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HYPERVELOCITY IMPACT DAMAGE IN CADMIUM TARGETS

Robert N. Teng

TECHNICAL REPORT NO. AFWL-TR-69-134

March 1970

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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HYPERVELOCITY IMPACT DAMAGE IN CADMIUM TARGETS

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ABSTRACT

Quantitative information on hypervelocity impact dynamics was obtained from 30 shots. Cadmium spheres projected at a velocity of 25,000 fps impacted against various multiplate targets. Instrumentation used during the test includes five channels of flash X rays, high-speed framing camera, model detectors, impact pressure probes, laser stress-wave sensors, and photostress analyzer. However, data from the pressure measurements and the stress-wave analysis are not included in this report. Some preliminary conclusions made from the test and a few remarks on the experimental techniques are included in this report.

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SECTION I

INTRODUCTION AND SUMMARY

A computer code has been developed to provide an analytical tool with which to study hypervelocity impact, where the impact velocity is sufficiently great and the projectile and target physical characteristics are such that the debris resulting from impact is either liquefied or vaporized. This code utilizes both hydrodynamic theory and strength-dependent relationships to describe impact and penetration phenomena. The usefulness of the computer code to predict the hypervelocity impact phenomena must be verified experimentally in a laboratory to at least the highest impact velocity currently available so that the prediction of impact characteristics of higher impact velocity can be used with confidence.

An experimental hypervelocity impact test program was conducted at the McDonnell Douglas Astronautics Company-Western Division (MDAC-WD) Aerophysics Laboratory. Thirty hypervelocity impacts of cadmium spheres into target plates at a velocity of 7.62 km/sec (25,000 fps) were obtained. All test objectives were met. The problems encountered in launching the cadmium spheres during the experiment and the techniques developed to overcome these difficulties are discussed in this report.

Cadmium was selected for use in the projectiles and front target plates because its low vaporization energy, low velocity of sound, and high density result in either liquefied or vaporized debris at impact velocities achievable with present light-gas gun launching capabilities. At the 7.62-km/sec impact velocity used in the test program, the debris impinging upon the secondary target plate was essentially vaporized. Five different materials were used for secondary target plates:

1. Cadmium
2. 1100-0 aluminum
3. 7075-T6 aluminum
4. Mild steel
5. Lead.

The parameters that were varied in the testing included:

1. Front-plate thickness
2. Void spacing between plates
3. Foam (of several densities) in the void
4. Rear-plate composition and thickness.

Data collected on each shot consisted of:

1. Front-plate damage
2. Debris velocity
3. Debris spray angle
4. Final rear-plate damage.

These data are included in Table I. The column heading DAL No. B-40 indicates the MDAC-WD Aerophysics Laboratory identification for each shot.

On eight of the shots, stagnation pressures on the secondary target plate were recorded by Gulf General Atomic personnel (Air Force Contract No. F29601-69-C-0076). On eight of the shots, measurements of the dynamic stress waves on the rear plates were made by personnel of the Hughes Aircraft Company, Fullerton (Air Force Contract No. F29601-69-C-0095). Detailed information on the stagnation pressures and the dynamic stress waves is not included in this report.

The raw data of the test are in storage at the Project Office of the Air Force Weapons Laboratory.

Table I

SUMMARY OF TEST RESULTS

Test			Target(1)		Model(2)			Damage to Target			Instrument(3)				
											B&W		X ray		
Shot number	DAL No. B40-	Date	Material configuration	Dimension (in.)	Weight (Gm)	Diam (in.)	Velocity (fps)	Front plate max hole diam (in.)	Rear plate max hole diam (in.)	Other	Frame/ µsec	Streak mode	In flight	Impact 1	Impact 2
1	29	8/8/69	Cd	8x8x2-3/4	1.76	0.286	24,500	---	---	Crater Diameter: 2.0 in. Crater Depth: 1.1 in. Crater Volume: 37.2 cm^3	---	---	X	---	---
2	16	7/23/69	Cd-V-Cd	0.072/ 2.29/ 0.125	1.76	0.286	24,300	0.9	3.5	Back spall noted on rear plate	X 0.955	X	X	△	△
3	2	6/12/69	Cd-V-Al(1)	0.075/ 2.29/ 0.062	1.76	0.286	25,100	0.95	6.75	Near catastrophic failure	X 0.993	X	△	X	X
4	4	6/17/69	Cd-V-Al(2)	0.072/ 2.29/ 0.064	1.76	0.286	25,200	0.95	---	Rear plate completely shattered	X 0.983	X	X	X	X
5	21	7/29/69	Cd-V-Fe	0.072/ 2.29/ 0.125	1.76	0.286	24,700	0.85	1.9	Back spall on rear plate	X	X	X	X	X
6	17	7/23/69	Cd-V-Cd	0.072/ 3.43/ 0.125	1.76	0.286	24,750	0.8	---	Bulged rear plate; slight cracking; back spall	△ 0.952	△	X	X	X
7	22	7/29/69	Cd-V-Al(1)	0.072/ 3.43/ 0.125	1.76	0.286	24,700	0.85	---	Extreme rearward bulge on rear plate with slight cracking	X	X	X	X	X
8	52	8/29/69	Cd-V-Fe-Pb	0.072/ 2.29/ 0.070/ 0.250	1.76	0.286	24,250	0.85	1.5	Rear plate severe back spall; middle Fe plate did not get penetrated; no back spall	X 0.955	X	X	X	X
9	54	9/2/69	Cd-f-Al(1)	0.072/ 2.29/ 0.125	1.76	0.286	24,300	0.9	5.0	Front plate bent forward; rear plate bent double; bulging aft	---	---	X	X	X
10	47	8/26/69	Cd-f-Al(2)	0.072/ 2.29/ 0.125	1.76	0.286	24,550	0.9	---	Front plate bowed forward; rear plate completely shattered	---	---	X	X	X
11	23	7/30/69	Cd-f-Fe	0.072/ 2.29/ 0.125	1.76	0.286	24,450	0.9	1.75	Front plate bowed forward; rear plate bowed aft	X	X	X	X	X
12	53	8/29/69	Cd-f-Fe-Pb	0.072/ 2.29/ 0.070/ 0.250	1.76	0.286	24,250	0.9	2.0	Front plate bent forward; mid plate small holes from spray; rear plate bent aft	---	---	X	X	X
13	24 25	8/1/69 8/2/69	Cd-f-Al(1)	0.072/ 3.43/ 0.125	1.76	0.286	24,600	0.9 0.8	4.0 2.5	(24) Rear plate bent double bulging rearward	△ X	△ X	X X	△ X	△ X
14	35	8/18/69	Cd-f-Al(1)	0.072/ 2.29/ 0.064	1.76	0.286	24,500	0.85	---	Rear plate catastrophic failure	---	---	X	X	X
15	55	9/2/69	Cd-f-Al(1)	0.072/ 2.29/ 0.125	1.76	0.286	24,300	1.15	4.9	Front plate bowed forward; rear plate bent double; bulged rearward	---	---	X	X	X
16	14	7/19/69	Cd-V-Al-Fe	0.072/ 2.29/ 0.064/ 0.070	1.76	0.286	25,000	0.95	3.7	Peripheral cracking around hole in middle aluminum plate	X 0.967	X	X	X	X

Legend appears at the end of the table.

Table I

MMARY OF TEST RESULTS

get	Instrument(3)						Debris Characteristics		Remarks
	B&W		X ray						
er	Frame/ µsec	Streak mode	In flight	Impact 1	Impact 2	Impact 3	Average velocity (fps)	Spray half angle (deg)	
er: 2.0 in. 1.1 in. e: 37.2 cm^3	---	---	X	---	---	---	---	---	Semi-infinite target
ed on rear	X 0.955	X	X	△	△	△	≈23,400	≈ 41	Data obtained from B&W
phic failure	X 0.993	X	△	X	X	X	24,400	34	
npletely	X 0.983	X	X	X	X	X	24,600	41	
rear plate	X	X	X	X	X	X	22,400	32	Hughes No. 1
ate; slight spall	△ 0.952	△	X	X	X	X	23,200	40	
vard bulge vith slight	X	X	X	X	X	X	23,100	40	Hughes No. 2
ere back e plate did ted; no	X 0.955	X	X	X	X	X	21,800	34	
nt forward; double;	---	---	X	X	X	X	17,300	35	Foam density: 0.1 gm/cm^3
ved forward; pletely	---	---	X	X	X	X	17,700	39	Foam density: 0.1 gm/cm^3
ved forward; ed aft	X	X	X	X	X	X	17,500	37	Foam density: 0.1 gm/cm^3 Hughes No. 3
nt forward; l holes from ate bent aft	---	---	X	X	X	X	17,600	37	Foam density: 0.1 gm/cm^3
bent double rward	△ X	△ X	X X	△ X	△ X	△ X	15,600	23	Foam density: 0.1 gm/cm^3 Hughes No. [illegible] No. 24 B&W failed No. 25 1-1/4 in. off center
astrophic	---	---	X	X	X	X	20,600	34	Foam density: 0.05 gm/cm^3
ved forward; double; d	---	---	X	X	X	X	12,800	25	Foam density: 0.5 gm/cm^3
cking around aluminum	X 0.967	X	X	X	X	X	23,900	37	

