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Gas gun impact experiments and computational simulations were performed to investigate a technique for increasing flyer plate velocities. Stainless steel impactors, PMMA and aluminum buffers, and stainless steel flyers were used. Charged contact pins were used to measure impactor and flyer velocities. The velocities of the flyers were on the order of 1.5 times the impactor velocities, in agreement with computational results.

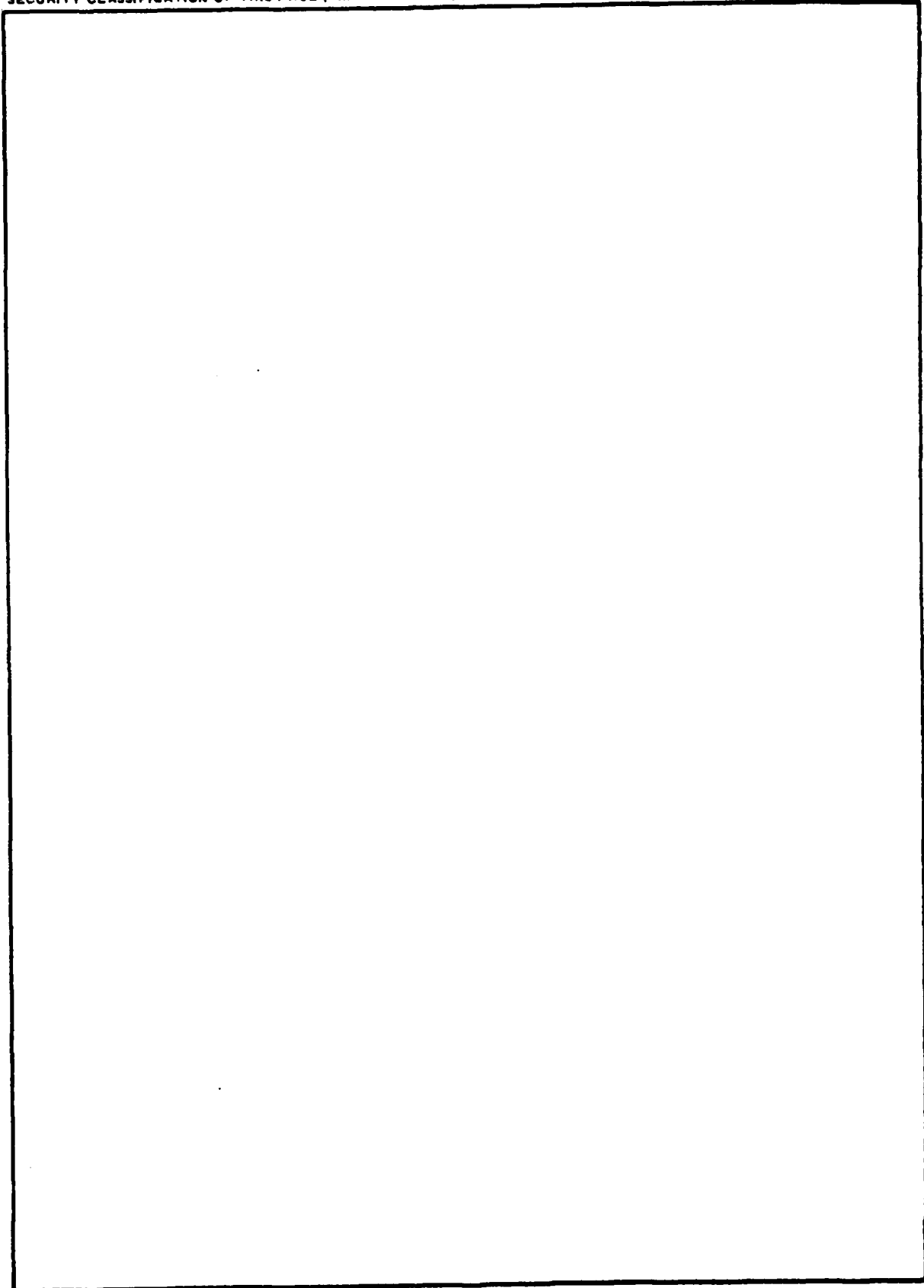DD FORM 1473   EDITION OF 1 NOV 65 IS OBSOLETE
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FOREWORD

This report describes impact experiments performed with the NSWC gas gun to investigate a technique for increasing flyer plate velocities. This work was supported by NAVSEA Block No. SF-33-354-391.

