation

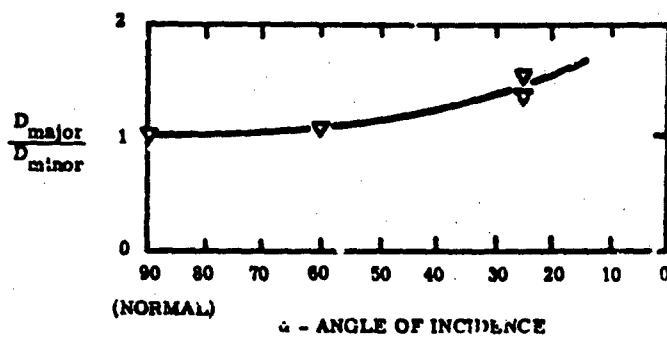


Fig. 9b Shape of Perforation

16

Fig. 9 Shield Damage, Ni - Al ($t_g/d = 0.534$, $v = 25,000$ fps)

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PROJECTILE MATERIAL: DEPLETED URANIUM

SHIELD MATERIAL: AZ31B-H24 MAGNESIUM

DIAMETER: 0.143 IN.

THICKNESS: 0.100 IN.

VELOCITY: 23,350 fps

$t_p/d : 0.70$

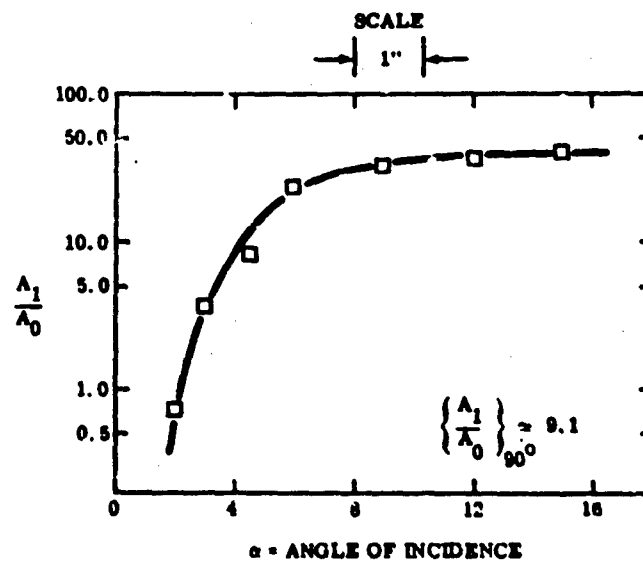
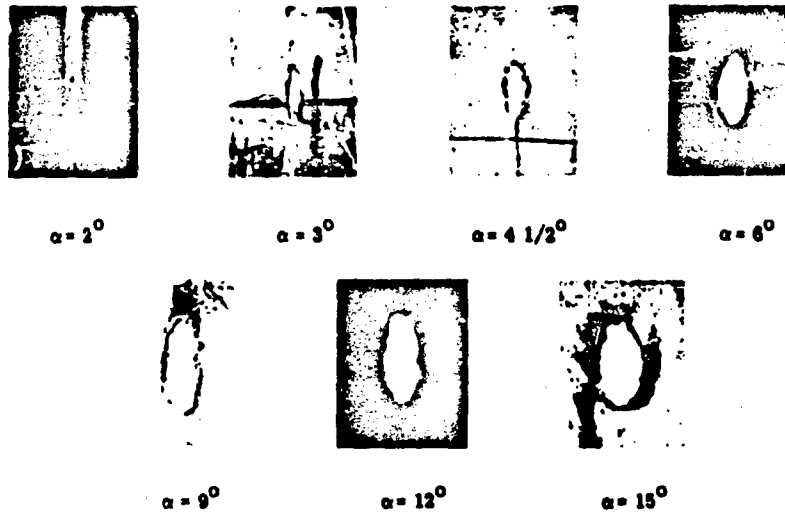


Fig. 10 Typical Shield Perforation - Effect of Varying Angle

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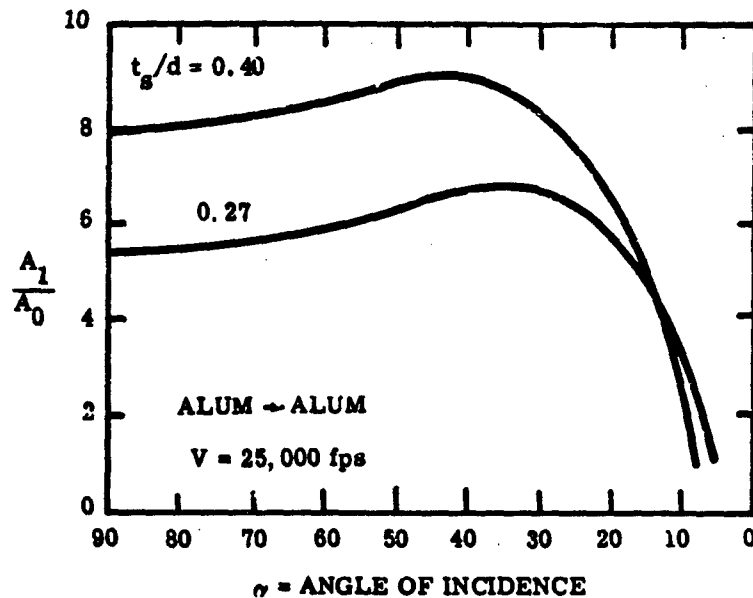


Fig. 11 Shield Damage, Effect of Variation of Sheet Thickness, Constant Velocity

suffers little damage during perforation. For a thick ductile shield, the edge of the hole is thickened due to the plastic flow. (Ref. 7) Brittle materials fail by punching; that is, a disc of approximately projectile size is sheared out of the shield. (Ref. 7) Thin sheets (small t_s/d) tend to fail by petalling. (Several simplified theories for these various modes of failure are reviewed in Reference 8.) At increased velocity, these elastic or shear waves are replaced by shock waves that result in hypervelocity impact phenomena. Perforations associated with hypervelocity for conditions of normal impact have been treated extensively, both theoretically and experimentally, in Refs. 9 and 10. These demonstrate that the process of fracture of projectile and shield can be interpreted as a multiple-spalling phenomenon which starts at the free surfaces, and that the hole area ratio increases linearly with velocity.

Al - Al normal impacts (Fig. 12) generated during the course of this program compare favorably with those predicted by Equation (1) from Ref. 10, i.e.,

$$\frac{A_1}{A_0} = \left\{ \frac{D}{d} \right\}^2 = \left\{ 0.1372 v \left(\frac{t_s}{d} \right)^{2/3} + 0.90 \right\}^2 \quad (\text{Ref. 10}).$$

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T8 ALUMINUM

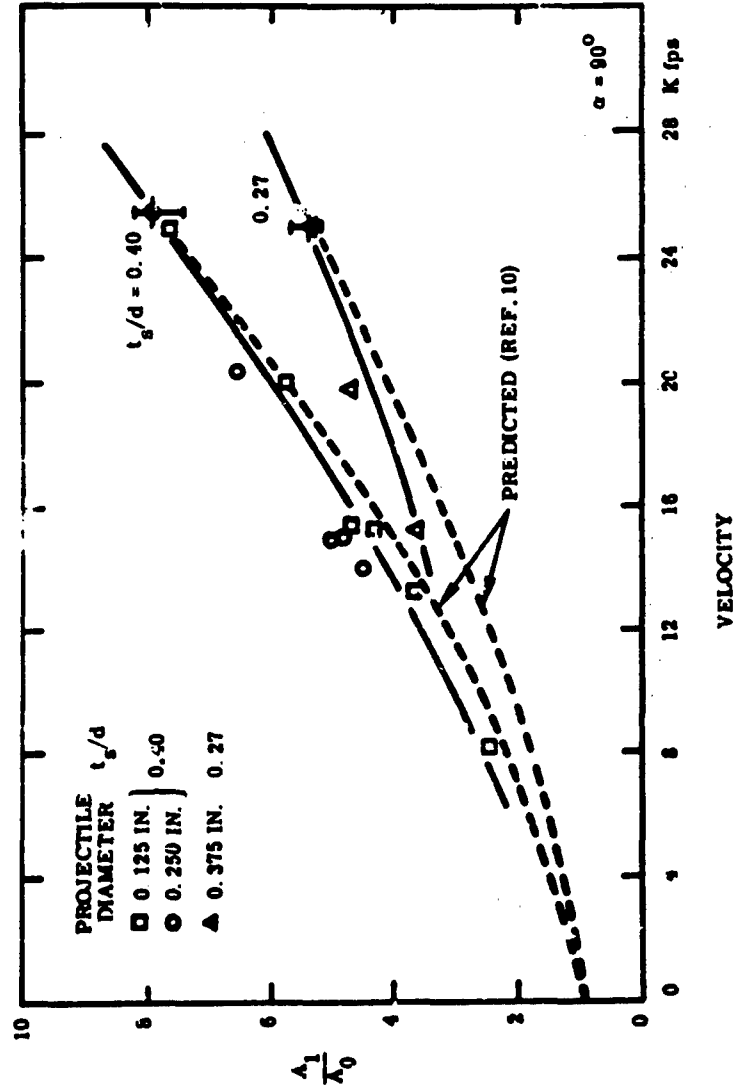


Fig. 12 Shield Damage, $\alpha = 90^\circ$, Effect of Variation of Velocity

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where

D = hole diameter in shield
d = projectile diameter
v = impact velocity, kfps

The minor differences, especially at the lower velocities, can be attributed to the dissimilarity in materials tested (the empirical formula was derived for shields of 2024-T3 aluminum) and the dearth of data points to determine the experimental scatter, especially for the thinner targets.

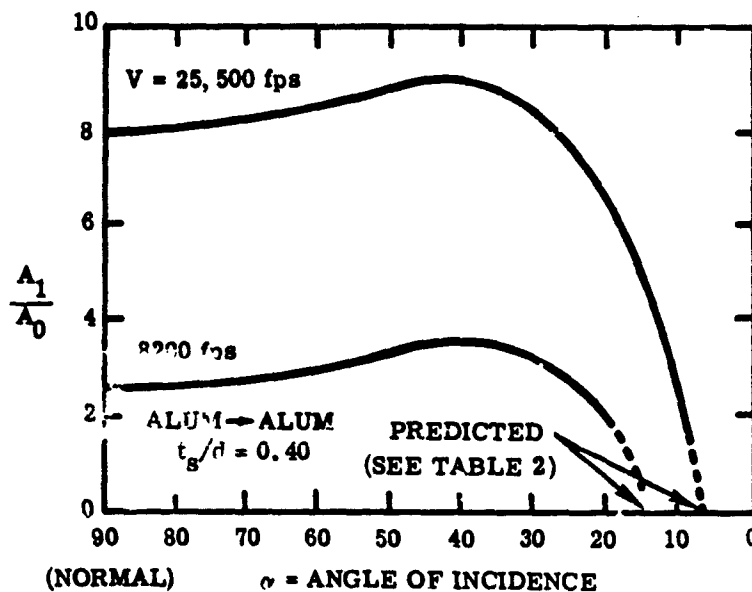


Fig. 13 Shield Damage, Effect of Variation of Velocity, Constant t_s/d

The data in Fig. 13 presents another aspect of shield damage with respect to velocity change. Even though the velocity here has been decreased from 25,500 fps (data from Fig. 7) to 8200 fps, the characteristic shape of the A_1/A_0 - α curve described previously is unaltered except when $\alpha = 30^\circ$. In this region the slope of the curve is less steep, and although the shield was perforated when $\alpha = 20^\circ$, it was not perforated when $\alpha = 10^\circ$. There is, then, a shield angle that causes the projectile to ricochet so that perforation does not occur. It is interesting to note the correlation between the observed angular region of ricochet-perforation and that predicted by considering the equivalent semi-infinite target penetration, $(P/d)_{\text{semi } \infty}$, of the projectile at a given velocity, then applying a thin sheet conversion factor and equating this result, $(P/d)_{\text{thin target}}$, with the apparent thickness of the shield, t_A (t_A is the thickness of the shield measured in the direction of the projectile velocity vector (see Fig. 14)).