Test			Target[1]		Model[2]			Damage to Target			Instrument[3]				
											B&W		X ra...		
Shot number	* DAL No. B40-	Date	Material configuration	Dimension (in.)	Weight (Gm)	Diam (in.)	Velocity (fps)	Front plate max hole diam (in.)	Rear plate max hole diam (in.)	Other	Frame/ µsec	Streak mode	In flight	Impact 1	Im...
17	18	7/24/69	Cd-V-Al-Fe	0.072/ 3.43/ 0.064/ 0.070	1.76	0.286	24,600	0.85	---	Middle and rear plates were not penetrated--only bulged	X 0.943	X	X	X	
18	19	7/24/69	Cd-V-Al-Fe	0.125/ 2.29/ 0.064/ 0.070	1.76	0.286	24,600	1.3	1.5	Middle plate shattered; rear plate back spall	X 0.948	X	X	X	
19	48	8/27/69	Cd-f-Al-Fe	0.072/ 2.29/ 0.063/ 0.070	1.76	0.286	24,600	0.95	4.0	Front plate bowed forward; middle plate shattered; rear plate bent aft	X 0.963	X	X	X	
20	51	8/28/69	Cd-f-Al-Fe	0.072/ 3.43/ 0.063/ 0.070	1.76	0.286	24,550	0.9	3.5	Front plate bowed forward; middle aluminum plate severely cracked	---	---	X	X	
21	50	8/28/69	Cd-f-Al-Fe	0.125/ 2.29/ 0.063/ 0.070	1.76	0.286	24,560	1.2	5.4	Middle aluminum plate broke into several pieces	---	---	X	X	
22	27	8/6/69	Cd-V-P_R	0.072/ 2.29/ 0.5	1.76	0.286	24,700	1.0	---		X 0.872	X	X	X	
23	36	8/19/69	Cd-V-P_R	0.072/ 3.43/ 0.5	1.76	0.286	24,700	0.95	---		X 0.960	X	X	X	
24	46	8/26/69	Cd-V-P_R	0.125/ 2.29/ 0.5	1.76	0.286	24,600	1.3	---		X 0.957	X	X	X	
25	44	8/25/69	Cd-f-P_R	0.072/ 2.29/ 0.5	1.76	0.286	24,800	1.05	---	Front plate bowed forward	---	---	X	X	
26	41	8/21/69	Cd-f-P_R	0.072/ 3.43/ 0.5	1.76	0.286	24,600	0.9	---	Front plate bowed forward	---	---	X	X	
27	42	8/22/69	Cd-f-P_R	0.125/ 2.29/ 0.5	1.76	0.286	24,750	1.25	---	Front plate bowed forward	---	---	X	X	
28	43	8/22/69	Cd-f-P_R	0.072/ 2.29/ 0.5	1.76	0.286	24,550	0.9	---	Front plate bowed forward	---	---	X	X	
29	45	8/25/69	Cd-f-P_R	0.072/ 2.29/ 0.5	1.76	0.286	24,700	1.1	---	Front plate bent forward severely	---	---	X	X	
30	56	9/3/69	Cd-V-Al(1)	0.072/ 3.43/ 0.125	1.91	0.300	23,800	0.9	3.4	Very symmetrical spray pattern on second plate spray maximum diameter 6.0 in. (approx)	X 0.964	X	X	X	

(1) Target Code
Cd - Cadmium
V - Void
f - Foam
Fe - Mild steel
Pb - Lead
P_R - Steel mounting plate for pressure probes
Al(1) is Al 1100-0; Al(2) is Al 7075-T6; Al is Al 7075-T6

(2) All models except shot No. 30 were cadmium spheres.
Range pressure 10 Torr/Air

(3) Instrumentation Code
\- Does not apply, or not required
X Yes
△ Missed

*MDAC-WD Aerophysics Laboratory test designation

(cont'd)

	Instrument(3)					Debris Characteristics		
B&W		X ray						Remarks
e/	Streak mode	In flight	Impact 1	Impact 2	Impact 3	Average velocity (fps)	Spray half angle (deg)	
3	X	X	X	X	X	23,200	37	B&W light source failed
8	X	X	X	X	X	18,900	25	
3	X	X	X	X	X	19,300	30	Foam density: 0.1 gm/cm^3
	---	X	X	X	X	18,200	36	Foam density: 0.1 gm/cm^3
	---	X	X	X	X	16,400	27	Foam density: 0.1 gm/cm^3
72	X	X	X	X	X	23,500	35	Gulf General Atomic No. 1 Hughes No. 5
0	X	X	X	X	X	24,200	37	Gulf General Atomic No. 2 Hughes No. 6
7	X	X	X	X	X	19,300	25	Gulf General Atomic No. 3
-	---	X	X	X	X	19,000	29	Foam density: 0.1 gm/cm^3 Gulf General Atomic No. 4 Hughes No. 7
-	---	X	X	X	X	19,700	29	Foam density 0.1 gm/cm^3 Gulf General Atomic No. 5 Hughes No. 8
-	---	X	X	X	X	16,900	26	Foam density 0.06 gm/cm^3 Gulf General Atomic No. 6
-	---	X	X	X	X	20,000	35	Foam density: 0.05 gm/cm^3 Gulf General Atomic No. 7
-	---	X	X	X	X	15,000	31	Foam density: 0.5 gm/cm^3 Gulf General Atomic No. 8
4	X	X	X	X	X	21,300	30	Only steel sphere shot - target compares with shot No. 7

le
r

NOTES:
Cd-V-Cd means cadmium front plate, a void, and a cadmium rear plate; f designates foam between the plates.

0.072/2.29/0.064 means that the front plate thickness was 0.072 inch, the spacing between the plates was 2.29 inches, and the rear plate thickness was 0.064 inch.

B

SECTION II

EXPERIMENTAL TESTING APPARATUS

1. PROJECTILE LAUNCHING EQUIPMENT

The experiments were conducted at Ballistic Range B of the MDAC-WD Aerophysics Laboratory. Range B incorporates a two-stage light-gas gun with a nominal 0.30-inch launch-tube bore. A schematic diagram of Range B is shown in Figure 1. A complete description of all facilities at Range B is presented in Reference 1.

The light-gas gun used for this program operates like the gun described in Reference 2. Specifically, this gun is of the two-stage, heavy-piston type. The goal of the near-isentropic compression process used is to produce conditions suitable for keeping the sabot/projectile base pressure approximately constant during the launch cycle. The operating cycle is as follows: Pressure from the burning of gun powder in the combustion chamber propels a polyethylene piston down the pump tube. The piston moves slowly enough so that the hydrogen launch gas is compressed nearly isentropically. Initial conditions of the gun are set so that the piston is near the taper section when the pressure level for projectile launch is reached; at this time the diaphragm breaks and the projectile starts down the launch tube. The piston enters the taper section and continues to compress the reservoir gas at a rate such that the pressure on the projectile base remains nearly constant.

As described in Reference 3, MDAC-WD has developed a launching technique whereby a solid lexan sabot with an aluminum insert is launched from a barrel that is slotted and tapered near the muzzle end. The decreased driving pressure and increased wall friction encountered in this region produce a small separation between the projectile and the sabot. Subsequently, the sabot is deflected by a slight bend in the launch tube while the projectile, being smaller in diameter, is unaffected by the bend. After leaving the sabot stripping section, the cadmium sphere continues to travel straight until it impacts on the target while the sabot is stopped by a sabot trap 25 feet upstream of the target. With less dense projectiles, made from materials such as glass or aluminum, a muzzle velocity of 10 km/sec can be obtained.

2. INSTRUMENTATION

a. Projectile Velocity and Integrity

The minimum requirements for determination of velocity and projectile integrity for this program were one in-flight photograph and two time-versus-position data points. However, a certain amount of redundancy was useful for the following reasons:

1. The increased reliability reduced the chances of total instrumentation failure.

2. Confidence in the velocity determination was increased through comparison of several independent measurements.

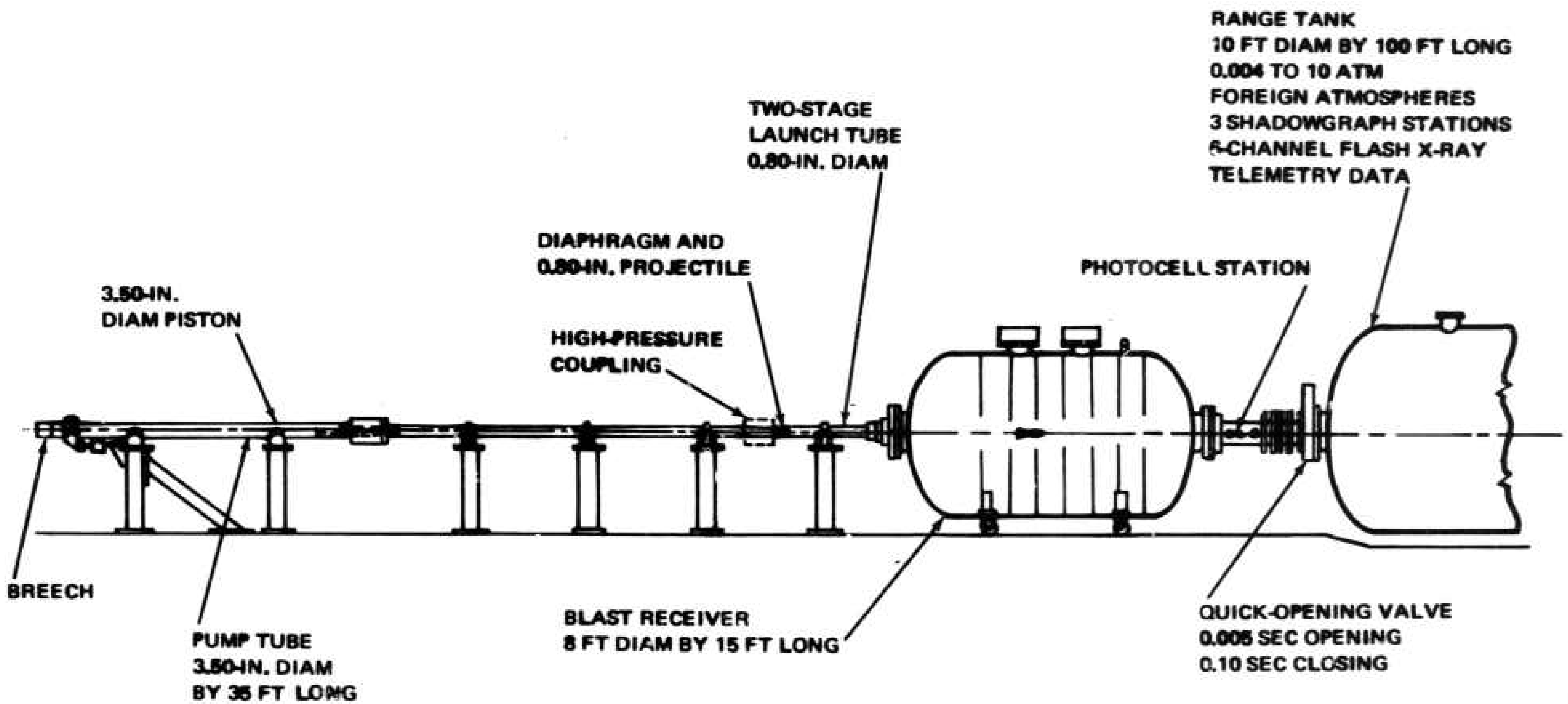


Figure 1. Light-Gas Gun Ballistic Range B

3. Three or more time-versus-position data points allowed a direct measurement of drag losses whenever those losses were significant.

4. Several in-flight projectile photographs decreased the possibility of any damage to the projectile being undetected.

The following instruments were used for projectile velocity measurement:

1. Three electro-optical model detectors.

2. Two flash X-ray units.

3. One impact-flash photodiode at the target.

The flash X-ray units, in conjunction with Beckman counters, generated velocity data to within an accuracy of 0.20 percent. The outputs of the model detectors and the impact-flash phototube provided velocity data within a 3 percent accuracy when displayed on Tektronix oscilloscopes.

The arrangement of the test instrumentation is shown in Figure 2.

b. High-Speed Camera

The camera used for the task was a continuous writing, simultaneous streak and framing camera.* The camera settings are briefly summarized in Table II.

During the test, the camera was located outside the impact tank, viewing the target through a 4-inch-wide x 18-inch-long Plexiglas window and a front surface mirror (shown in Figure 2). The field of view at the target area was approximately 3.2 x 4.6 inches. The camera light source was a high-intensity xenon flashlight** designed specifically for this type of camera. The source looked through the target plates into the camera viewing port. Light from the flash unit was collimated by an 8-inch-diameter condensing lens. The entire lamp and optics assembly was protected by a replaceable Plexiglas sheet. The flash lamp was triggered by the third velocity station through a delay chosen to allow the lamp to reach full intensity a few microseconds before impact. Figure 3 shows typical framing pictures.

For the streak portion of the camera, some excellent streak records of the debris bubble were obtained from shots impacting nearly in line with the center of the slit. (A streak record is highly desirable because it shows any variations in velocity as the debris scans the region between target plates.)

Three limitations of this high-speed camera setup were noted:

1. The camera could not look simultaneously along the surface of each plate; therefore, a 1/8-inch layer near one or the other of the target plates was obscured.

*Beckman and Whitley Model 330
**Beckman and Whitley Model 1001

2. The long time coverage required (80 μs) made it necessary to operate the camera at a low framing rate. As a consequence, the image of the projectile moved approximately 0. 10 inch (or 40 percent of its diameter) during each frame exposure of 0.33 μs.

3. A certain amount of rewrite was noted, caused by the highly luminous impact of the debris cloud against the second plate. However, the resulting degradation of image quality was not severe enough to warrant use of an auxiliary shutter.

c. Flash X Ray

Three-channel flash X-ray units* were used in the test to determine the bubble geometry and velocity after impact. The arrangement of the X rays with respect to the target is shown in Figure 2. The three X-ray heads were mounted outside of the impact tank with the center of the X-ray sources lying in the same plane of the front target sheet, which was orthogonal to the trajectory of the cadmium sphere. Hence, the front target sheet appeared as a line in all three X-ray pictures. The advantages of this arrangement were:

1. All three pictures were taken with the same reference plane, the edge view of the front target plate.

2. Simple geometrical scaling yielded the true position of the bubble in space at a given time.

The three flash X-ray units were fired sequentially through preset delays by the impact flash of the projectile against the first target plate. Figure 4 shows a sequential flash X-ray picture.

The time from impact to each of the three X-ray pulses was measured by time-interval counters. The accuracy of these time measurements is considered crucial because a 100-nanosecond error amounts to 2 percent of the typical time intervals measured. Since the resolution of the time-interval counters was ±100 nanoseconds, the combined error in determining the interval between radiograms could be 4 percent in the worst case. In view of such large random errors, it was important that systematic errors be kept well under 100 nanoseconds.

Prior to the start of the test, a search for systematic errors was conducted in the following areas:

1. The time relation between the actual X-ray burst and the output pulse of various monitoring devices (photodetectors, pickup coils, spark gap switches, fluorescent screen/photodetector combinations, and the capacitive voltage-divider monitor built into some flash X-ray equipment).

2. The response of the time-interval counters to the extremely sharp-rise X-ray monitor signals.

*Field Emission, Inc.