This report has been reviewed and approved by C. A. Cooper, Head, Gun Systems and Munitions Division.

Released by:

R/Arthur for

CAPT R. P. FUSCALDO
Assistant for Weapons Systems
Weapons Systems Department

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I. INTRODUCTION

This report describes gas gun experiments and computational simulations for planar impact staging to achieve high velocities for flyer plates. Staging techniques take advantage of multiple wave interactions in impacted layered targets and have been the subject of several experimental and analytical studies.[1-3] For certain conditions the velocity of the flyer plate (the target layer farthest from the impact plane) can be greater than that of the impactor plate (see Figure 1) by 60% or more.[3]

BUFFER

IMPACTOR **FLYER**

$V_1^{Impactor}$ $V_1^{Flyer} = 0$ $V_2^{Impactor}$ $V_2^{Flyer} > V_1^{Impactor}$

BEFORE IMPACT **AFTER IMPACT**
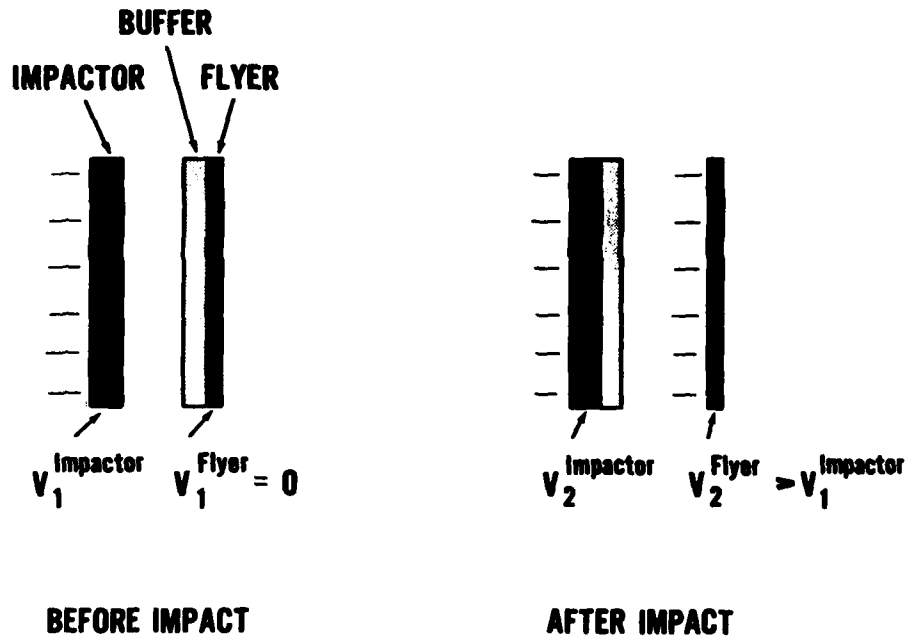
Figure 1. Schematic of planar impact staging. $V_1^{Impactor}$ and $V_2^{Impactor}$ are the initial and final velocities of the impactor, respectively. V_1^{Flyer} and V_2^{Flyer} are the initial and final velocities of the flyer, respectively. For certain combinations of the materials and relative thicknesses of the impactor, buffer, and flyer, V_2^{Flyer} can be greater than $V_1^{Impactor}$. The shock impedance of the buffer is assumed to be less than that of the impactor or flyer.

1

Explosive plane wave lens experiments[2] and two-stage light gas gun experiments[3] have demonstrated this effect with impactors and multilayered targets consisting of materials having a wide range of shock impedances, from high-impedance tantalum to low-impedance lithium. The layered targets were constructed so that the layers of "buffer" material (between the impactor and the final "flyer" layer) were arranged in order of decreasing shock impedance and the thicknesses of the buffer layers were selected so that the stress wave transit times in the layers were approximately the same.

The impact experiments described in this report were performed with the NSWC gas gun[4] for simple one- and two-layer buffers, using common materials: 304 stainless steel, 6061-T6 aluminum and polymethyl methacrylate (PMMA) (trade-named Lucite or Plexiglas). These experiments are described in Section II and the results are presented in Section III. Oscilloscope records for velocity measurements of the stainless steel flyers are provided in Appendix A. Appendix B contains postshot photographs of a stainless steel impactor disc and a stainless steel flyer disc.