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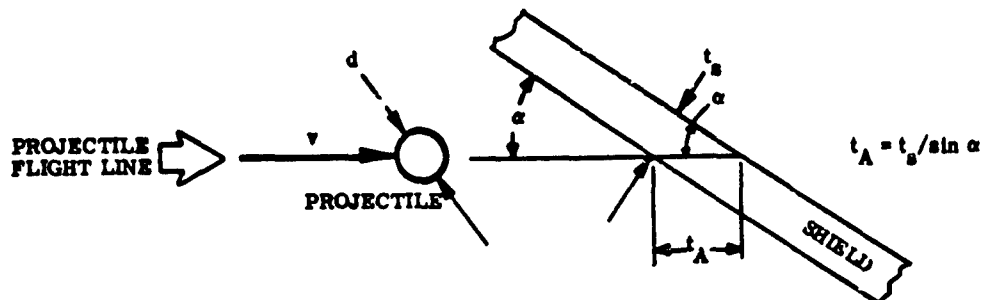


Fig. 14 Schematic of Shield Geometry

Although several empirical relationships are available to compute $(P/d)_{\text{semi } \infty}$, (Refs. 11, 12, 13) that of Herrmann and Jones has been chosen because of its low-velocity data fit, i. e.,

$$(P/d)_{\text{semi } \infty} = K_1 (\rho_P / \rho_T)^{2/3} \log_e \left[1 + \left\{ \frac{\rho_T^{2/3} \rho_P^{1/3} v^2}{K_2 \text{BHN}} \right\} \right] \quad (\text{Ref. 14})$$

The relationship for the conversion of semi-infinite target penetrations to those of thin sheets is not well defined, (Refs. 10 - 16) appearing to be a function of projectile and target material as well as velocity. Therefore, the following relationships were chosen as being representative:

$$\begin{aligned} (P/d)_{\text{thin target}} &= 1.5 (P/d)_{\text{semi } \infty} \quad (\text{min}) \\ &= 2.0 (P/d)_{\text{semi } \infty} \quad (\text{max}) \end{aligned}$$

As noted, the equating of $(P/d)_{\text{thin target}}$ to t_A will produce a shield angle below which ricochet occurs and above which perforation occurs. This shield angle is defined as σ_1 .

The results of this equation are shown in Table 2.

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Table 2
RICOCHET-PERFORATION CROSSOVER REGION

PROJECTILE		SHIELD		
d (inches)	v (fps)	t _s (inches)	α ₁	
			Experimental	Predicted
0.250	25500	0.100	α ₁ < 10°	5° < α ₁ < 8°
0.125	8200	0.050	10° < α ₁ < 20°	13° < α ₁ < 18°
0.375	25100	0.100	α ₁ < 10°	9° < α ₁ < 12°

Note: α₁ is the shield angle below which ricochet occurs and above which perforation occurs.

Figures 15 and 16 demonstrate the variation of perforation area with velocity for shield angles of 60 degrees and 25 degrees respectively. For comparison, these graphs are replotted to show variation of perforation with respect to velocity for constant t_s/d; see, for example, Fig. 17a (t_s/d = 0.27) and Fig. 17b (t_s/d = 0.40). Although normal impacts show an essentially linear variation with velocity, this does not seem to be the case for shield angles other than normal. The perforation area increases with velocity, but the rate of increase decreases with increasing velocity. This rate also seems to be a function of shield angle and thickness. It is interesting to note that for Al - Al impacts, the following variation of Equation (1) represents the hole minor diameter in the region 20° < α ≤ 90°:

$$\frac{D_{\text{minor}}}{d} = 0.1372 v \sin \alpha \left\{ \frac{t_A}{d} \right\}^{2/3} + 0.90$$

$$\text{where } t_A = t_s / \sin \alpha$$

Although the perforations are elliptical, the hole major diameter is a function of velocity, thickness, and angle; hence no simple adequate expression for actual area can be derived without making gross assumptions. This expression, however, is believed to represent a minimum perforation area and to be especially representative of the damage when 60° < α ≤ 90°, for it is in this region that D_{major} ≈ D_{minor}.

The properties of projectile and target materials also govern hole size. It has been demonstrated that, all else constant, a decrease in the shield strength will produce a larger hole. (Ref. 16) Other physical property variations have produced indeterminate results and no definite correlations are

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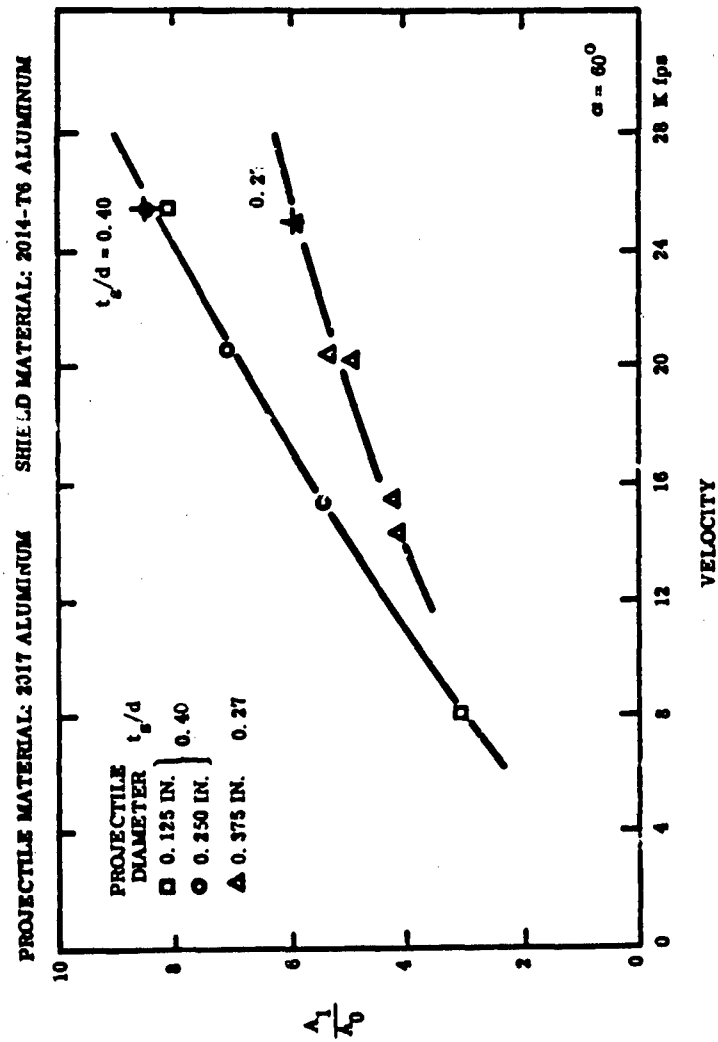


Fig. 15 Shield Damage, $\alpha = 80^\circ$, Effect of Variation of Velocity

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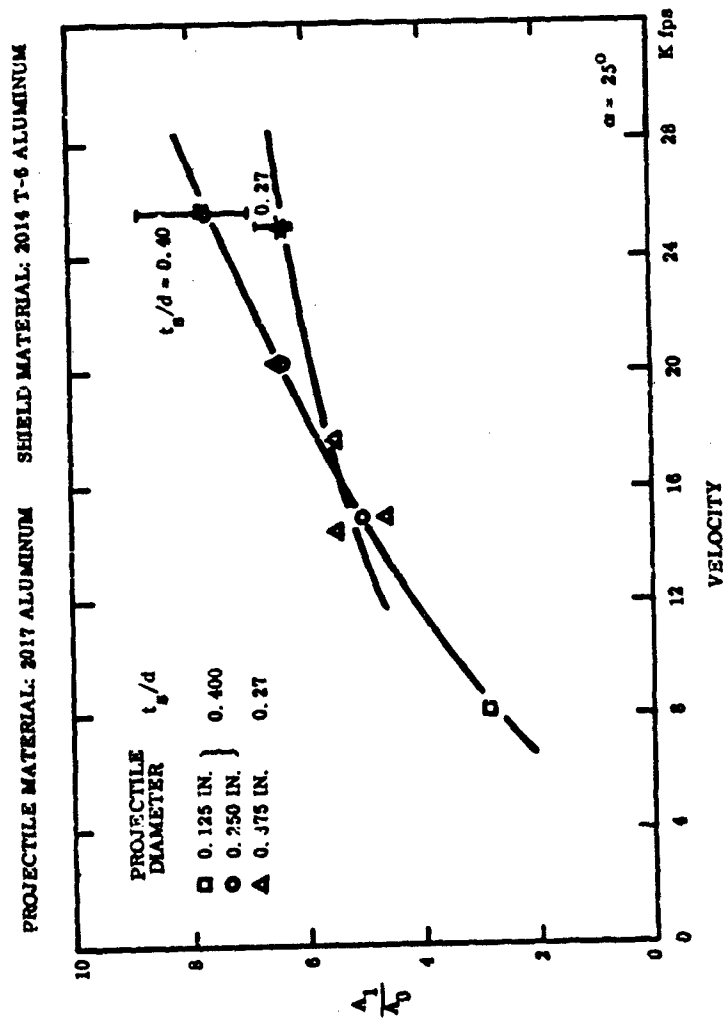


Fig. 16 Shield Damage, $\alpha = 25^\circ$, Effect of Variation of Velocity

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PROJECTILE MATERIAL: 2017 ALUMINUM

SHIELD MATERIAL: 2014-T6 ALUMINUM

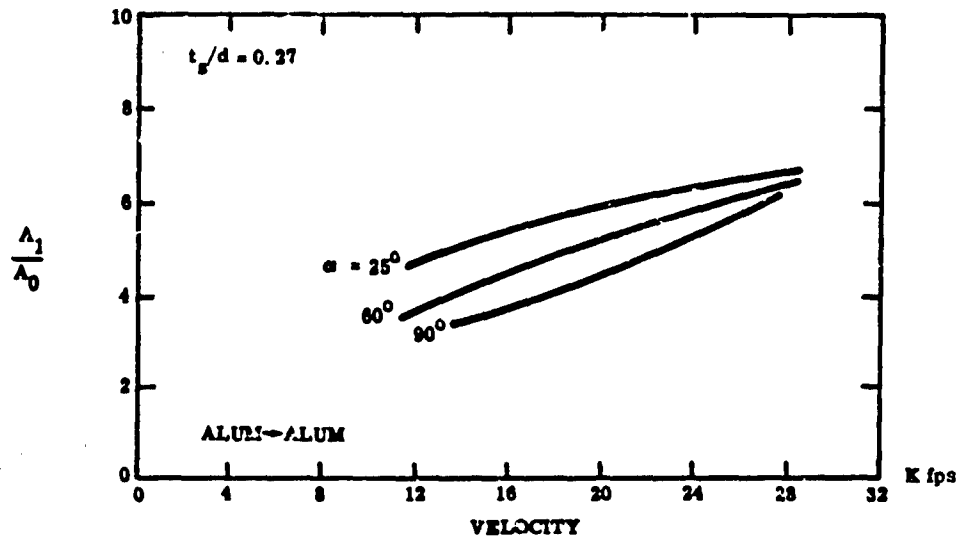


Fig. 17a $t_s/d = 0.27$

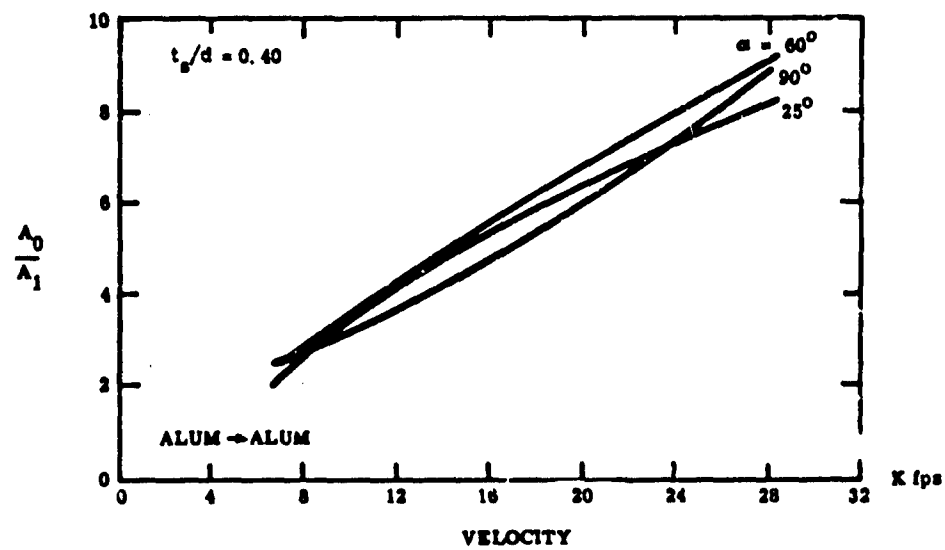


Fig. 17 Shield Damage, Effect of Variation of Velocity, Constant t_s/d

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available. However, the changes in hole area resulting from the differences in physical properties appear to be insignificant compared to the changes in hole area resulting from different angles of incidence.

2.4 Target Sheet Analysis

The effect of projectile impact on the shield, or "outer spacecraft shell," has been explored extensively on the preceding pages. The subsequent effects of impact will next be investigated. In certain cases, the second sheet (target sheet) in the analog structure is the main hull - the structural-load-carrying hull. The vulnerability of this sheet, then, is of paramount importance. In review (see Fig. 4), the target sheets for this program have been primarily 0.100-in. 2014-T6 aluminum, except for a short test series with 0.028-in., Type 302 stainless steel targets. The spacing between the target sheet and its shield has been varied from 4 to 24 inches, and the angle of incidence β of the target sheet has been set at 90, 60, and 25 degrees.