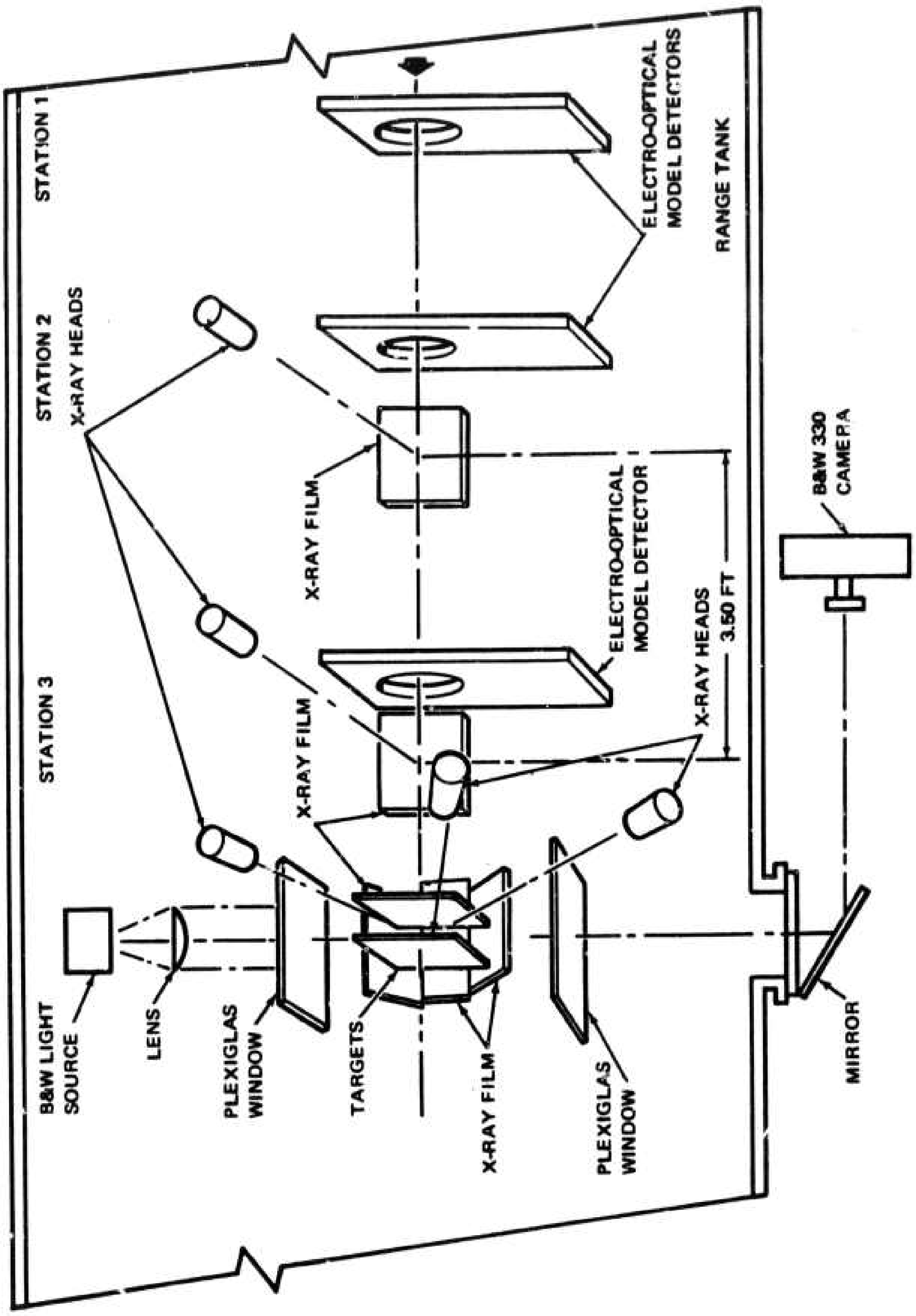


Figure 2. Arrangement of Target Plates and Instrumentation

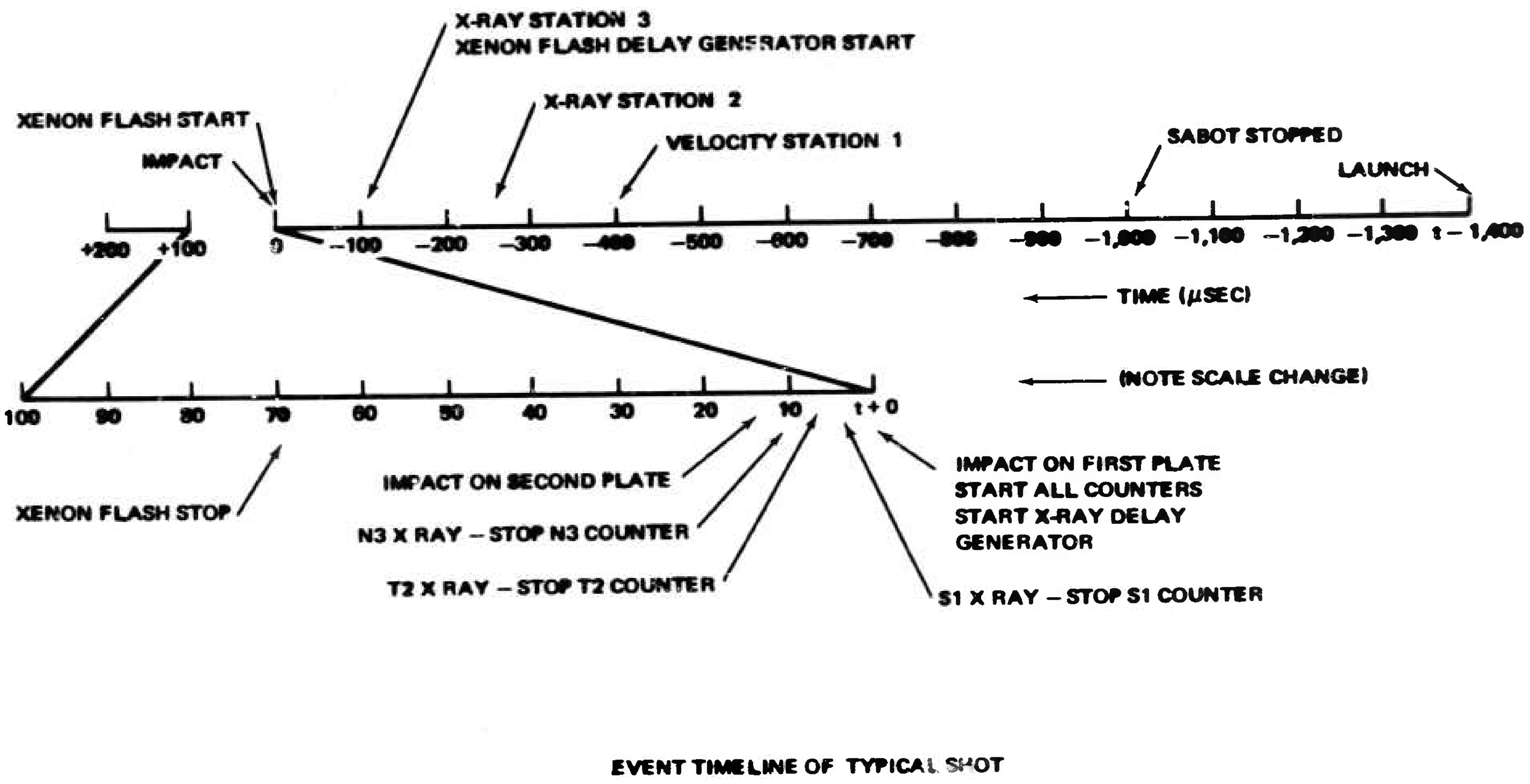


Figure 2 (cont'd). Arrangement of Target Plates and Instrumentation

Table II

CAMERA CHARACTERISTICS

	Framing section
Frame rate	1×10^6 fps
Recording time	80 μs
Exposure time (1/2 stops)	0.33 μs
Frame size	0.7 in. x 1.0 in.
No. of frames	80
Resolution on Plus X	26 lines/mm, minimum
	Streak section
Writing rate	5.32 mm/μs
Slit width (on film)	0.2 mm (standard)
Record size	25 x 430 mm
Time resolution	5×10^{-9} sec

3. Other sources of error, such as unequal signal-path lengths, etc.

A special time-interval counter* was employed in these experiments to act as a reference standard. This counter has a resolution of 1 nanosecond, with no count ambiguity, and has been found through previous use to be extremely reliable.

As a result of these experiments, many systematic errors were eliminated, and it is felt that the resulting time measurements were as good as can be made with 0.1-μs counters. The high-resolution counter was used throughout the test series, and was connected in parallel with one of the three 0.1-μs counters for each shot. The x-t plots of the debris show points measured by the counter as "starred" circles to emphasize the greater accuracy of these points.

*Eldorado Model 796

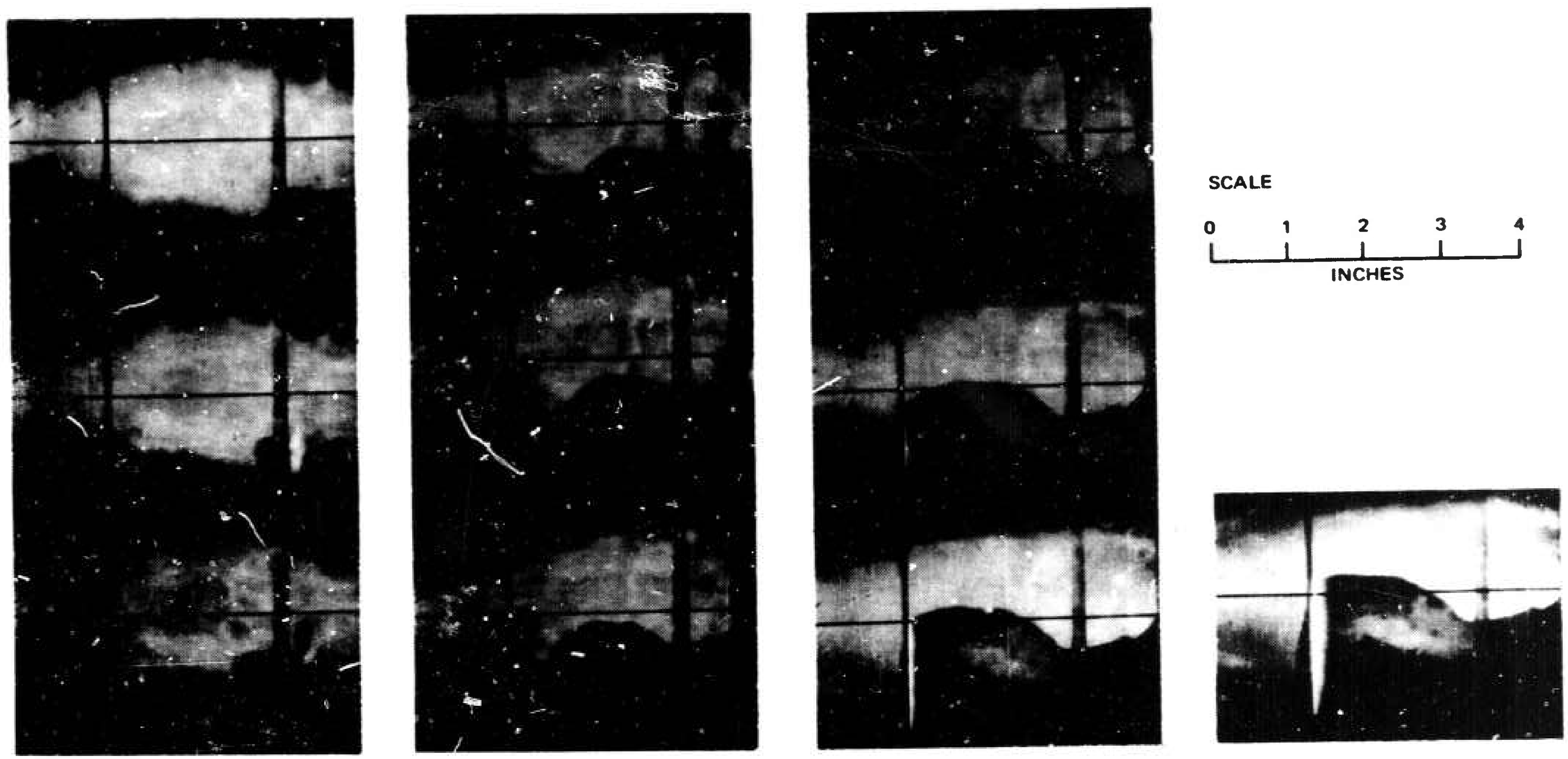


Figure 3. Typical B&W Framing Camera Pictures Taken at 1-Microsecond Intervals of Cadmium Sphere Impact on 0.072/2.29/0.064 in. Cd-V-Al(2) Target