II. EXPERIMENTAL DETAILS

Type 304 stainless steel was selected for the high impedance impactor and flyer materials because of its relatively low Hugoniot elastic limit ($\sim$0.23 GPa[5]) and the absence of shock-induced phase transitions[5,6] in the stress range for the present experiments and for potential future experiments at higher impact velocities. These properties should result in a relatively low amplitude elastic wave and only a single plastic wave generated initially in the impactor and flyer, thereby simplifying the interpretation of the experimental results. The PMMA and 6061-T6 aluminum buffer materials were selected on the basis of their shock impedances being less than that of stainless steel and on the availability of Hugoniot and related material properties data. [5-8]

Figure 2 is a schematic of the 40-mm-bore gas gun used for these experiments. Figure 3 is a schematic of the muzzle region of the gun. The impactor disc is carried in a recess in the front of the projectile. The buffer and flyer discs were held together by a thin layer of adhesive (Homalite 1100) and were held in the target holder by epoxy (Castall 300-RT7). The epoxy potting of the target assembly was accomplished on a precision granite surface plate (coated with a thin layer of

2

fluorocarbon mold release agent). This was to ensure the planarity of the buffer and flyer combination with the surface of the target holder that would be in contact with the target mounting flange of the gas gun.
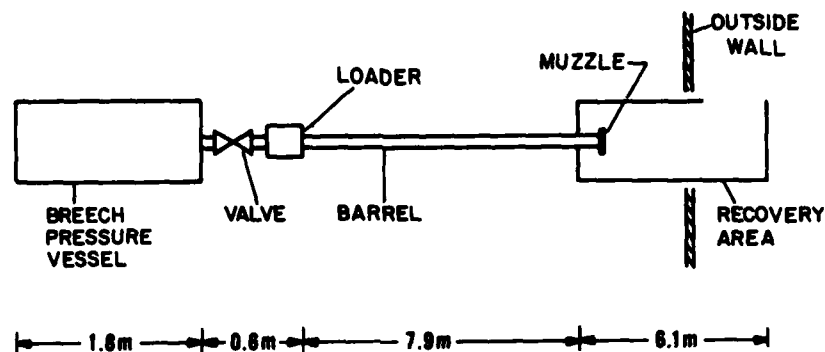
Figure 2. Schematic of gas gun.
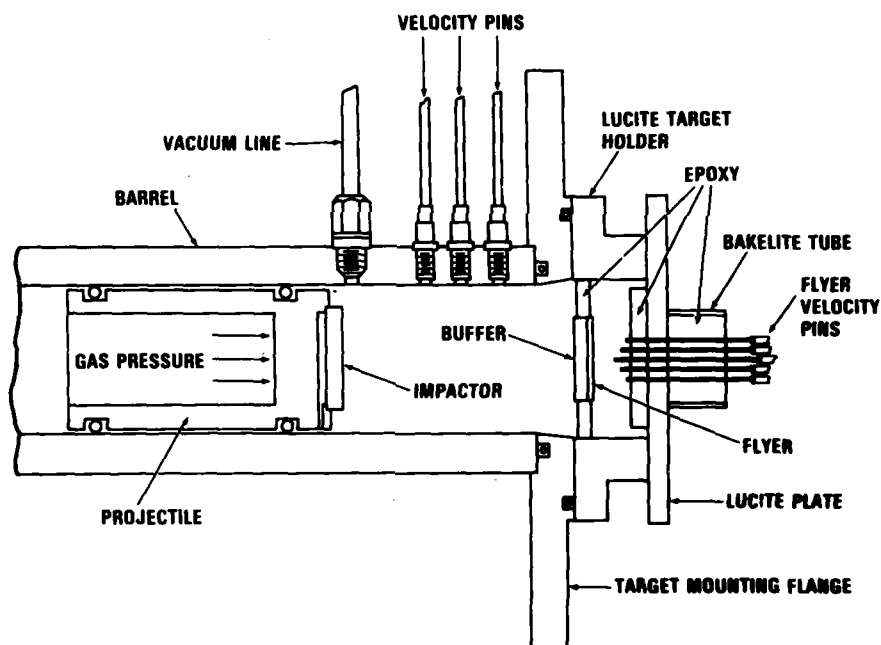
Figure 3. Schematic of the muzzle region of the gas gun with a target configuration for an impact staging experiment. The impactor disc is carried on the front of the projectile and impacts the buffer disc that is in contact with the flyer disc. After the flyer disc has moved a distance of approximately 6.4 mm, its velocity is measured with the array of charged velocity pins. The velocity of the projectile and impactor prior to impact is measured with the charged pins in the side of the barrel.