The spray patterns obtained from a typical sequence of firings using 2017-aluminum spheres are shown in Fig. 18. The spheres are 3/8 inch in diameter, the spacing between the shield and target along the projectile flight line is 24 inches, and the mean projectile velocity is 25,000 fps.

A review of these targets indicates that an appraisal of the damage potential of the spray is so complicated that a qualitative assessment is required. In order to understand the phenomenon, it is therefore necessary to consider first the simplest case, i.e., normal impact, referring both to the shield ($\alpha = 90^\circ$) and to the target sheet ($\beta = 90^\circ$) behind the shield.

The phenomena of normal hypervelocity impact has been summarized in Section I, and many authors have presented theories and corroborating experimental evidence (Refs. 9 - 13). Suffice to say, then, that impact velocity, more than any other factor, will affect the target damage resulting from any projectile-shield combination. Typical spray patterns obtained by varying the projectile velocity are shown in Fig. 12. These experiments at different velocities illustrate two important results.

(1) Increased velocity results in more complete fragmentation of both projectile and shield.

X-rays of impact show that at low velocities the projectile suffers very little damage during perforation (see Fig. 19), and that only sparse, large, irregular fragments emanate from the shield. At 25,000 fps, however, the spray particles emitted from the back of the shield are so minute and diverse that they are difficult to distinguish from the background of the radiograph.

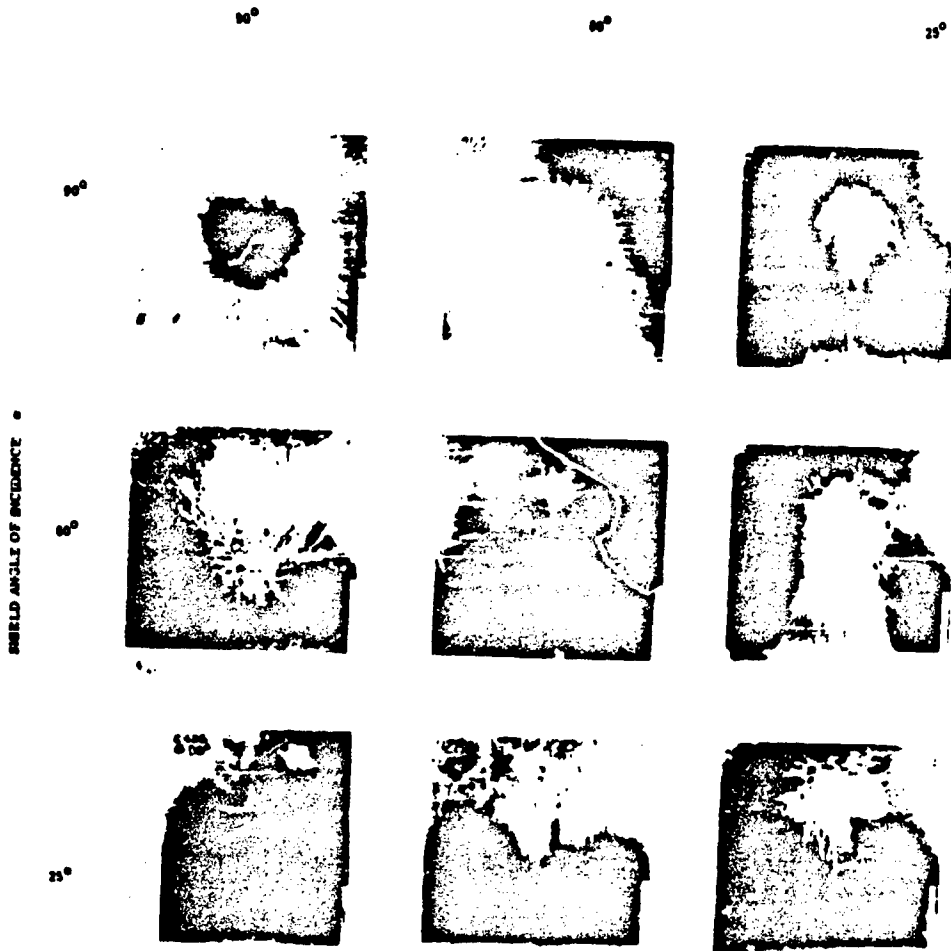
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PROJECTILE MATERIAL: 2017 ALUMINUM
DIAMETER: 0.315 in.
VELOCITY: > 25,000 fpm

SHIELD
TARGET

MATERIAL: 2014-T6 ALUMINUM
THICKNESS: 0.100 in.
SPACING: 24 in.

TARGET ANGLE OF INCIDENCE - θ



NOTE: TARGET IN LOWER LEFT CORNER IS 26" x 50". ALL OTHER TARGETS SHOWN ABOVE ARE 26" x 36"

Fig. 18 Typical Target Spray Patterns (Shields removed), Al - Al

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2017 T6 ALUMINUM
SHIELD TO TARGET SPACING = 12 INCHES

$t_s/d = 0.40$	0.27	0.27
$d = 0.125$ IN	0.375 IN	0.375 IN

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$V = 25,000$ fms



$V = 20,000$ fms



$V = 15,000$ fms



$V = 8,000$ fms

Fig. 19 Typical Target Spray Patterns -- Effect of Variation of Velocity

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(2) Increased velocity results in a greater dispersal of both projectile and shield fragments.

This result can also be seen in Fig. 19. With each increase in velocity (intersheet spacing constant), a greater target sheet area is affected. This effect of velocity on projectile-shield fragment dispersal is also shown graphically (Fig. 20) for Al - Al impacts by plotting projectile- and spall-spray semi-angles for two combinations of projectile and shield. The projectile-spray semi-angle γ is defined here as

$$\gamma = \tan^{-1} \frac{D_p}{2S}$$

where D_p is relevant diameter of damage on the target sheet, and S is intersheet spacing between shield and target, measured along the projectile flight line. The spall-spray semi-angle θ is

$$\theta = \tan^{-1} \frac{D_s}{2N}$$

where D_s is relevant damaged diameter centered at the point where a normal drawn from the point of impact on the shield intersects the target, and N is the length of the appropriate perpendicular (in this case where $\alpha = \beta = 90^\circ$, $N = S$). Figures 18 and 19, however, show that it is difficult to define a meaningful diameter of damage, and that physical limitations preclude the inclusion of all spall fragments. As a result, the criterion that was chosen provided that approximately 90 percent of the spall damage to the target should fall within the chosen diameter. A typical target with appropriate measurements is shown in Fig. 21.

In addition to demonstrating that fragment dispersion increases with increasing velocity, Fig. 20 shows effects of sheet thickness (t_s/d) on dispersion angles. It can be seen that at high velocities the spall-spray from the thinner target is more concentrated about the flight line, and the maximum dispersion angle is smaller. The projectile-spray angle appears to be independent of such small changes in t_s/d .

An interesting side note is provided by Fig. 22, in which the angles γ and θ are superimposed on a radiograph of a projectile-shield combination 10 μ sec after impact.

It has been shown that the spray emitted from the rear of the shield at normal incidence is symmetric about the original projectile flight line. Under conditions of oblique impact, however, the spray distribution is deflected from the flight line towards the normal through the center of the perforation. The spray seems to be composed of two patterns:

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM

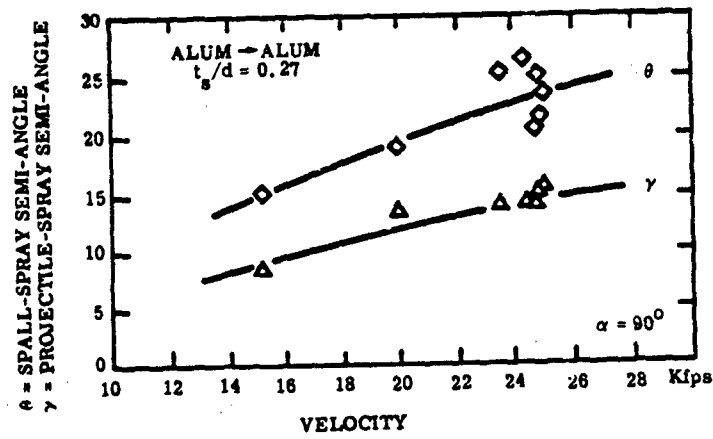


Fig. 20a $t_s/d = 0.27$

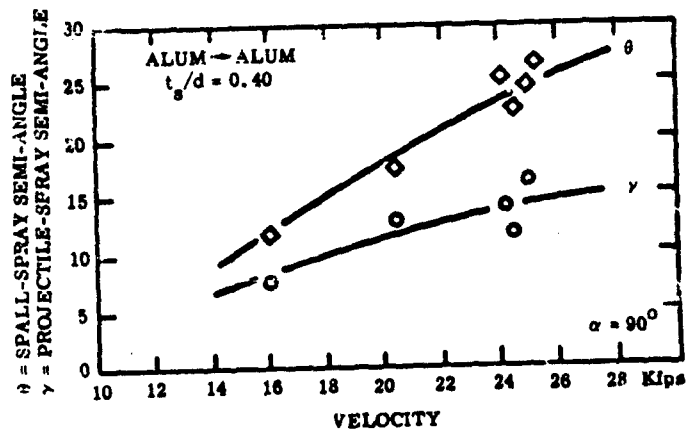


Fig. 20b $t_s/d = 0.40$

Fig. 20 Spall and Projectile Spray Angle Variation with Velocity ($\alpha = 90^\circ$)

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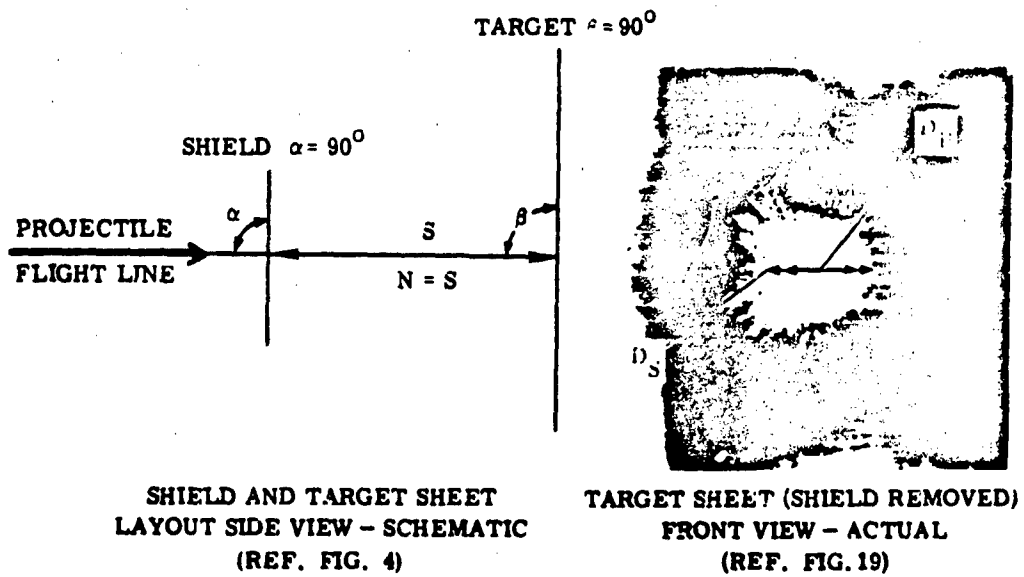


Fig. 21 Analysis of Spall and Projectile Spray Angles

PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM

DIAMETER: 0.375 IN.

$t_s/d : 0.27$

VELOCITY: 23,500 fps

$\theta : 25^\circ$

$\gamma : 14^\circ$ (REF. FIG. 20a)

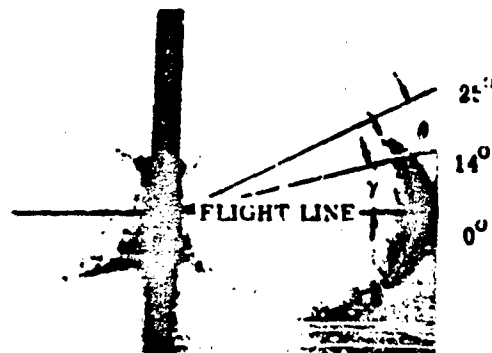


Fig. 22 Superposition of Spray Angles on Typical X-Ray of Projectile-Shield Impact

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(1) Fragments distributed about a normal through the shield (probably resulting from shock propagation through the target, i. e., target spall)

(2) Fragments distributed about the original projectile flight line (composed mainly of projectile fragments)

The radiographs shown in Fig. 23 illustrate this point. The normal configuration is the same one noted earlier. In this case, the projectile is completely pulverized and spread over so large a surface that it is difficult to distinguish between damage from the projectile and damage from spall fragments. As the shield incident angle α decreases, however, the obliquity or incident angle effect becomes more apparent. Thus, at $\alpha = \beta = 60^\circ$ the two patterns are easily discernible and it can be seen that the spall-spray angle θ has decreased. At $\alpha = \beta = 25^\circ$ the target has nearly defeated the projectile (note the minor damage on the plane of the projectile flight line), and the severe target damage has been caused by the large, irregular pieces of spall ejected normally from the shield surface. These observations have been plotted as $\gamma - \alpha$ and $\theta - \alpha$ for two combinations of projectile and shield (Figs. 24 and 25). In both cases it is apparent that as α is decreased, the target sheets are subjected to spall-spray damage long after the hazard from projectile-spray has ceased.