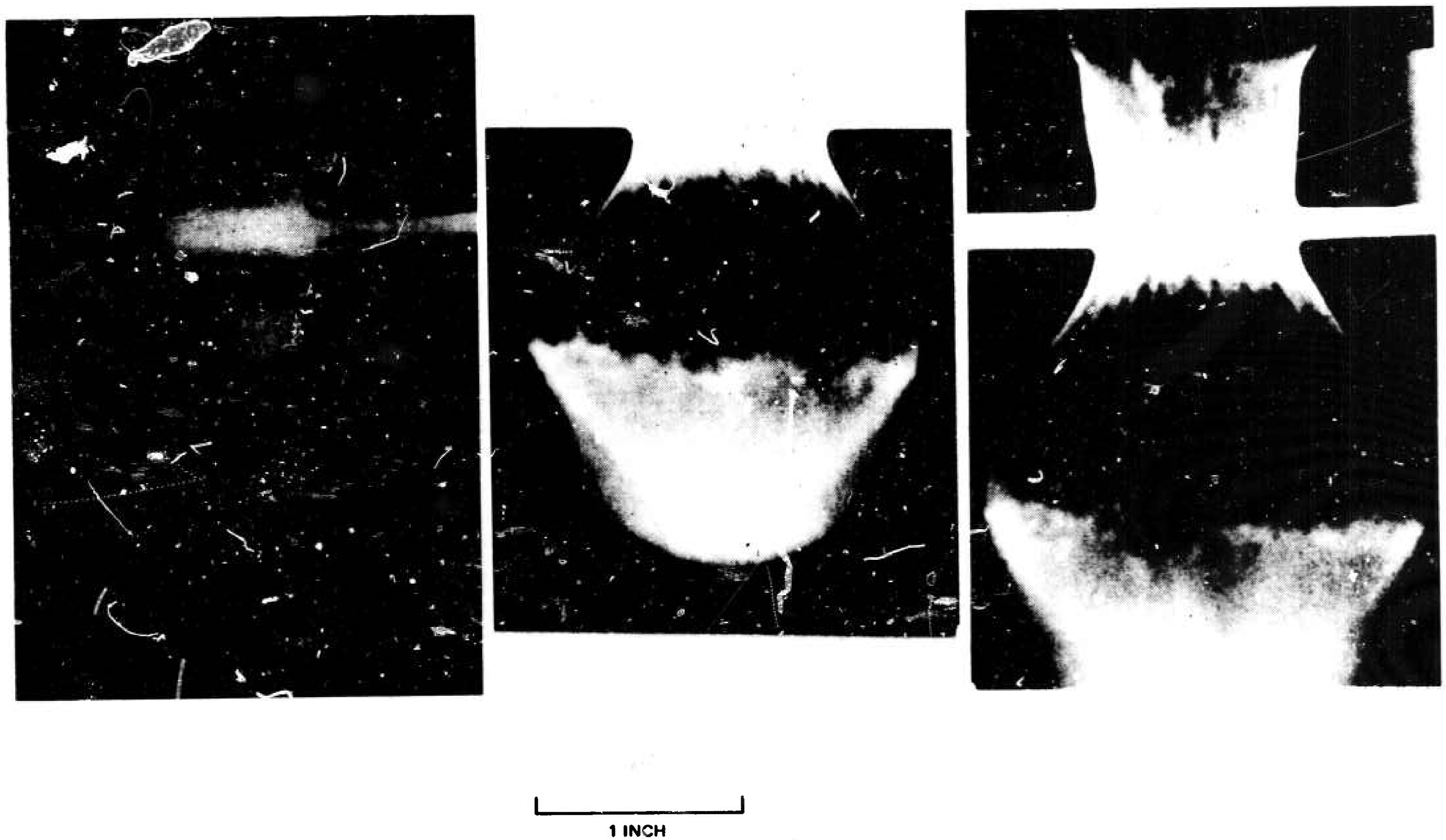


Figure 4. Typical Sequential X-Ray Photographs of Cadmium Sphere Impact on 0.072/2.29/0.125 in. Cd-V-Cd Target Taken at 2.5, 6.6, and 7.6 μsec After Impact

SECTION III

HYPERVELOCITY IMPACT TEST

1. DEFINITIONS FOR DATA POINTS

All the data points obtained for the test program conformed strictly to the definitions below:

a. Energy

A minimum mean pellet energy of 50 kJ.

b. Velocity

A minimum mean pellet velocity of 7.62 km/sec (25,000 fps).

c. Velocity Uncertainty

A measured velocity uncertainty of ±100 fps or better.

d. Velocity Spread

At least 80 percent of the shots (24 shots) had a measured pellet velocity deviating no more than ±500 fps from the required velocity of 25,000 fps; no shot had a measured velocity of more than ±750 fps from the required velocity.

e. Aiming Accuracy

No shot impacted farther than 1 inch from the center of the target.

f. Materials

Pellets were cadmium spheres and targets had cadmium front plates; rear plates were as specified in Table I. Material properties furnished include the density, longitudinal and transverse sound speeds, and yield strength of each target material (Table III).

g. Targets

Each target plate was 8 inches square with a thickness as specified in Table I.

h. Projectile Deformation

The cadmium spheres impacted intact, with a minimum of deformation.

Table III

SOUND SPEEDS AND YIELD STRENGTHS OF TARGETS

Material	Longitudinal speed (ft/sec)	Transverse speed (ft/sec)	Yield strength (psi)
Al 1100-0	20,300	10,300	5,000
Al 7075-T6	19,700	9,990	73,000
Mild steel	19,000	9,850	46,000
Cadmium (99.5%)	9,125	4,900	6,500*

Approximate Error: ±5 percent
Frequency: 15 MHz

*Value of cadmium yield strength is an approximate value based on its tensile strength.

i. Instrumentation

Instrumentation included the following: (1) framing camera coverage of each shot, including the pellet before impact, pellet impact, and rear plate failure (approximately 100-μsec time coverage); (2) three sequential flash X rays of the debris between the plates on each shot; (3) flash X ray of the cadmium sphere in flight before impact.

j. Data Requirements

Data collected on each shot included: (1) front plate damage; (2) debris velocity; (3) debris spray angle, and (4) final rear plate damage.

k. Shot Criteria

A shot was considered successful only if it met the requirements set forth in Paragraphs III. 1. a through III. 1. h; if the framing camera coverage (discussed in Section III. 1. i) was of sufficient quality to show, as a minimum, the pellet before impact, pellet impact, and the debris bubble (only if there was no foam between the plates) expanding between the plates until it impacted the rear plate; if at least two of the three sequential flash X rays clearly showed the debris bubble between the plate so that the debris velocity could be determined; and if a flash X ray was obtained showing the cadmium sphere in flight before impact (Section III. 1. i).

2. HYPERVELOCITY IMPACT TEST RESULTS

Thirty data points were obtained. The results of hypervelocity impact damage in the subject cadmium target test, designated as Test B-40, are tabulated in Table I. Target damages and condition of experiment are shown in Plates 1 through 30. Several important changes and deviations were made during the testing period. They are indicated in the following paragraphs.

a. Change of Second Sheet Thickness

It became evident, after the first few shots, that the rear target plates as specified in the original proposal were not sufficiently thick. To amend this, the thickness of the remaining 16 rear target plates was doubled. As a consequence of this change, the damage made in the rear target plates ranged from slight bulges to catastrophic failure. These results were considered highly satisfactory.

b. Change of Target Material

During the test, it was noted from the results of Shots 2 and 6 that no additional meaningful information could be obtained from Shots 8 and 12 if the originally proposed targets were used. Changes of the second target plate from a single cadmium to a 1/16-inch steel plate and a 1/4-inch lead plate composite were made. The results of these two shots were quite spectacular. The lead spalled badly while the steel plate remained relatively undamaged. The interesting momentum exchange mechanisms and the importance of design criteria for future spacecraft of composite wall structure have been clearly demonstrated by the shots.

c. Changes of Shots Participated in by Hughes Aircraft Company, Fullerton

As a result of target changes, the shots involving Hughes Aircraft Company personnel were changed to Shots 5, 7, 11, and 13 for the photo-stress experiment; and to Shots 22, 23, 25, and 26 for stress-wave experiments. Details of these experiments can be found in a separate publication by Hughes Aircraft Company, AFWL-TR-69-154.

d. Deviation from Shot Criteria

Several shots deviated slightly from the original shot criteria, but were accepted by the contract monitor. They were:

Shot No. 2	Impact X ray missing (nearly identical information can be found from Shots 3, 4, 5, 6, 7, 8, 16, 17, 22, and 23; also from backup framing camera records of Shot No. 2)
Shot No. 13	Information from Shots B-40-24 and B-40-25 combined to give a complete coverage. Because the point of impact was more than 1 inch away from the center, more stress fringes were recorded by the camera.

e. Shot No. 30

Shot No. 30 was originally set aside as a backup to the eight shots for pressure measurement which were to be made by Gulf General Atomic with pressure transducers. However, no such repeat was needed after the test series. It was decided that a steel sphere of equivalent mass impacting on the target of Shot No. 7 would be useful as a comparison to cadmium-cadmium impact.

SECTION IV

CONCLUSIONS AND REMARKS

No conclusions have been drawn from the test data because evaluation and correlation of these data are beyond the scope of this contract. However, a few remarks on the test are stated below:

1. The deformation of the cadmium sphere during launch was up to 20 percent in diameter. The deformed spheres tumbled slightly. Noticeable variations in hole sizes in the front plate and in bubble geometry were observed. The debris velocity variations, however, were not significant.

2. When model deformation is not an important factor, launching of cadmium spheres to velocities considerably over 25, 000 fps appears possible.

3. Launch tube erosion per shot was high (0. 002 inch per shot) in comparison with previous experience of 23, 000 fps shots where only 0. 0005-inch erosion per shot was observed.

4. Reliability of the sabot design and sabot stripping techniques used in this test (Reference 3) was over 90 percent. The aiming accuracy, however, was less reliable.

5. The pressure generated between the first and second target plates by the cadmium vapor after impact behaved in two different ways. When there was foam filler between the target plates, long-duration pressure pulses existed. Violent damage occurred to both the first and second plates. When the spacing was void, sharp, short-duration pressure pulses occurred. Nearly all damage was done to the second plates only.

6. Although theory predicted complete vaporization of the cadmium sphere and target when impacted at 25, 000 fps, a few signs of particle impact were observed on some of the second plates along the circumference of a circle. This is believed to be the result of weak shock strength at the outer edge of the sphere-plate interaction.

7. On Shot No. 30, a mild steel, 1. 91-gm sphere was impacted on a cadmium target. The test results warrant closer study!