3

A set of four flyer velocity measurement pins positioned at 90° intervals on a 12.6-mm-diameter circle around a central grounding pin were mounted in a Lucite and epoxy holder behind the flyer. A Lucite mold (coated with layer of vacuum grease) was used to fabricate the velocity pin holder. The pins were made from 50-mm lengths of 0-80 UNF stainless steel threaded rod; one end of each rod was lapped perpendicular to the rod axis. The threads were coated with a fluorocarbon mold release agent prior to being potted in the epoxy; this permitted turning of the rods in the cured epoxy to adjust the relative positions of the pin tips. After the buffer and flyer discs were secured in the target holder, a precision 6.35-mm-thick copper spacer disc was placed on the back side of the flyer. The holder for the pins was then secured to the target holder by two 10-32 UNF screws. The grounding pin was then adjusted until it contacted the spacer disc. The pin holder was then demounted from the target holder and mounted on a special granite fixture[4] for precision positioning of the velocity pin tips. A dial indicator height gauge with 0.002-mm resolution (Scherr-Tumico Model BL5) was used to measure the relative heights of the velocity pin tips from the plane of the tip of the ground pin.

Two of the velocity pin tips (at 0 and 180° positions) were adjusted to be 0.51 ±0.02 mm below the plane of the ground pin tip. The remaining two pin tips (at 90 and 270° positions) were adjusted to be 0.51 ±0.02 mm below the plane of the first pair of pin tips. All the pins were then secured with fast setting epoxy (Hardman 8173). The pins were connected by coaxial cables to time-of-contact measurement circuits.[9] The four velocity pins were electrically charged and have the voltage ratios 6:3:2:1, respectively. These ratios are used to distinguish between the grounding closure of each of the four pin circuits. (The flyer contacts the ground pin first to ensure proper pin pulse responses).

Figure 4 shows an unassembled target configuration. The target holder containing a buffer and flyer disc combination is shown in front of the velocity pin holder. Figure 5 shows views of an assembled target configuration.
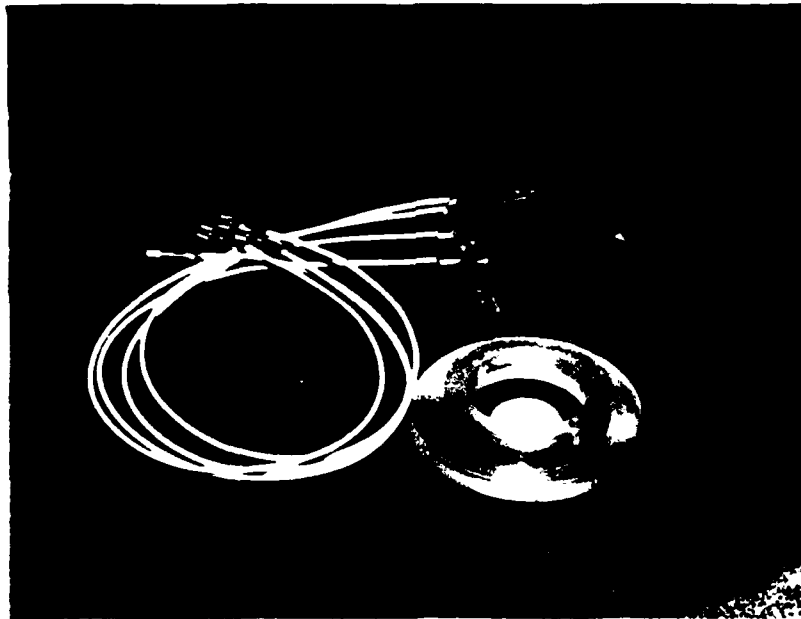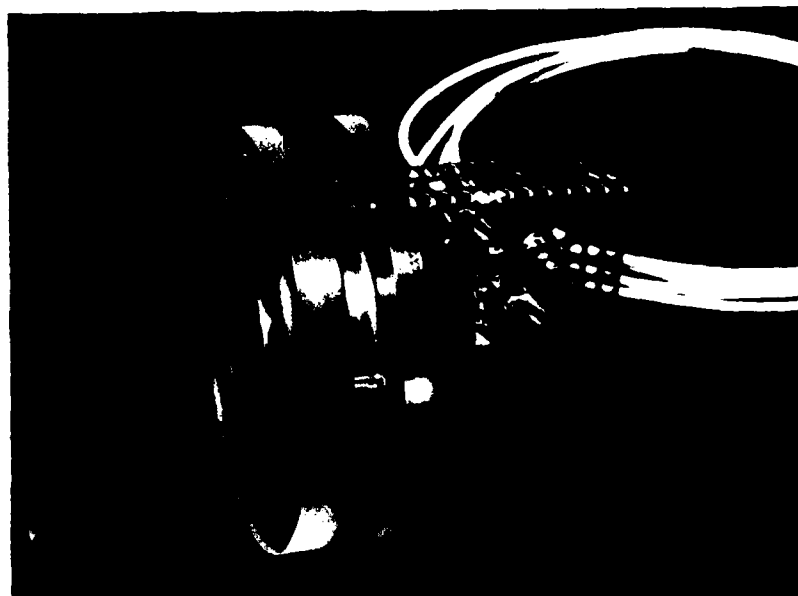
Figure 4. Photograph of an unassembled target configuration. The target holder containing a buffer and flyer combination is shown in front of the velocity pin holder. The array of four velocity pins and the central grounding pin can be seen protruding from the epoxy part of the velocity pin holder. The coaxial cables connect the velocity pins to the charging and contact sensing circuits.