Superimposed on the spall-spray curves are the lower limit predictions ($\theta = 0$) found in Table 2. These predictions seem to be in good agreement with the trend of the curves, but further testing will be required to obtain a velocity-dependent T^*/P for 2014-T8 aluminum that may exceed the assumed value of 2.0. (Note: T^* = maximum thickness of target for complete penetration, and P = crater depth of semi-infinite target.)

The lower limit of the projectile-spray curve ($\gamma = 0$) can be predicted by the expression,

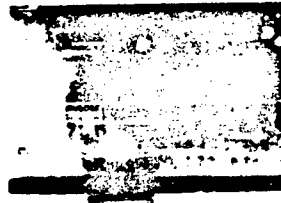
$$t_A = d \sqrt{\rho_P / \rho_T} \quad \text{where } t_A = t_s / \sin \alpha^* \quad (\text{Ref. 13})$$

This simple variation of the proven expression of primary penetration depth (Ref. 15) defines an angle α^* below which there will be no damage from in-line spray particles, i. e., no target damage in the direction of the projectile flight line. Typical values of α^* are shown in Table 3.

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PROJECTILE MATERIAL: 2017 ALUMINUM
DIAMETER: 0.375 IN.
VELOCITY: 25,000 ft/sec
SHIELD TARGET MATERIAL: 2014 T6 ALUMINUM
 $t_s/d : 0.27$
SPACING: 12 INCHES

$\alpha = 90^\circ$



FLIGHT
↑
LINE

$\alpha = 60^\circ$



$\alpha = 30^\circ$



PLANE OF
↑
FLIGHT LINE



Fig. 23 Typical Target Patterns - Effect of Variation of Shield Angle

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PROJECTILE MATERIAL: 2017 ALUMINUM
DIAMETER: 0.375 IN
VELOCITY: 25000 fps

SHIELD MATERIAL: 2014-T6 ALUMINUM
 $t_s/d : 0.27$

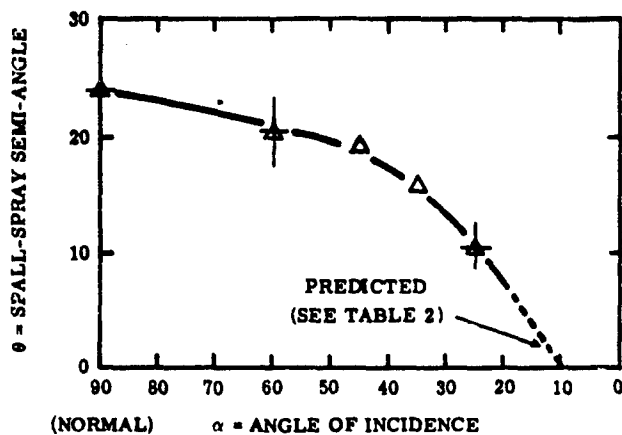


Fig. 24a Spall-Spray Semi-Angle

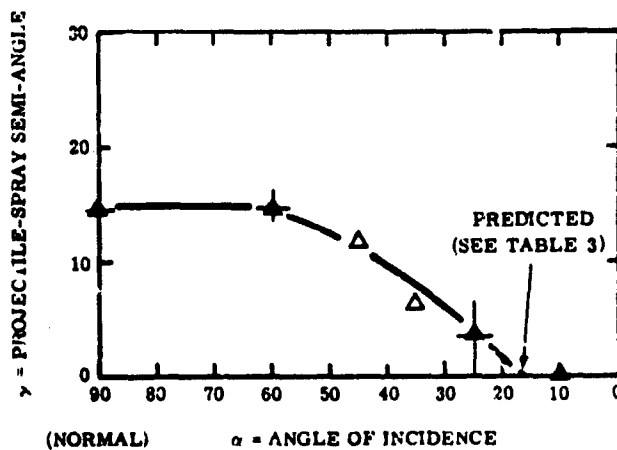


Fig. 24b Projectile-Spray Semi-Angle

Fig. 24 Spall and Projectile Spray Angle Variation with Shield Angle - Al - Al ($t_s/d = 0.27$)

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM
DIAMETER: 0.25 IN $t_g/d : 0.40$
VELOCITY: 25,500 fps

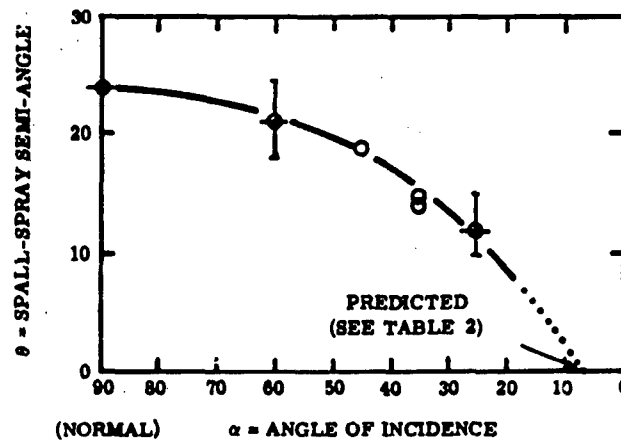


Fig. 25a Spall-Spray Semi-Angle

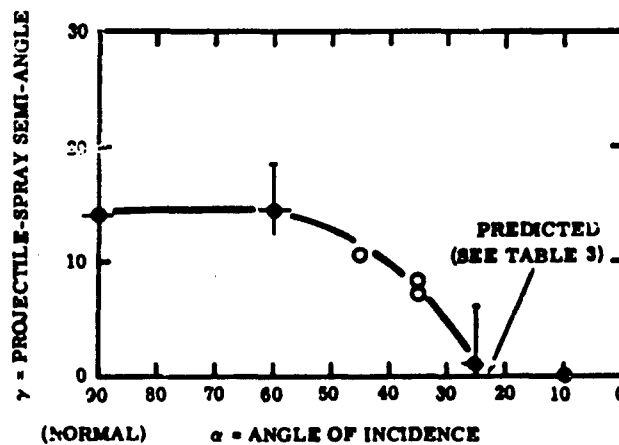


Fig. 25b Projectile-Spray Semi-Angle

Fig. 25 Spall and Projectile Spray Angle Variation
with Shield Angle - Al - Al ($t_g/d = 0.40$)

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Table 3
LIMITING SHIELD ANGLE TO PREVENT PROJECTILE SPRAY DAMAGE

ρ_P (gm/cc)	ρ_T (gm/cc)	t_s/d	α^*	
			Experimental	Predicted
2.70	2.70	0.27	16° (Fig. 24)	15.5°
2.70	2.70	0.40	24° (Fig. 25)	23.6°
19.1	1.77	0.70	12° < α^* < 15° ⁽⁶⁾	12.3°
8.90	2.70	0.534	-	17.2°
8.90	8.1	0.15	-	8.2°

The lack of data precludes experimental predictions of α_1 and α^* for impacts of Ni - Al and Ni - stainless steel; although no data has been plotted, selected points are included in Appendix I.

Figure 26 illustrates the variation with velocity of spall-spray and projectile-spray angles when $\alpha = 60^\circ$. The curve trends shown here are similar to those of Fig. 20 for $\alpha = 90^\circ$; hence, the conclusions are the same. Insufficient data prevents comment on velocity variation when $\alpha = 25^\circ$.

2.5 Total Target Vulnerability

The purpose of these tests is to define the vulnerability of the total structure, or system, under set conditions of projectile impact. There is, therefore, an interest in total penetration, because penetration is indicative of (1) the ability of a shield to fragment the projectile, to spread these fragments and reduce their velocities, and (2) the ability of the target sheet to resist these fragments.

Material considerations aside, total penetration is primarily a function of sheet thickness, projectile velocity, and intersheet spacing. (For this report, only total penetrations when $\alpha = \beta = 90^\circ$ have been plotted. Target damage is shown both pictorially (Fig. 27) and graphically (Fig. 28).) When intersheet spacing is small, target failure takes the form of perforation by projectile and spall fragments, and petalling from the high impulse loads. As the spacing is increased, neither perforation nor petalling occurs. Note that at larger spacings the target sheet is vulnerable to the projectile of greater mass, e. g., when $t_s/d = 0.27$ and $t_s = 0.100$ in. (Fig. 27).

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM

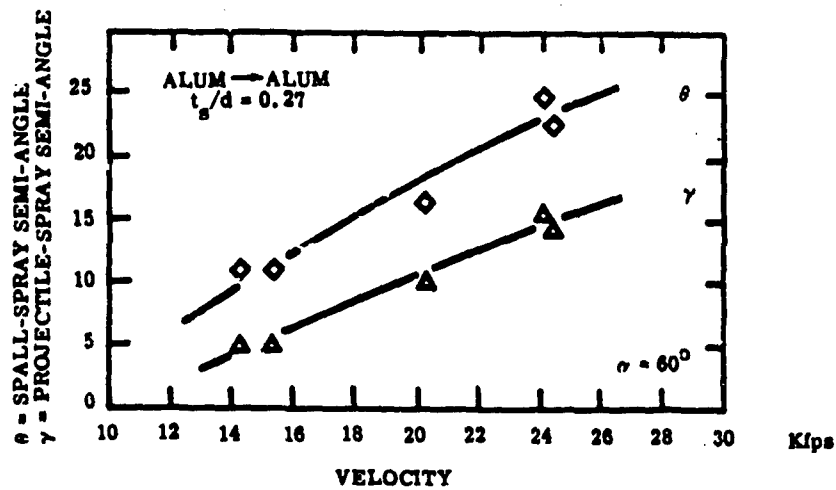


Fig. 26a $t_s/d = 0.27$

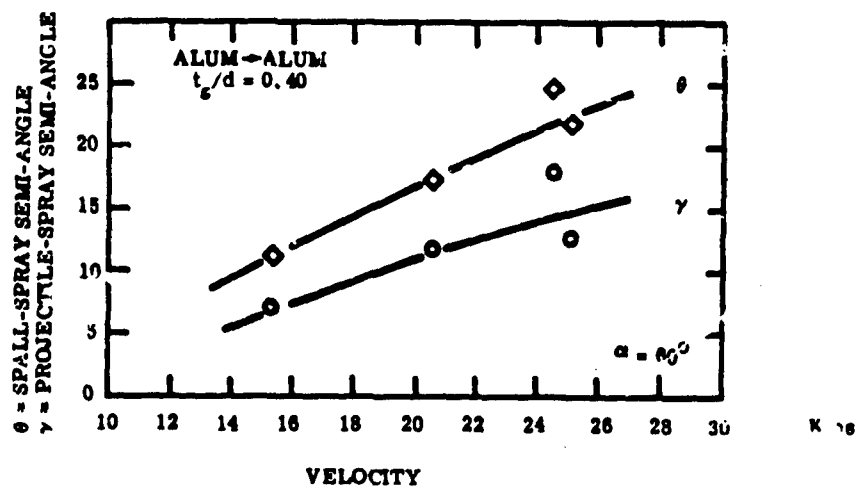


Fig. 26b $t_s/d = 0.40$

Fig. 26 Spall and Projectile Spray Angle Variation with Velocity ($\alpha = 60^\circ$) 37

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PROJECTILE MATERIAL: 2017 ALUMINUM
DIAMETER: 0.375 IN.
VELOCITY: 25,000 fps

SHIELD } MATERIAL: 2014-T6 ALUMINUM
TARGET }

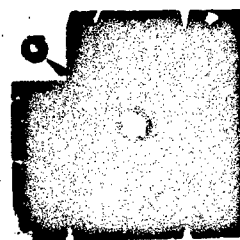
$\alpha = \beta = 90^\circ$

INTER-SHEET SPACING 4 IN.
(S)

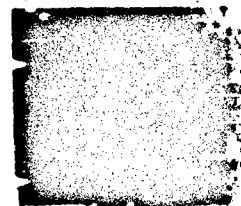
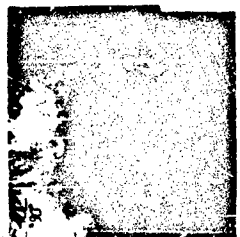
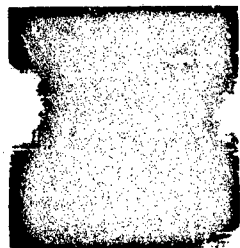
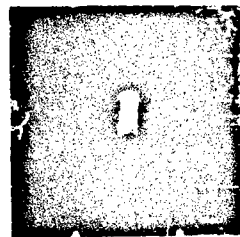
6 IN.