APPENDIX

A complete set of photographic plates of the damaged targets of the 30 data shots are included in this section. The plate number assigned is identical to the shot number. Damaged targets are in storage at the Project Office of the Air Force Weapons Laboratory.

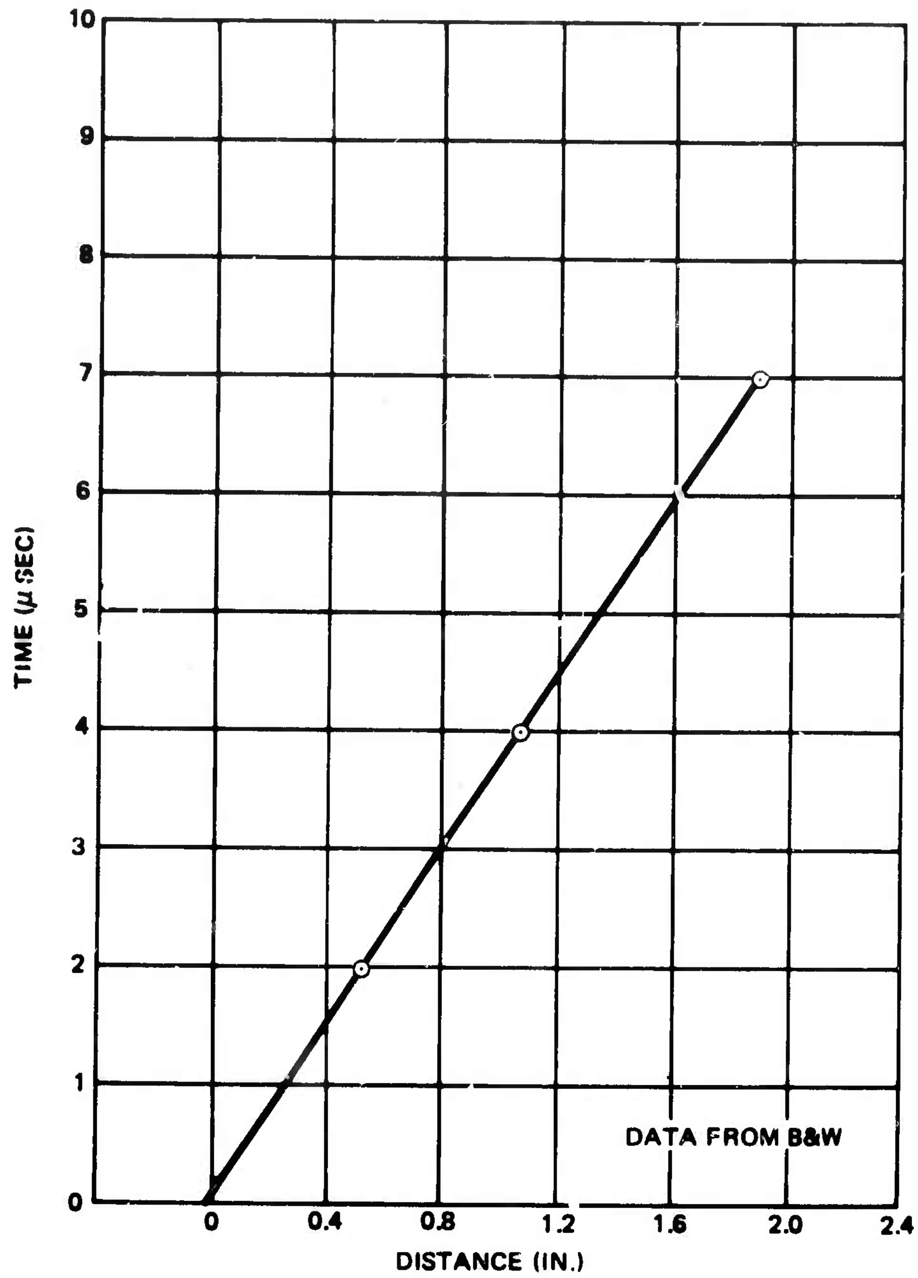
The x-t graphs show the debris position versus time for each shot. Time was measured from impact (by detecting the impact flash with a high-speed photodiode) to the X-ray pulse at each station. Distance was measured from the second (inner) surface of the first plate to the crest of the debris cloud as seen on the radiograph, with corrections applied for X-ray geometry. Points indicated with a circle were measured with conventional 0.1-μs resolution counters. The circle has a radius equivalent to 0.1μs to indicate the degree of uncertainty for these points. "Starred" points indicate that time was measured with a counter having a 1-nanosecond resolution.

Inspection of the graphs for the void shots shows that in general these points fall on a straight line that passes through zero time at a point to the left of zero distance by the amount of the bumper thickness. Consequently, all void-shot graphs show a straight line connecting the zero time point with the point measured with the high-resolution counter. Foam shots show straight lines between adjacent points.

PLATE NO.	1
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,500 FPS
TARGET CONFIGURATION:	Cd 8 x 8 x 2-3/4 IN.
CRATER DIAMETER:	2.0 IN.
CRATER DEPTH:	1.1 IN.
CRATER VOLUME:	2.27 CUBIC IN.