(a)
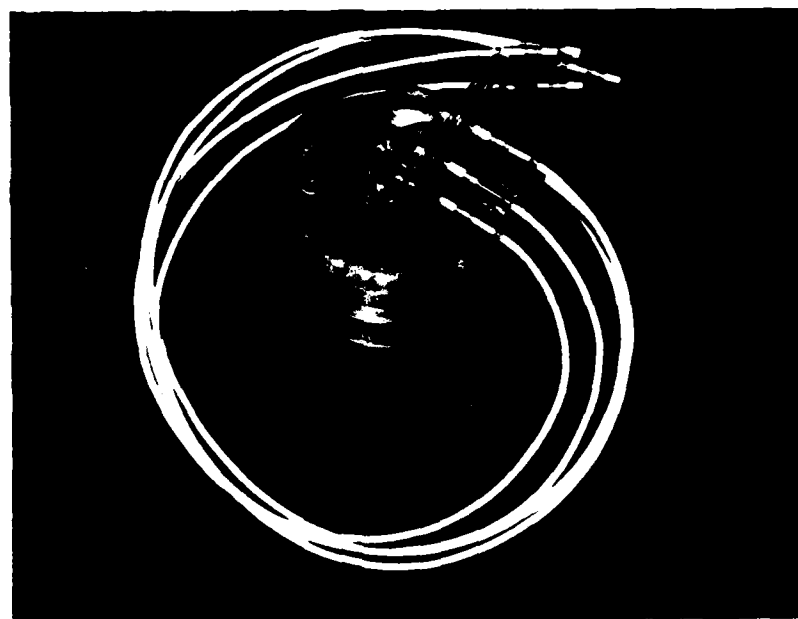
(b)

Figure 5.   Photographs of an assembled target configuration. (a) Side view showing the impact
surface of the buffer disc (at left of target holder) and the concentric annular surface
of the target holder that contacts the target mounting flange of the gas gun. (b) Back
view showing attachment of velocity pins to the coaxial cables.

III. RESULTS AND SUMMARY

The details of the planar impact staging experiments are presented in Table 1. The impactor discs were 35.6-mm-diameter, 5.0-mm-thick, 304 stainless steel. For Shot 161, with a single 3-mm-thick PMMA buffer layer and a 1-mm-thick stainless steel flyer, the measured flyer velocity was 1.40 times the initial velocity of the impactor. For Shot 162, the 3-mm-thick buffer consisted of a 1.8-mm-thick aluminum alloy layer and a 1.2-mm-thick PMMA layer; the measured velocity of the 1-mm-thick stainless steel flyer was 1.59 times the initial velocity of the impactor.

The SRI PUFF 8 one-dimensional stress wave propagation computer program[7] was used to calculate the velocities of the material layers. Figures 6 and 7 show the calculated impactor and flyer velocities as a function of time after impact for Shots 161 and 162, respectively. The calculated and measured velocities for the stainless steel flyers agree to within 10%. Calculations with the Sandia Laboratories WONDY IV computer program[10] gave very similar results.[12] The PUFF 8 calculations indicate that the stainless steel impactor velocities for Shots 161 and 162 decreased by an average of about 53% after impact. The calculated final velocity for the aluminum alloy buffer layer (Shot 162) indicated that the metal part of the buffer was accelerated to within 17% of the impactor initial velocity.