12 IN.

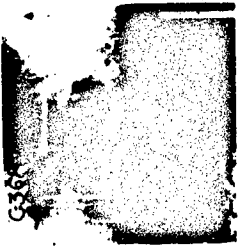
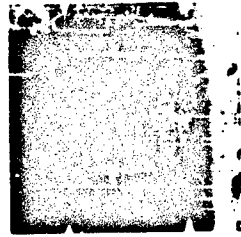
24 IN.



$t/d = 0.37$



$t/d = 0.40$



TARGET SHEETS WHERE S = 4 AND S = 6 ARE 18 IN. x 18 IN.; OTHERS SHOWN ARE 36 IN. x 36 IN.

Fig. 27 Typical Target Patterns - Effect of Variation of Intersheet Spacing

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PROJECTILE MATERIAL: 2017 ALUMINUM
 SHIELD: }
 TARGET: } MATERIAL: 2014-T6 ALUMINUM
 WITNESS: }

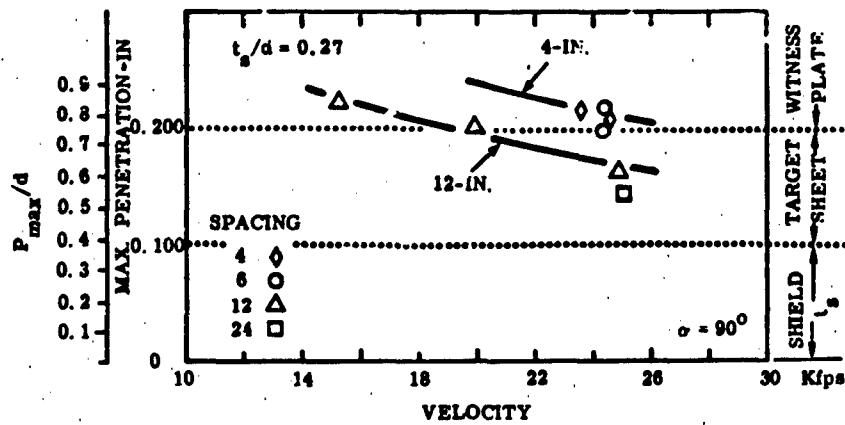


Fig. 28a $t_s/d = 0.27$

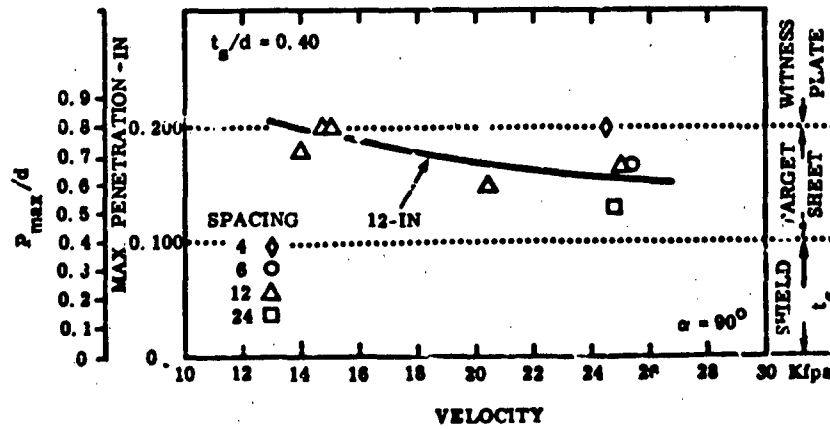


Fig. 28b $t_s/d = 0.40$

Fig. 28 Effect of Velocity on Maximum Penetration - Al - Al ($\alpha = 90^\circ$)

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To present an overall picture of the vulnerability of the aluminum analog structures, a ballistic limit approach has been chosen: either perforation or no perforation of the target sheet. Spacings of both 12 and 24 inches have been considered, along with the surmised cause of damage - either projectile fragments or spall. This data is presented in Figs. 29 and 30, which show that as the shield and target impact angles are varied, target sheet failure results from different mechanisms. However, it can be seen that the resultant damage of any configuration is governed primarily by the shield angle α . Since the results for all four cases are similar, discussion is limited to the case where $t_s = 0.27$ and intersheet spacing = 12 inches. Under conditions of normal impact, no perforations from either projectile fragments or spall occurred, although the target sheet from the $\alpha = \beta = 90^\circ$ impact appeared in danger of rupture from projectile-fragment and spall-fragment momentum loading. When $\alpha = 60^\circ$, no perforations resulted from spall, although the projectile fragments perforated when $\beta = 60^\circ$ and 90° . It is felt that the extreme obliquity of the target sheet when $\beta = 25^\circ$ defeated these fragments. When $\alpha = 25^\circ$, the major damage to the target sheets resulted from the irregular spall fragments ejected from the shield; these perforated the target sheet under all conditions. Again, when $\beta = 25^\circ$, the angle of obliquity of the target sheet was sufficient to defeat the projectile fragments.

With the 0.3-gm 2017 aluminum projectiles and the 0.100-inch 2014-T6 aluminum shield and target as references, two series of tests involving nickel spheres of equivalent mass and Type 302 stainless steel shields and targets of equivalent strength were conducted. Typical results are shown pictorially in Fig. 31 and numerically in Appendix I. It can be seen that in all cases the nickel projectiles are more lethal than the aluminum. A review of the witness sheet penetrations indicates that the stainless steel analog structure is generally less vulnerable than the aluminum when impacted by nickel projectiles. However, a larger sample of materials should be tested before any conclusions are drawn regarding projectile and shield-target physical properties.

2.6 Impact Flash Phenomenon

An investigation of the phenomenon of impact flash was made along with the hypervelocity impact study. This investigation was to qualitatively determine the pertinent variables affecting impact flash with the ultimate goal of using the information to assess the impact flash phenomenon as a spatial hit detector or target discriminator. Although open-shutter and high-speed framing cameras have provided results concerning total radiant energy and flash duration (Fig. 32), more precise empirical data will be required for the above application. Pursuant to this, a series of photomultiplier detectors, sensitive to visible and near-visible radiation, were chosen for a parametric investigation. (See Section 2.1 for instrumentation details.) During this study, only the peak luminosity I_p displayed on the typical oscilloscope trace (Fig. 32) has been correlated (I_p is defined as the maximum

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PROJECTILE: MATERIAL: 2017 ALUMINUM
DIAMETER: 0.375 IN.
VELOCITY: 25,000 fps

SHIELD } MATERIAL: 2014-T6 ALUMINUM
TARGET } THICKNESS: 0.100 IN.
 $t_g/d: 0.27$

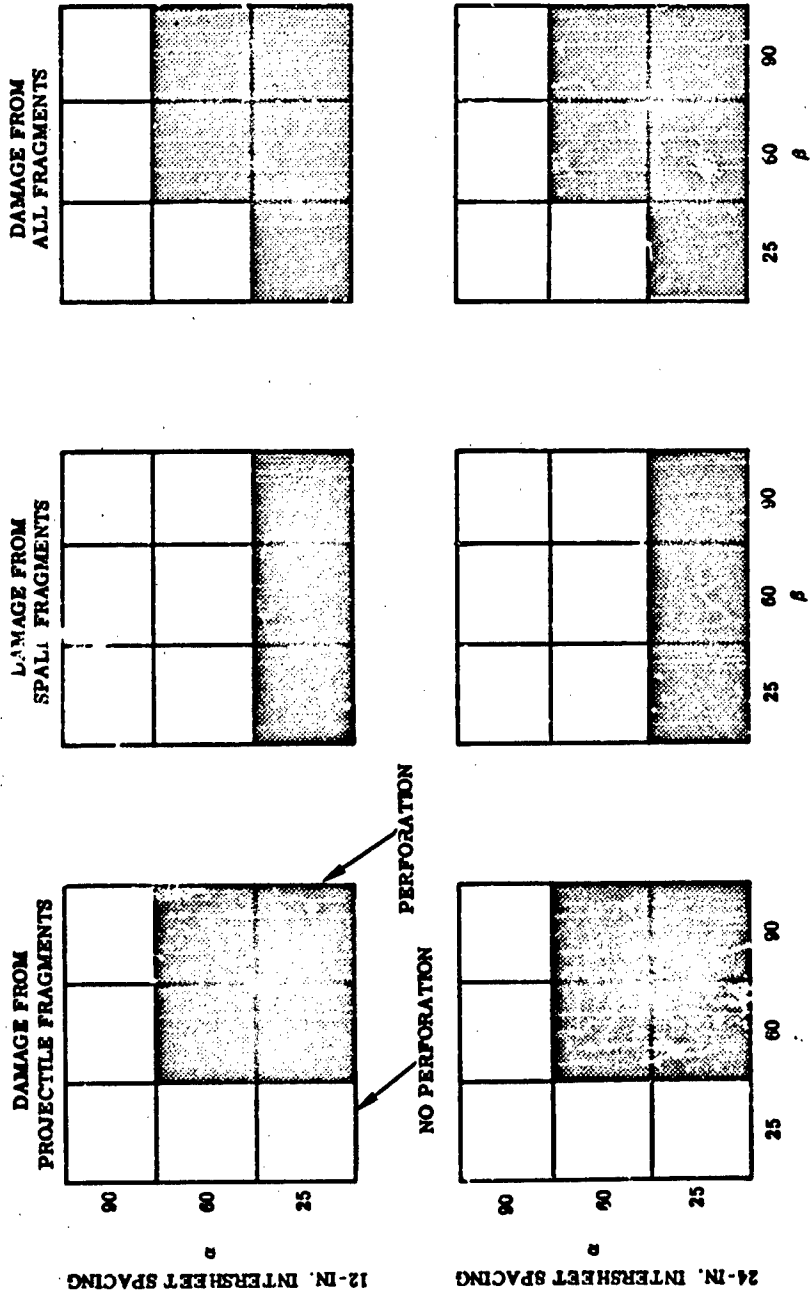


Fig. 29 Vulnerability of Multisheet Thin Target Assembly, Al - Al ($t_g/d = 0.27$, $v = 25,000$ ps)

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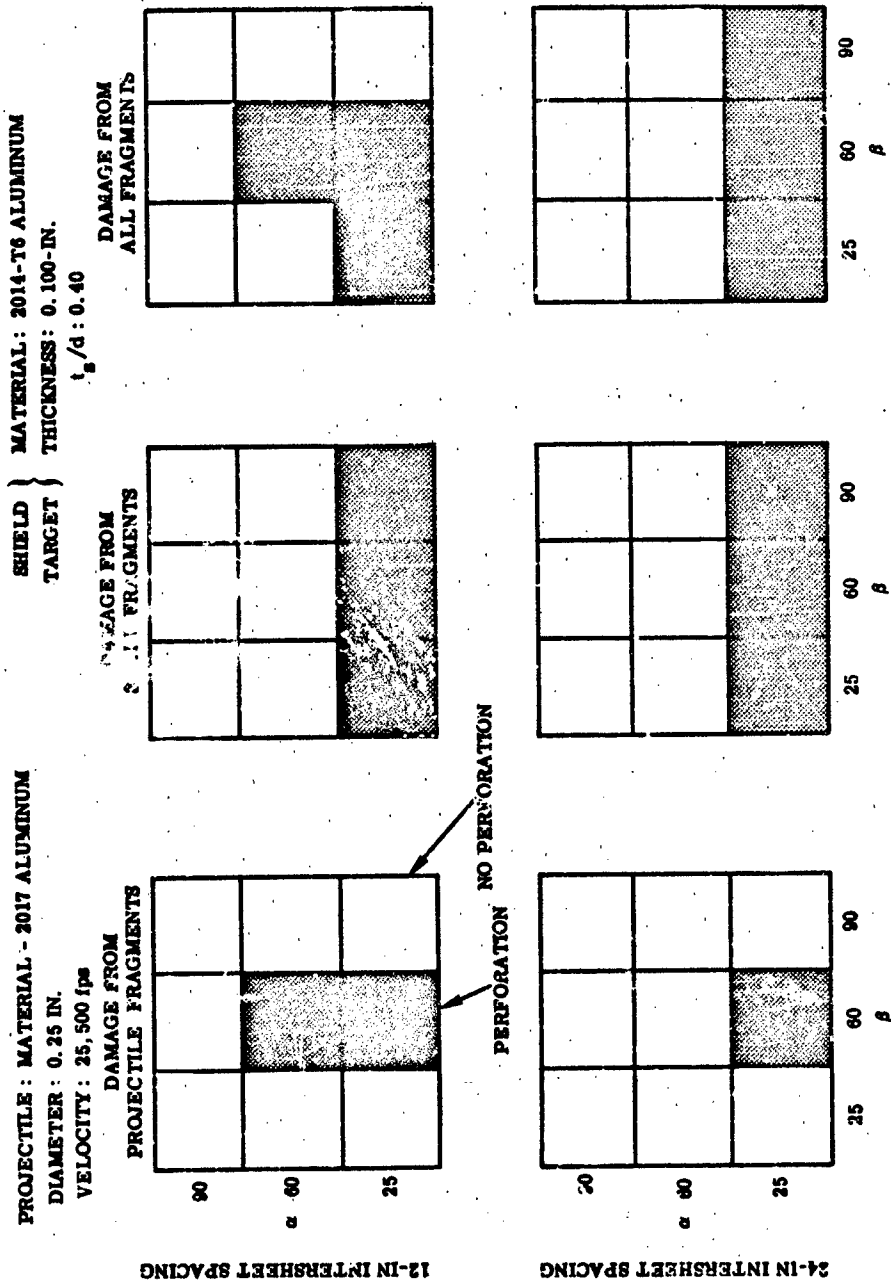