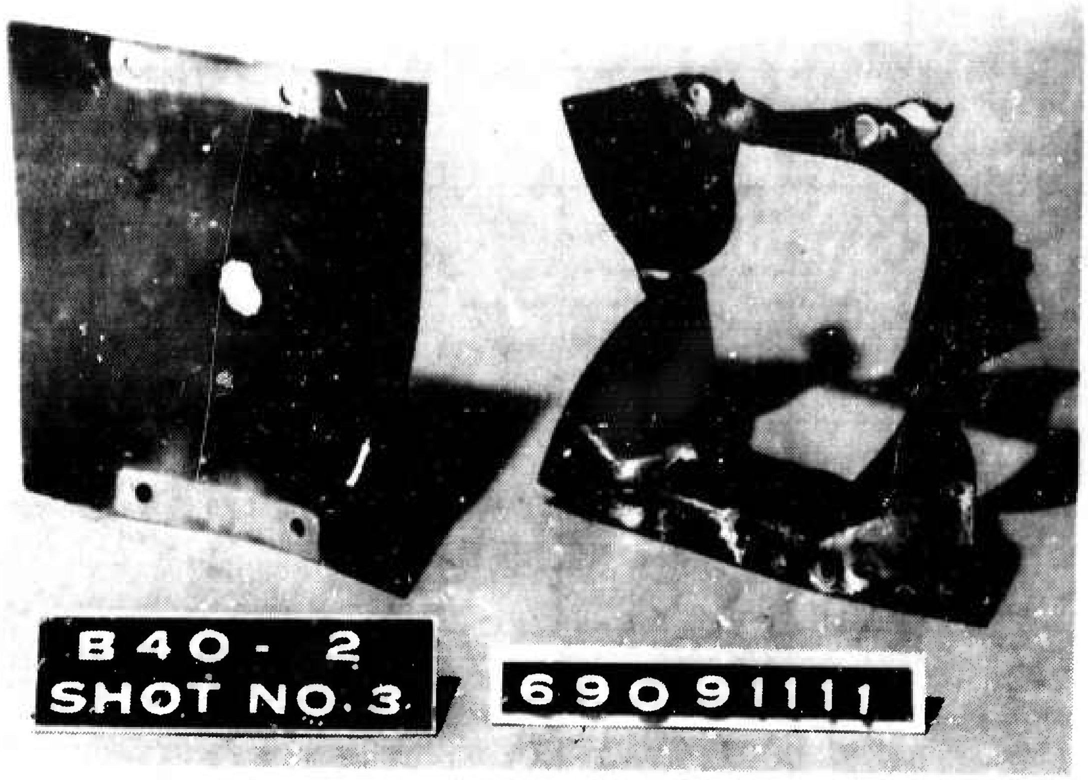

B40-16
SHOT NO. 2
69091118


B40-16
SHOT NO. 2
69091117

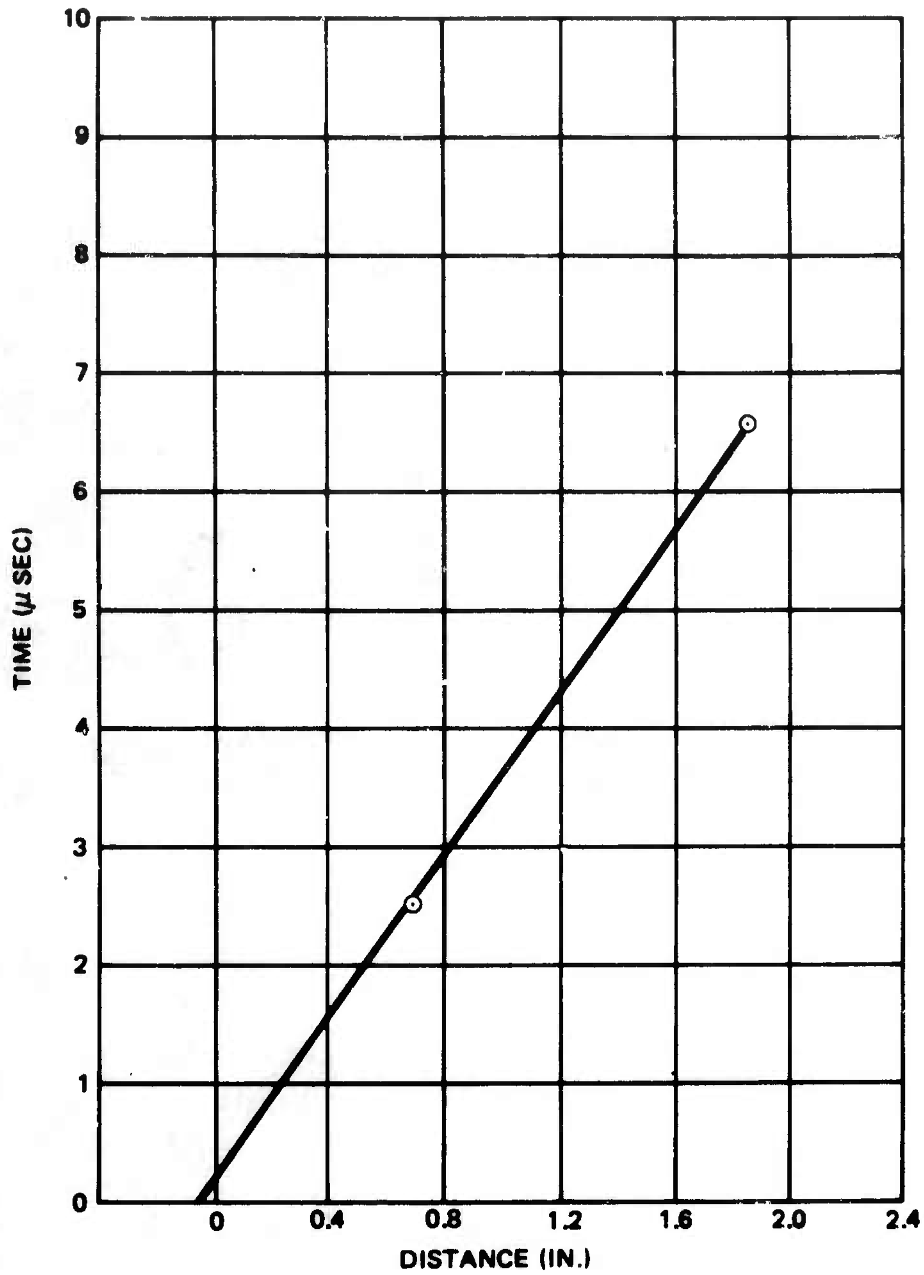


Sprey Position vs Time

PLATE NO.	2
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,300 FPS
TARGET CONFIGURATION:	Cd-V-Cd 0.072/2.29/0.125 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	3.5 IN.


B40- 2
SHOT NO. 3
69091111


B40- 2
SHOT NO. 3
69091112



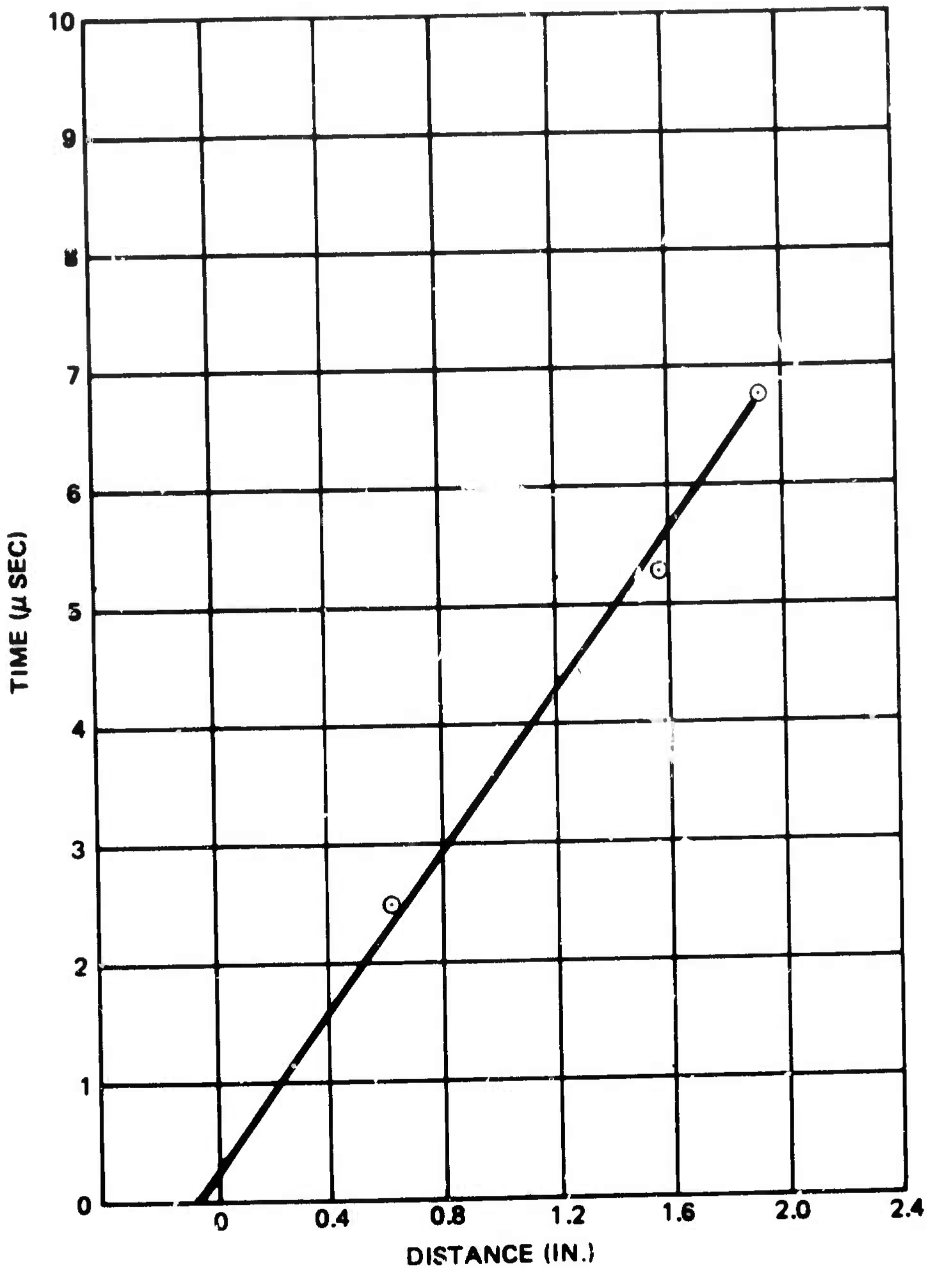
Spray Position vs Time

PLATE NO.	3
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	25,100 FPS
TARGET CONFIGURATION:	Cd-V-Al(1) 0.075/2.29/0.062 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.95 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	6.75 IN.