In summary, it has been demonstrated that for these simple one- and two-layer buffer planar staging configurations it is possible to launch metal flyer layers at velocities approximately 1.5 times that of the initial impactor velocity.

Table 1. Data summary for planar impact staging experiments.

Shot No.	Impactor[a]				Buffer[a]			Flyer[a]				Flyer/Impactor Velocity Ratio[e]
					6061-T6 Aluminum		PMMA					
	Material	Thickness (mm)	Impact Velocity[b] (km/s)	Final Velocity[c] (km/s)	Thickness (mm)	Velocity[c] (km/s)	Thickness (mm)	Material	Thickness (mm)	Measured Velocity[d] (km/s)	Calculated Velocity[c] (km/s)	
161	304 stainless steel	5.0	0.89	0.43	f	f	3.0	304 stainless steel	1.0	1.25	1.38	1.40
162	304 stainless steel	5.0	0.88	0.41	1.8	0.73	1.2	304 stainless steel	1.0	1.40	1.30	1.59

a The impactor diameters were all 35.6 min. The buffer and flyer diameters were all 27.9 mm.

b Average of two velocity measurements, each over 10-mm distance, just prior to impact.

c Calculated using the SRI PUFF 8 one-dimensional stress wave propagation computer program.[7] For Shot 161, the number of computational cells for the impactor, buffer, and flyer were 10, 6, and 4, respectively. For Shot 162, the number of computational cells for the impactor, aluminum buffer layer, PMMA buffer layer, and flyer were 10, 4, 3, and 4, respectively. The 304 stainless steel Hugoniot and associated data for the computations were obtained from Reference 8. The 6061-T6 aluminum and PMMA Hugoniots and associated data including yield strength were obtained from Reference 7. Calculations using the Sandia WONDY IV computer program[10] gave very similar results. The Hugoniots and associated data were obtained from References 6 and 11 (the aluminum Hugoniot data used in WONDY IV for the impactor, buffer, and flyer layers were 50, 30, and 20, respectively. For Shot 161 the number of computational cells used in WONDY IV for the impactor and flyer were the same as for Shot 161; there were 18 and 30 cells in the aluminum and PMMA buffer layers, respectively.[12]

d Measured with charged impact pins over a distance of 0.51 mm, after the flyer has moved 6.36 mm. Prior to the time of measurement the flyer had separated from the buffer and was essentially in an unstressed state, according to WONDY IV calculations.

e Ratio of the measured velocity of the flyer to the velocity of the impactor just prior to impact.

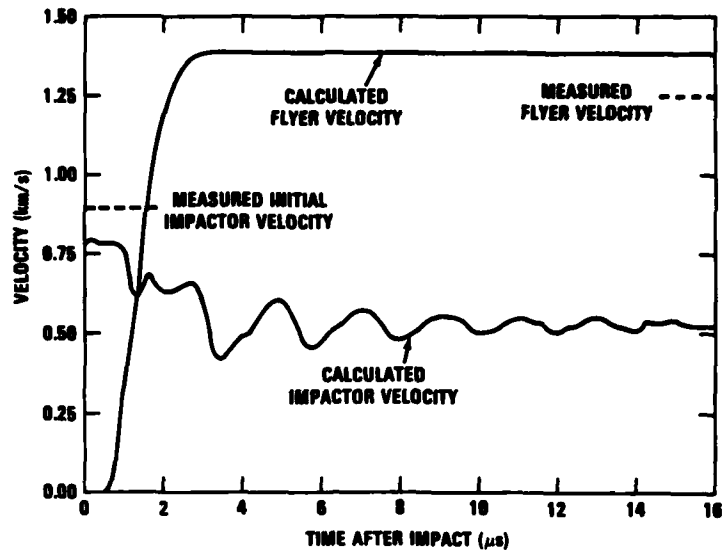f No aluminum buffer layer was used in this experiment.