Fig. 30 .ulnerability of Multisheet Thin Target Assembly, Al ~ Al ($t_s/d = 0.40$, $v = 25,000$ fps)

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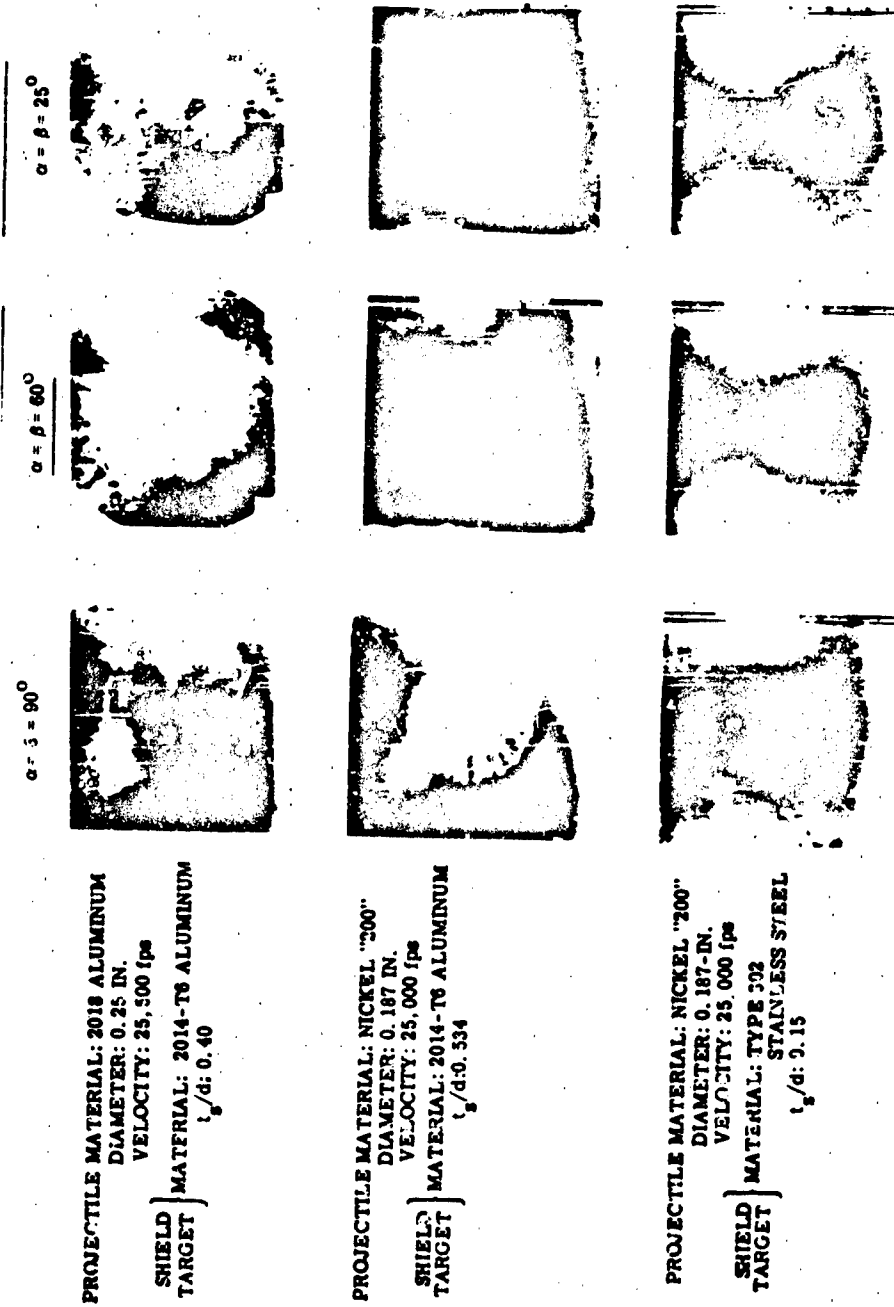


Fig. 31 Typical Target Patterns - Effect of Varied Projectile and Target Assembly Materials

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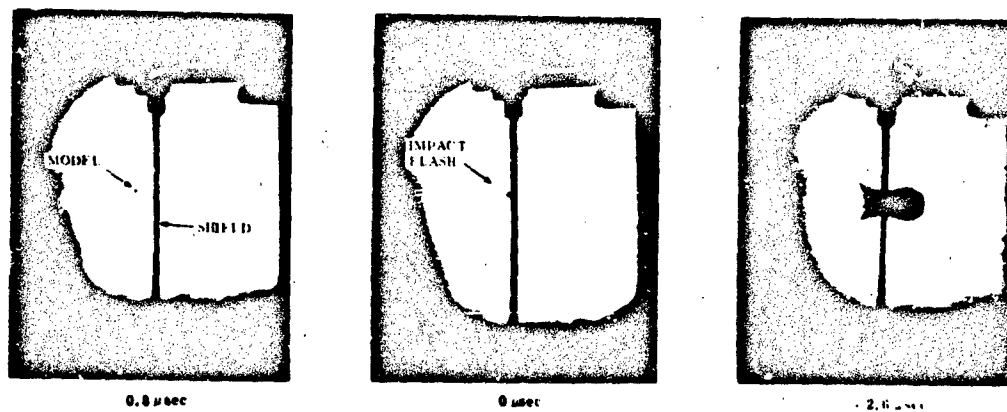


Fig. 32a Typical B/W Framing Camera Sequence of Impact Flash

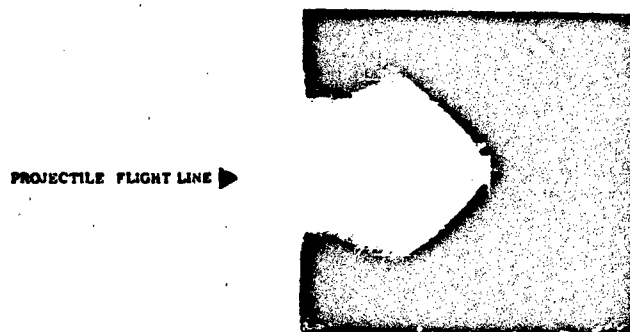


Fig. 32b Typical Open-Shutter Camera Photograph of Impact Flash

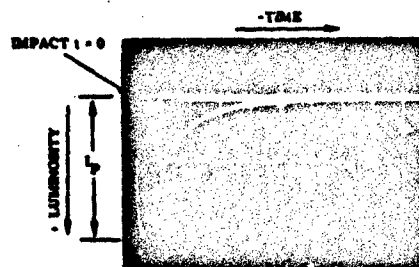


Fig. 32c Typical Oscilloscope Trace Showing Intensity-Time History of Impact Flash

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recorded luminosity occurring within the first few microseconds after contact of the projectile with the shield and before any possible interference effects from spall splatter on the target sheet or on the walls of the impact chamber).

Again, since one of the projected uses of the impact flash phenomenon is that of a spatial hit detector or target discriminator, obviously the existence of impact flash under environmental conditions of reduced gas pressure must be proved. To this end, experiments involving Al - Al impacts were conducted in reduced atmospheres of air and helium (the helium simulates an inert atmosphere). It can be seen in Fig. 33, for V-constant, that the peak luminosity is essentially invariant in an inert atmosphere and also that only above 1 torr (mm of Hg) is the surrounding air observed to have any significant effect.

To determine the relationship of the impact flash to the many possible projectile parameters, experiments were conducted in which size and velocity of the projectile varied. Projectile and target materials were limited to those discussed earlier - 2017 Al for the projectile and 2014-T6 Al for the target. Three independent tubes monitored tests with projectiles 0.125 inch in diameter to determine any dependence of frequency response to velocity. (See Fig. 34.) Plotted log-log, the peak luminosity is shown to vary as the fourth power of velocity, a relationship independent of the monitored frequency. When data obtained from larger projectiles (0.25 inch and 0.375 inch) was compared to that from the 0.125-inch projectile impacts, the impact flash intensity was found to be a direct function of the area presented by the projectile.

These experimental results confirmed that the following empirical relationship, generated from tests on semi-infinite targets, can be applied to thin sheet impacts under conditions of normal impact.

$$I_{np} = CAv^n \quad (\text{Ref. 17})$$

where

I_{np} = peak luminosity (see definition), normal impact

A = cross-sectional area of projectile

v = projectile velocity, fps

n = velocity exponent

C = a constant

Within the scope of the experiments conducted, measured values for the coefficient C are listed in Table 3 for Al - Al impacts.

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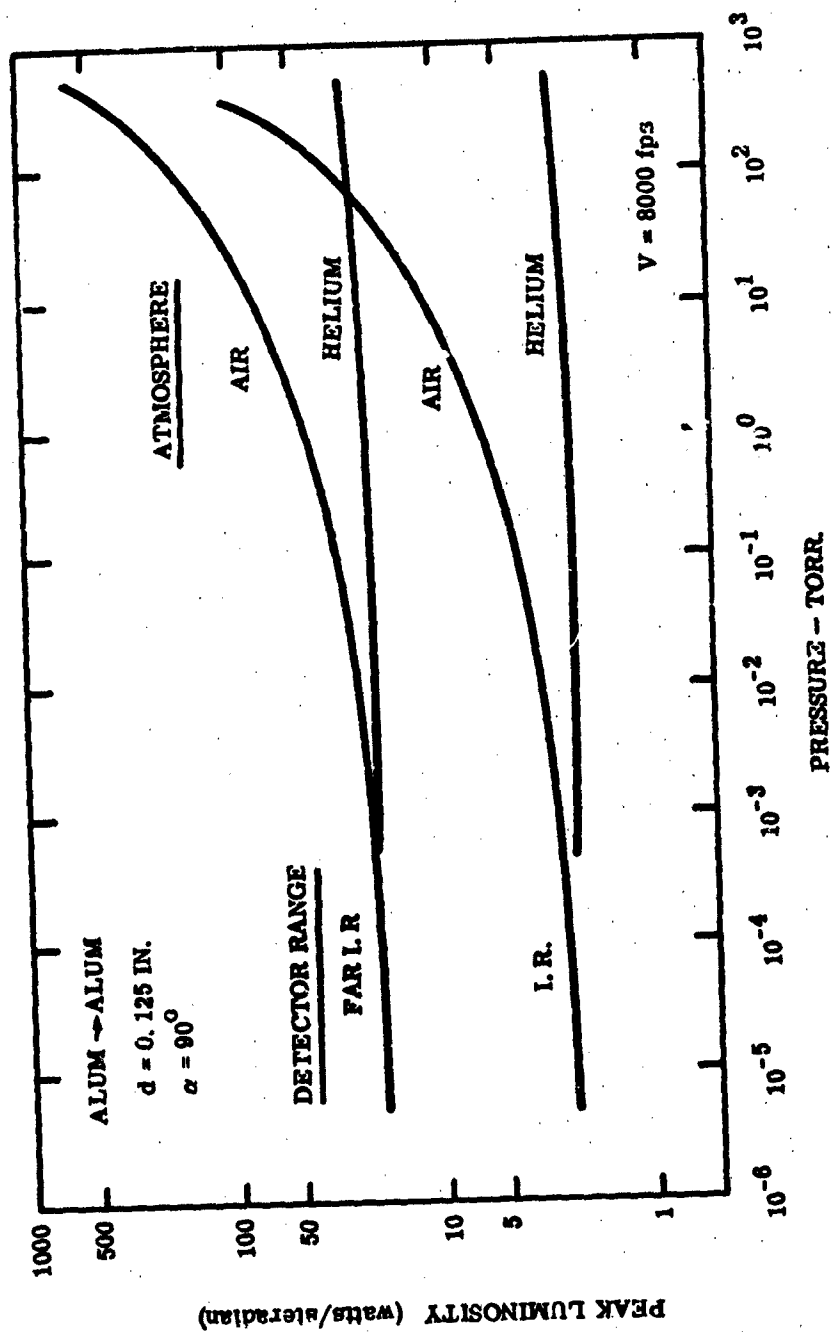


Fig. 33 Reduced Data - Air and Helium Atmospheres - Variation of Peak Luminosity with Range Pressures, Velocity Constant

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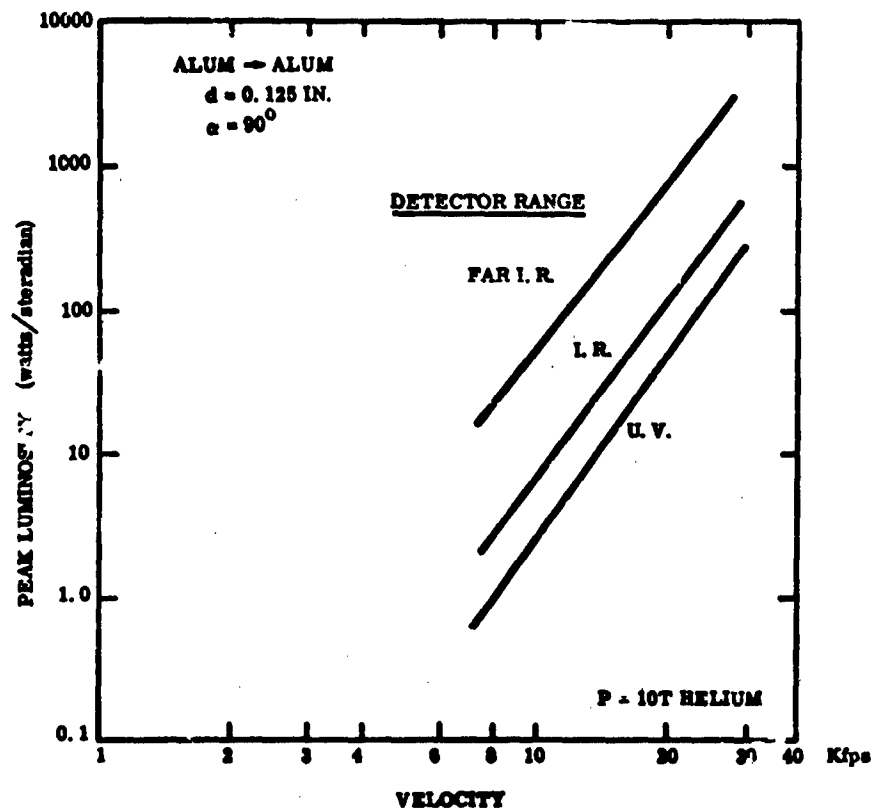


Fig. 34 Variation of Peak Luminosity with Velocity

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Table 3

$$I_{np} = C A v^n$$

VALUES OF TERMS FOR Al → Al IMPACTS

DETECTOR RANGE	n	C
0.18 μ to 0.55 μ	4.2	5.24×10^{-13}
0.594 μ to 1.0 μ	4.1	3.27×10^{-12}
1.0 μ to 5.5 μ	3.9	1.66×10^{-10}

Note: units of C - watts per steradian/ft² (fps)ⁿ

To appraise the effect of target incidence on peak luminosity, two series of tests were fired - one with semi-infinite targets, and the other with thin targets (Fig. 35). Within the limits of the data scatter, no differentiation can be made between the two sets of results. Furthermore, although data trends are indicated at $v = 9,000$ fps, there seems to be little variation in the peak luminosity (less than one order of magnitude) over the range of tested incident angles. Data from impacts at $v = 25,000$ fps confirms the velocity-power relationship over the range of tested incident angles.

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PROJECTILE MATERIAL: 2017 ALUMINUM SHIELD MATERIAL: 2014-T6 ALUMINUM
DIAMETER: 0.125 IN.

P: 10T HELIUM

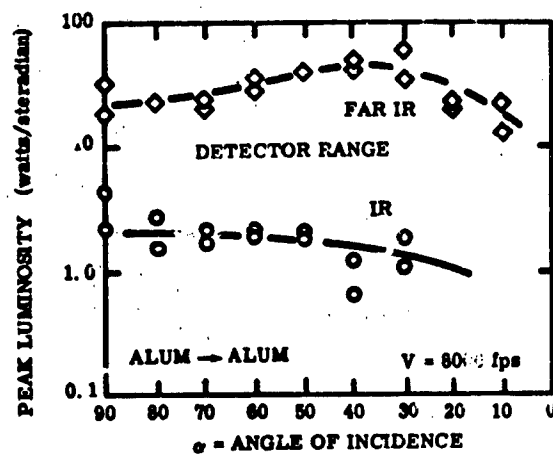


Fig. 35a Semi-Infinite Targets

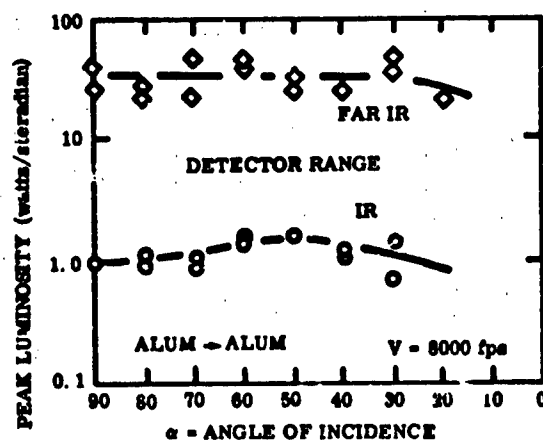


Fig. 35b Thin Targets - $t_s/d = 0.40$

Fig. 35 Reduced Data - Variation of Peak Luminosity with Shield Angle (Semi-Infinite and Thin Targets)

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SECTION III SUMMARY

In summary, the data has covered a range of incident angles from 2 to 90 degrees with various projectile-target combinations. Impact velocities have ranged from 8,000 to 25,600 fps, and shield-to-target spacings have varied from 4 to 24 inches. Although these experimental results are specific, they indicate more general behavior trends; thus, the following observations may be made:

- (1) For all projectile-shield material combinations, there is a shield angle below which ricochet occurs and above which perforation occurs. This angle is a function of projectile and shield material, projectile velocity, shield thickness, and impact angle. For Al - Al impacts when $v = 25,000$ fps, this angle is less than 10 degrees. For Ur - Mg impacts when $v = 23,000$ fps and $t_s/d = 0.70$, it is less than 2 degrees.
- (2) At constant hypervelocity, the ratio of shield perforation area to projectile presented area (A_1/A_0) increases slowly from its value at $\alpha = 90^\circ$ (normal) to maximum in the region $\alpha < 60^\circ$, then decreases sharply as $\alpha \rightarrow 0^\circ$. The magnitude and angular location of this maximum is a function of the projectile and shield materials, projectile velocity, and shield thickness. For any projectile-shield combination, greater damage is sustained by the thicker shield (velocity constant).
- (3) For normal impacts, the perforation area ratio (A_1/A_0) increases with approximately the first power of the impact velocity. However, for shield incident angles other than normal, although the perforation ratio (A_1/A_0) increases with velocity, the rate of increase decreases with increasing velocity.
- (4) Increased velocity results in more complete fragmentation of both projectile and shield, and in a greater dispersal of these fragments. Fragment dispersal increases with an increase in shield thickness.
- (5) Although spray angles are very difficult to define accurately, certain conclusions regarding their general behavior can be made. The projectile spray angle γ approaches zero degrees at some impact angle α^* where $\alpha^* > 0^\circ$ (velocity constant). This angle (α^*) may be predicted empirically using the shaped-charge primary penetrative formula. The spall-spray angle θ also decreases with decreased angle of incidence (velocity constant). Its lower limit may be predicted when it is considered that perforation ceases to occur when $\theta = 0$.

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- (6) Total penetration of target structure has been shown to be a function of
- (a) projectile and target materials
 - (b) projectile velocity
 - (c) intersheet spacing
 - (d) shield and target sheet angles of incidence

Of all the variables considered, shield and target angle are the most critical, since rarely will a conical or cylindrical spacecraft be struck normally. It has been shown that damage to any target structure is primarily governed by the shield angle, α . To illustrate: with $v = 25,000$ fps and $s = 12$ inches, no target sheet perforation was noted with the shield normal to the projectile attack. When the shield angle was set at 25 degrees, however, the target sheet was perforated in all cases, regardless of orientation.

- (7) The investigation of the phenomenon of impact flash may be summarized as follows:
- (a) Peak luminosity is independent of pressure in an inert atmosphere, and only above 1 torr is the surrounding air observed to have any significant effect.
 - (b) With normal impact, peak luminosity is a direct function of the projectile presented area.
 - (c) Peak luminosity (within the scope of the experiment) is independent of target sheet thickness. It should be noted that no tests have been performed using extremely thin foils as targets.
 - (d) Peak luminosity has a power relationship with velocity. For Al $\rightarrow$ Al impacts, $I_p \propto v^4$.
 - (e) Peak luminosity does not change significantly with changes of projectile impact angle.
 - (f) Peak luminosity is independent of viewing angle.

REFERENCES

1. F.L. Whipple, "The Meteoric Risk to Space Vehicles," Vistas in Astronautics, Vol. 2, Pergamon Press, New York, 1958, pp. 115-124
2. D.R. Christman, J.W. Gehring, C.J. Maiden, and A.B. Wenzel, "Study of the Phenomena of Hypervelocity Impact," Summary Report, Contract NAS8-5067, GM DRL Report No. TR63-216, Santa Barbara, Calif., Jun 1963
3. "Aerospace Research Capabilities," GM DRL Report No. TR63-223 (Revised), Santa Barbara, Calif., Apr 1964
4. "Propulsion System Damage Study (U)," ASD-TDR-63-2, Vols. I, II and III, Eglin AFB, Florida, Jan 1964
5. S.M. Halperson, "Some Phenomena Associated with Impacts Into Aluminum," Proc. of the Sixth Symposium on Hypervelocity Impact, Vol. II, Part 2, Cleveland, Ohio, May 1963
6. J.W. Gehring and R.L. Warnica, "Summary Report on Hypervelocity Impact Experiments," Contract AF 63(635)-2783, ASD-TDR-64-5, Eglin AFB, Florida, Feb 1964
7. G.R. Ny-mith and J.L. Summers, "An Experimental Investigation of the Impact Resistance of Double-Sheet Structures at Velocities to 24,000 Feet/Second," NASA TN-D-1431, Oct 1962
8. W. Herrmann and A.H. Jones, "Survey of Hypervelocity Impact Information," Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory, ASRL Report No. 83-1, Sep 1961
9. C.J. Maiden, J.W. Gehring, and A.R. McMillan, "Investigation of Fundamental Mechanism of Damage to Thin Targets by Hypervelocity Projectiles," Semiannual Report, Contract ARPA Nonr-3891(00)(X), General Motors Corporation, GM Defense Research Laboratories, Report No. TR63-208, Mar 1963. See also, C.J. Maiden, "Experimental and Theoretical Results Concerning the Protective Ability of a Thin Shield Against Hypervelocity Projectiles," Proc. of Sixth Hypervelocity Impact Symposium, Vol. III, Cleveland, Ohio, May 1963

10. C.J. Maiden, J.W. Gehring, and A.R. McMillan, "Investigation of Fundamental Mechanism of Damage to Thin Targets by Hypervelocity Projectiles," General Motors Corporation, GM Defense Research Laboratories Final Report, Contract ARPA Nonr-3891(00)(X), GM DRL Report No. TR63-225, Santa Barbara, Calif., Sep 1963
11. R.L. Bjork, "Meteoroids vs. Space Vehicles," ARS J., Vol. 31, No. 6, Jun 1961, pp. 803-807
12. A.C. Charters and J.L. Summers, "High-Speed Impact of Metal Projectiles in Targets of Various Materials," Proc. of the Third Symposium on Hypervelocity Impact, Armour Research Foundation, Chicago, Feb 1959
13. R.J. Eichelberger and J.W. Gehring, "Effects of Meteoroid Impact on Space Vehicles," ARS J., Vol. 32, No. 10, Oct 1962, pp. 1583-1591
14. W. Herrmann and A.H. Jones, "Correlation of Hypervelocity Impact Data," Proc. of the Fifth Symposium on Hypervelocity Impact, Colorado School of Mines, Nonr-(G)-0020-62(X), Vol. 1, Part 2, Apr 1962
15. E.P. Bruce, "An Experimental Evaluation of Hypervelocity Impact Effects on Spacecraft Structures (U)," GE MSD-RSD, GE Document No. 63SD819, Sep 1963
16. R.W. Watson, K.R. Becker, and F.C. Gibson, "Thin Plate Perforation Studies in the Velocity Range from 2 to 5 km/sec," Proc. of the Sixth Hypervelocity Impact Symposium, Vol. III, Cleveland, Ohio, May 1963
17. J.W. Gehring and D.W. Sieck, "Reaction of the Lunar Surface to the Impact of a Lunar Probe," Progress in Astronautics and Aeronautics, Vol. 10, Technology of Lunar Exploration, Academic Press, New York, 1963, pp. 97-136 (for a more complete discussion, see J.W. Gehring and R.L. Warnica, "An Investigation of the Phenomena of Impact Flash and Its Potential Use as a Hit Detection and Target Discrimination Technique," Proc. of Sixth Hypervelocity Impact Symposium, Vol. II, Part 2, Cleveland, Ohio, May 1963; J.W. Gehring, A.C. Charters, and R.L. Warnica, "Meteoroid Impact on the Lunar Surface," (paper presented at the Lunar Surface Material Conference, Boston, Massachusetts, May 21-23, 1963))