8

Figure 6. Calculated impactor and flyer velocities as a function of time after impact for Shot 161.
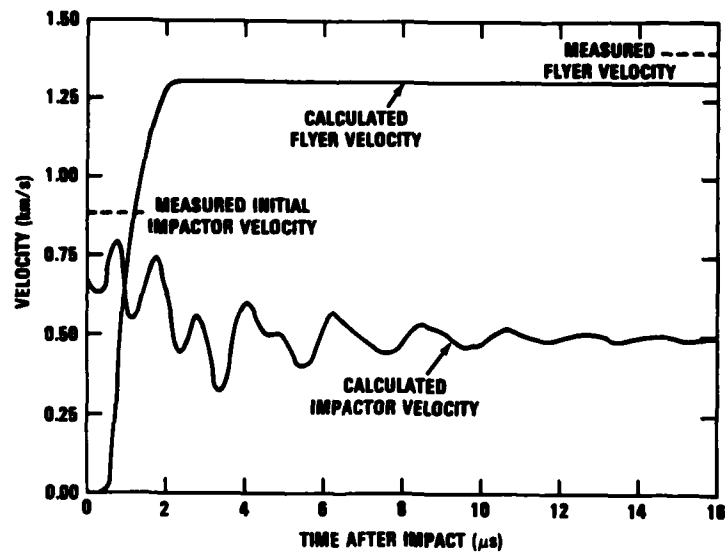

Figure 7. Calculated impactor and flyer velocities as a function of time after impact for Shot 162.