APPENDIX I

DATA

HYPERVELOCITY IMPACT DAMAGE

The following tables present the raw data gathered under the experimental portion of the program. The units are as follows:

- (1) All length measurements: inches
- (2) Velocity: feet-per-second
- (3) Weight: grams
- (4) Area: square inches

The errors on the data are as follows:

- (1) Projectile weight: $\pm .005$ gram
- (2) Projectile diameter: $\pm .0005$ inch
- (3) Projectile velocity: $\pm 1\%$
- (4) Sheet thickness: $\pm .001$ inch
- (5) Sheet spacing: $\pm .125$ inch
- (6) All hole and crater diamensions: $\pm .001$ inch

The measurements D_p and D_s (in inches) are defined in the text.

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57

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NAME & GRADE	AGE	SEX	PHYSICAL			MATH			READING			WRITING			TOTAL		
			HT.	WT.	HAIR	HT.	WT.	HAIR	HT.	WT.	HAIR	HT.	WT.	HAIR	HT.	WT.	HAIR
C-101	10	M	5'0"	110	B	5'0"	110	B	5'0"	110	B	5'0"	110	B	5'0"	110	B
C-102	10	F	4'8"	95	B	4'8"	95	B	4'8"	95	B	4'8"	95	B	4'8"	95	B
C-103	10	M	5'2"	120	B	5'2"	120	B	5'2"	120	B	5'2"	120	B	5'2"	120	B
C-104	10	F	4'6"	90	B	4'6"	90	B	4'6"	90	B	4'6"	90	B	4'6"	90	B
C-105	10	M	5'1"	115	B	5'1"	115	B	5'1"	115	B	5'1"	115	B	5'1"	115	B
C-106	10	F	4'9"	98	B	4'9"	98	B	4'9"	98	B	4'9"	98	B	4'9"	98	B
C-107	10	M	5'3"	125	B	5'3"	125	B	5'3"	125	B	5'3"	125	B	5'3"	125	B
C-108	10	F	4'7"	92	B	4'7"	92	B	4'7"	92	B	4'7"	92	B	4'7"	92	B
C-109	10	M	5'4"	130	B	5'4"	130	B	5'4"	130	B	5'4"	130	B	5'4"	130	B
C-110	10	F	4'5"	88	B	4'5"	88	B	4'5"	88	B	4'5"	88	B	4'5"	88	B
C-111	10	M	5'5"	135	B	5'5"	135	B	5'5"	135	B	5'5"	135	B	5'5"	135	B
C-112	10	F	4'4"	85	B	4'4"	85	B	4'4"	85	B	4'4"	85	B	4'4"	85	B
C-113	10	M	5'6"	140	B	5'6"	140	B	5'6"	140	B	5'6"	140	B	5'6"	140	B
C-114	10	F	4'3"	82	B	4'3"	82	B	4'3"	82	B	4'3"	82	B	4'3"	82	B
C-115	10	M	5'7"	145	B	5'7"	145	B	5'7"	145	B	5'7"	145	B	5'7"	145	B
C-116	10	F	4'2"	80	B	4'2"	80	B	4'2"	80	B	4'2"	80	B	4'2"	80	B
C-117	10	M	5'8"	150	B	5'8"	150	B	5'8"	150	B	5'8"	150	B	5'8"	150	B
C-118	10	F	4'1"	78	B	4'1"	78	B	4'1"	78	B	4'1"	78	B	4'1"	78	B
C-119	10	M	5'9"	155	B	5'9"	155	B	5'9"	155	B	5'9"	155	B	5'9"	155	B
C-120	10	F	4'0"	75	B	4'0"	75	B	4'0"	75	B	4'0"	75	B	4'0"	75	B
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C-123	10	M	6'1"	165	B	6'1"	165	B	6'1"	165	B	6'1"	165	B	6'1"	165	B
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C-125	10	M	6'2"	170	B	6'2"	170	B	6'2"	170	B	6'2"	170	B	6'2"	170	B
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C-147	10	M	7'1"	225	B	7'1"	225	B	7'1"	225	B	7'1"	225	B	7'1"	225	B
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C-159	10	M	7'7"	255	B	7'7"	255	B	7'7"	255	B	7'7"	255	B	7'7"	255	B
C-160	10	F	2'4"	25	B	2'4"	25	B	2'4"	25	B	2'4"	25	B	2'4"	25	B
C-161	10	M	7'8"	260	B	7'8"	260	B	7'8"	260	B	7'8"	260	B	7'8"	260	B
C-162	10	F	2'3"	22	B	2'3"	22	B	2'3"	22	B	2'3"	22	B	2'3"	22	B
C-163	10	M	7'9"	265	B	7'9"	265	B	7'9"	265	B	7'9"	265	B	7'9"	265	B
C-164	10	F	2'2"	20	B	2'2"	20	B	2'2"	20	B	2'2"	20	B	2'2"	20	B
C-165	10	M	8'0"	270	B	8'0"	270	B	8'0"	270	B	8'0"	270	B	8'0"	270	B
C-166	10	F	2'1"	18	B	2'1"	18	B	2'1"	18	B	2'1"	18	B	2'1"	18	B
C-167	10	M	8'1"	275	B	8'1"	275	B	8'1"	275	B	8'1"	275	B	8'1"	275	B
C-168	10	F	2'0"	15	B	2'0"	15	B	2'0"	15	B	2'0"	15	B	2'0"	15	B
C-169	10	M	8'2"	280	B	8'2"	280	B	8'2"	280	B	8'2"	280	B	8'2"	280	B
C-170	10	F	1'11"	12	B	1'11"	12	B	1'11"	12	B	1'11"	12	B	1'11"	12	B
C-171	10	M	8'3"	285	B	8'3"	285	B	8'3"	285	B	8'3"	285	B	8'3"	285	B
C-172	10	F	1'10"	10	B	1'10"	10	B	1'10"	10	B	1'10"	10	B	1'10"	10	B
C-173	10	M	8'4"	290	B	8'4"	290	B	8'4"	290	B	8'4"	290	B	8'4"	290	B
C-174	10	F	1'9"	8	B	1'9"	8	B	1'9"	8	B	1'9"	8	B	1'9"	8	B
C-175	10	M	8'5"	295	B	8'5"	295	B	8'5"	295	B	8'5"	295	B	8'5"	295	B
C-176	10	F	1'8"	6	B	1'8"	6	B	1'8"	6	B	1'8"	6	B	1'8"	6	B
C-177	10	M	8'6"	300	B	8'6"	300	B	8'6"	300	B	8'6"	300	B	8'6"	300	B
C-178	10	F	1'7"	4	B	1'7"	4	B	1'7"	4	B	1'7"	4	B	1'7"	4	B
C-179	10	M	8'7"	305	B	8'7"	305	B	8'7"	305	B	8'7"	305	B	8'7"	305	B
C-180	10	F	1'6"	2	B	1'6"	2	B	1'6"	2	B	1'6"	2	B	1'6"	2	B
C-181	10	M	8'8"	310	B	8'8"	310	B	8'8"	310	B	8'8"	310	B	8'8"	310	B
C-182	10	F	1'5"	1	B	1'5"	1	B	1'5"	1	B	1'5"	1	B	1'5"	1	B
C-183	10	M	8'9"	315	B	8'9"	315	B	8'9"	315	B	8'9"	315	B	8'9"	315	B
C-184	10	F	1'4"	0	B	1'4"	0	B	1'4"	0	B	1'4"	0	B	1'4"	0	B
C-185	10	M	8'10"	320	B	8'10"	320	B	8'10"	320	B	8'10"	320	B	8'10"	320	B
C-186	10	F	1'3"	0	B	1'3"	0	B	1'3"	0	B	1'3"	0	B	1'3"	0	B
C-187	10	M	8'11"	325	B	8'11"	325	B	8'11"	325	B	8'11"	325	B	8'11"	325	B
C-188	10	F	1'2"	0	B	1'2"	0	B	1'2"	0	B	1'2"	0	B	1'2"	0	B
C-189	10	M	9'0"	330	B	9'0"	330	B	9'0"	330	B	9'0"	330	B	9'0"	330	B
C-190	10	F	1'1"	0	B	1'1"	0	B	1'1"	0	B	1'1"	0	B	1'1"	0	B
C-191	10	M	9'1"	335	B	9'1"	335	B	9'1"	335	B	9'1"	335	B	9'1"	335	B
C-192	10	F	1'0"	0	B	1'0"	0	B	1'0"	0	B	1'0"	0	B	1'0"	0	B
C-193	10	M	9'2"	340	B	9'2"	340	B	9'2"	340	B	9'2"	340	B	9'2"	340	B
C-194	10	F	0'11"	0	B	0'11"	0	B	0'11"	0	B	0'11"	0	B	0'11"	0	

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APPENDIX II

DATA

IMPACT FLASH PHENOMENON

The following tables present the raw data gathered under the experimental portion of the program. The units are as follows:

- (1) Pressure: torr (mm of Hg)
- (2) OD: inches
- (3) Impact velocity: feet-per-second
- (4) I_p : watts per steradian
- (5) t_{peak} : microseconds

Instrumentation identification is as follows:

<u>Channel</u>	<u>Instrument Range</u>	<u>Viewing Angle</u>
1	1μ to 5.5μ	Normal to flight line
2	1μ to 5.5μ	Flight line (parallel)
3	0.594μ to 1μ	Normal to flight line
4	0.594μ to 1μ	Flight line (parallel)
4A	0.45μ to 1μ	Flight line (parallel)
5	0.18μ to 0.55μ	Flight line (parallel)

Numbers in parentheses (e. g., (10X)), refer to neutral density filter factors. An "S" after I_p results indicates that the channel was saturated and hence data is doubtful.

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DATE & TIME		OBS. AND OBS. NUMBER	POSITION		SPEED		IMPACT FLASH											
			DATE	TIME	DATE	TIME	1	2	3	4	5	6	7	8				
D-128	107	AI	2017	2329	23	2018-13												
D-129	107	AI		2400	20													
D-130	107	AI		2410	13													
F-187	107	AI		2420	00													
H-126	107	AI			00													
G-183	107	AI		2410	00													
G-180	107	AI		2410	00													
G-182	107	AI		2410	00													
G-181	107	AI		2410	00													
G-184	107	AI		2410	00													
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	ROLE	WT	ROL	T	ROLE	ROL
Hypervelocity projectiles						
Impact flash						
Impact shock						
Hypervelocity guns						
Fragmentation						
Kill probabilities						

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3. REPORT TITLE		
HYPERVELOCITY IMPACT EXPERIMENTS		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
Final Technical Report - July 1964		
5. AUTHOR(S) (Last name, first name, initial)		
Warnica, R. L. Gehring, J. W.		
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1964	68	17
8a. CONTRACT OR GRANT NO.	8b. ORIGINATOR'S REPORT NUMBER(S)	
AF 08(635)-2783	SRL-64-0417-S	
9. PROJECT NO.	9a. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
9850	ATL-TR-64-83	
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13. ABSTRACT		
(U) This final report describes the experimental results of a program conducted under Contract AF 08(635)-2783, "Hypervelocity Impact Experiments," to investigate the vulnerability of multiple sheet thin target assemblies to hypervelocity projectiles impacting at both normal and oblique angles. This study of penetration, perforation and spalling was conducted using an accelerated-reservoir light-gas gun to launch projectiles to velocities ranging from 5000 fps to 25,500 fps. Projectile incident angles ranged from 90 degrees (normal) to 10 degrees. Target damage was evaluated in terms of hold area, depth of penetration and affected area. Damage was correlated with impact velocity, impact angle, projectile variables, and target variables.		

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