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APPENDIX A

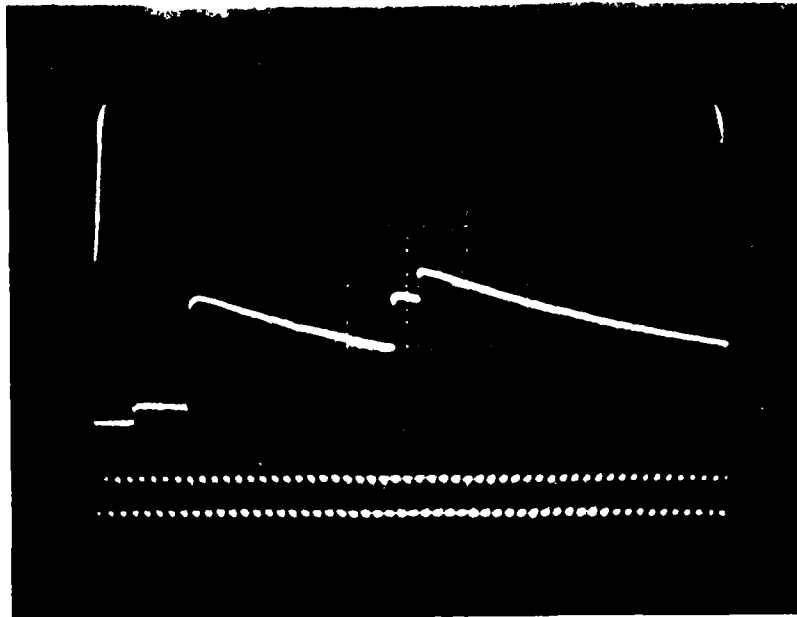OSCILLOSCOPE RECORDS OF PIN CLOSURE
PULSES FOR FLYER VELOCITY
MEASUREMENTS

A-1

Figure A-1. Oscilloscope record of flyer velocity pin closure pulses for Shot 161. The vertical scale is 2 v/div and the horizontal scale is 0.1 μs/div. A 0.02-μs period time calibration wave is shown at the bottom.
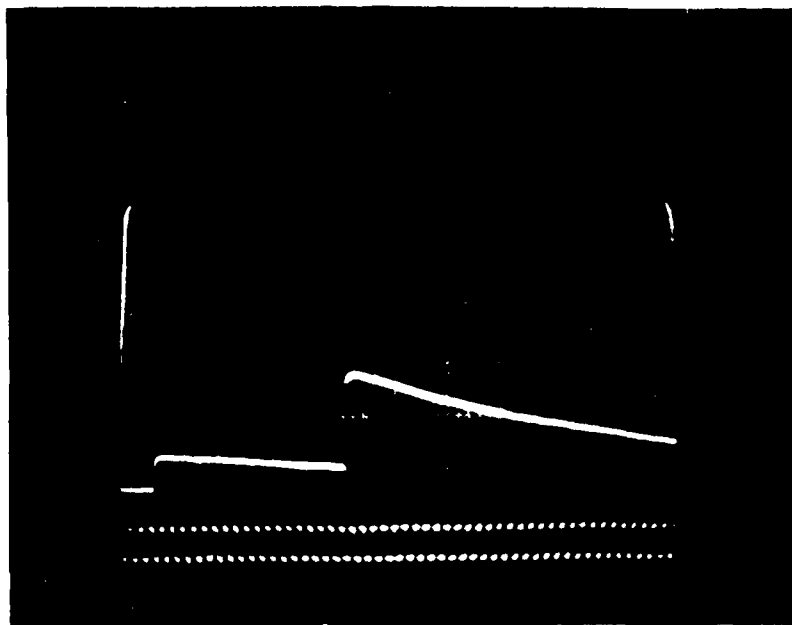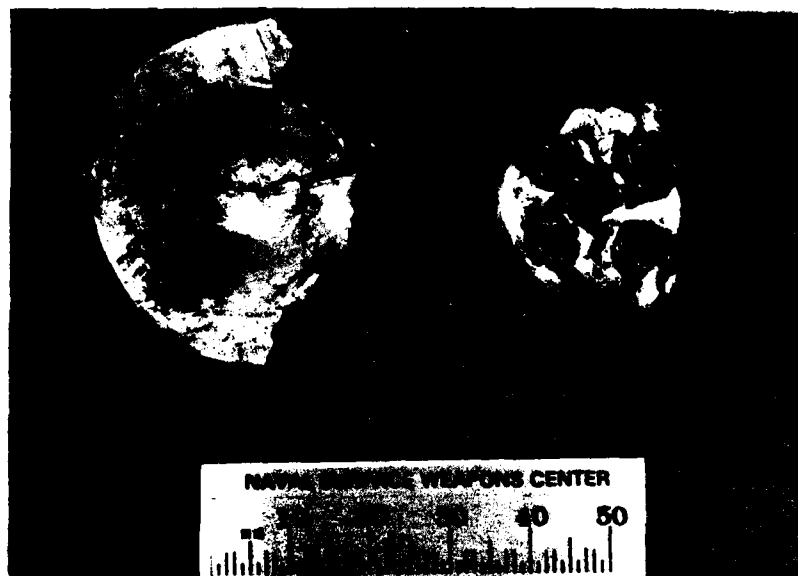

Figure A-2. Oscilloscope record of flyer velocity pin closure pulses for Shot 162. The vertical scale is 2 v/div and the horizontal scale is 0.1 μs/div. A 0.02-μs period time calibration wave is shown at the bottom.

APPENDIX B

**POSTSHOT PHOTOGRAPHS OF A STAINLESS
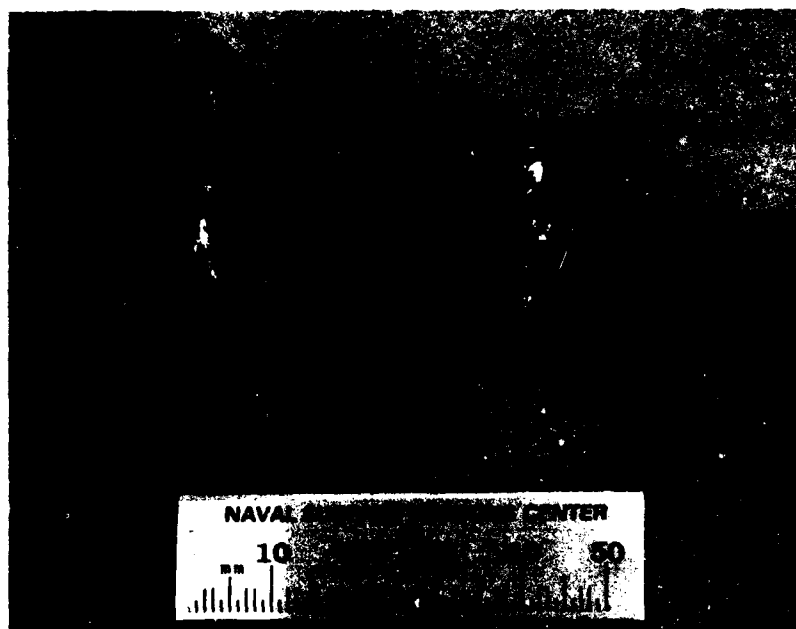STEEL IMPACTOR AND A STAINLESS
STEEL FLYER**

B-1

(a)

(b)

Figure B-1. Postshot photographs of the recovered stainless steel impactor and stainless steel flyer for Shot 161. (a) Surfaces that impacted the flyer velocity pins. (b) Opposite surfaces. (c) Edge view; direction of motion of impactor and flyer was from left to right in the figure.

(c)

Figure B-1 (Continued).

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