B40 - 4
SHOT NO. 4


69091123

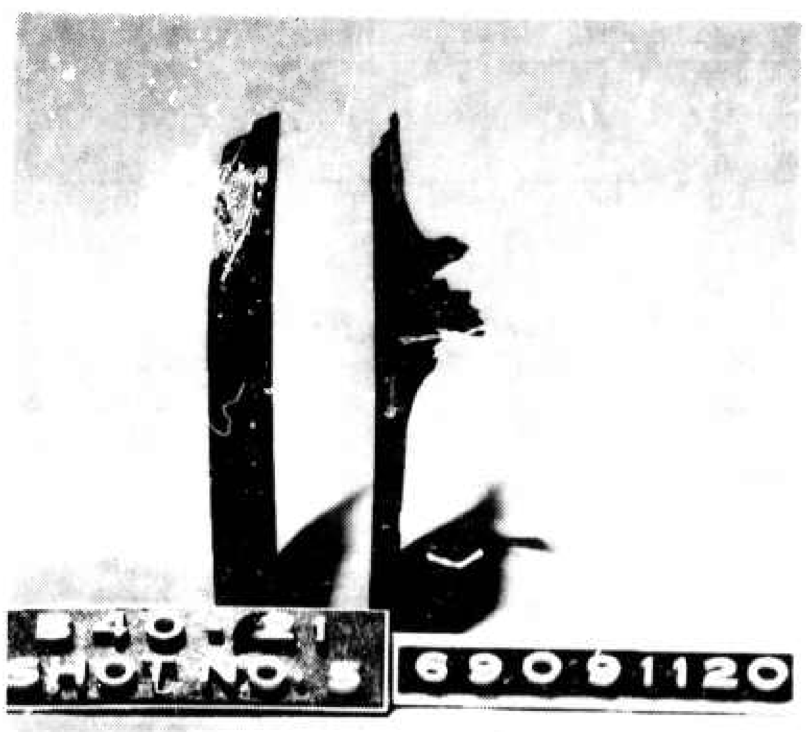

B40 - 4
SHOT NO. 4
69091124

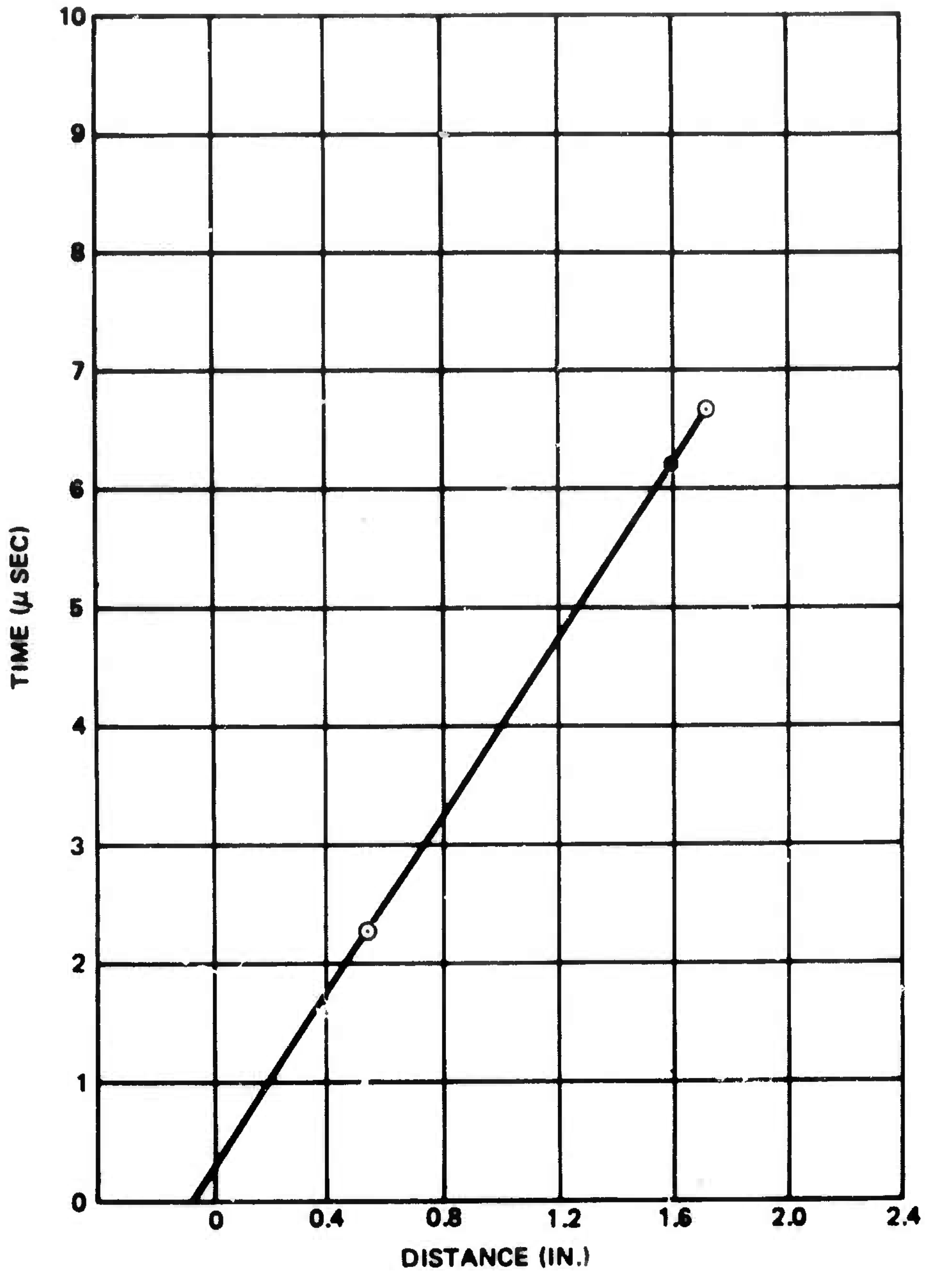


Spray Position vs Time

PLATE NO.	4
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	25,200 FPS
TARGET CONFIGURATION:	Cd-V-Al(2) 0.072/2.29/0.064 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.35 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B40-21
SHOT NO. 5
69091119


69091120

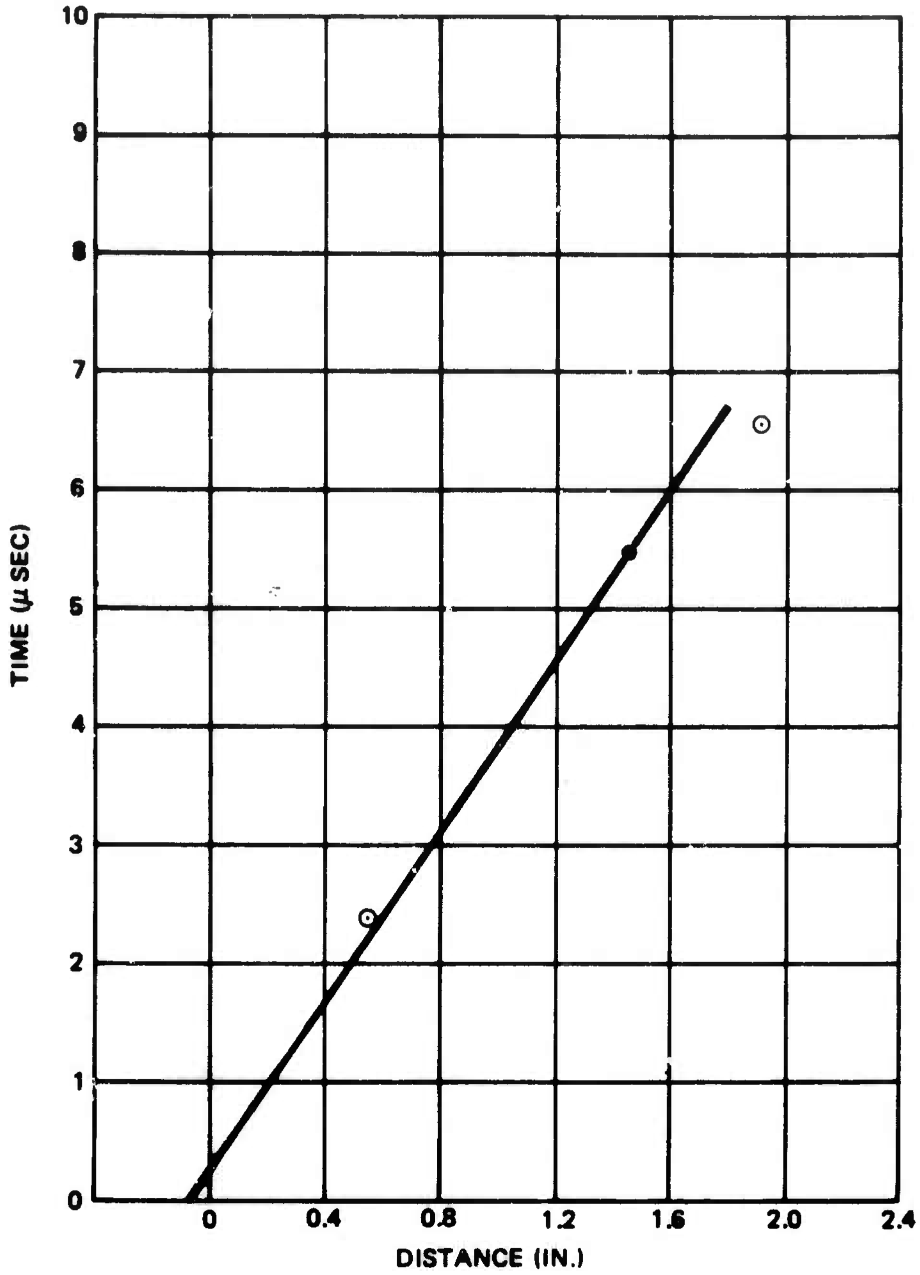


Spray Position vs Time

PLATE NO.	5
PROJECTILE:	CAOMIUM SPHERE
IMPACT VELOCITY:	24,700 FPS
TARGET CONFIGURATION:	Cd-V-Fe 0.072/2.29/0.125 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.85 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	1.9 IN.

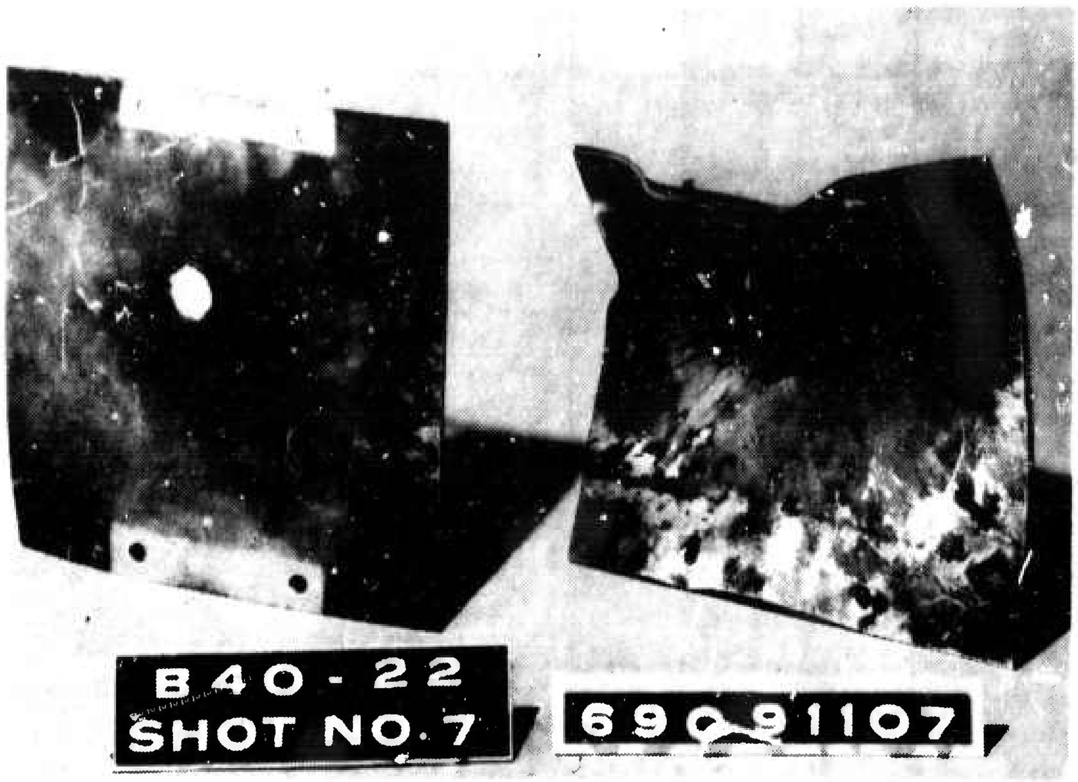

B40- 17
SHOT NO. 6
69091110


B40- 17
SHOT NO. 6
69091109

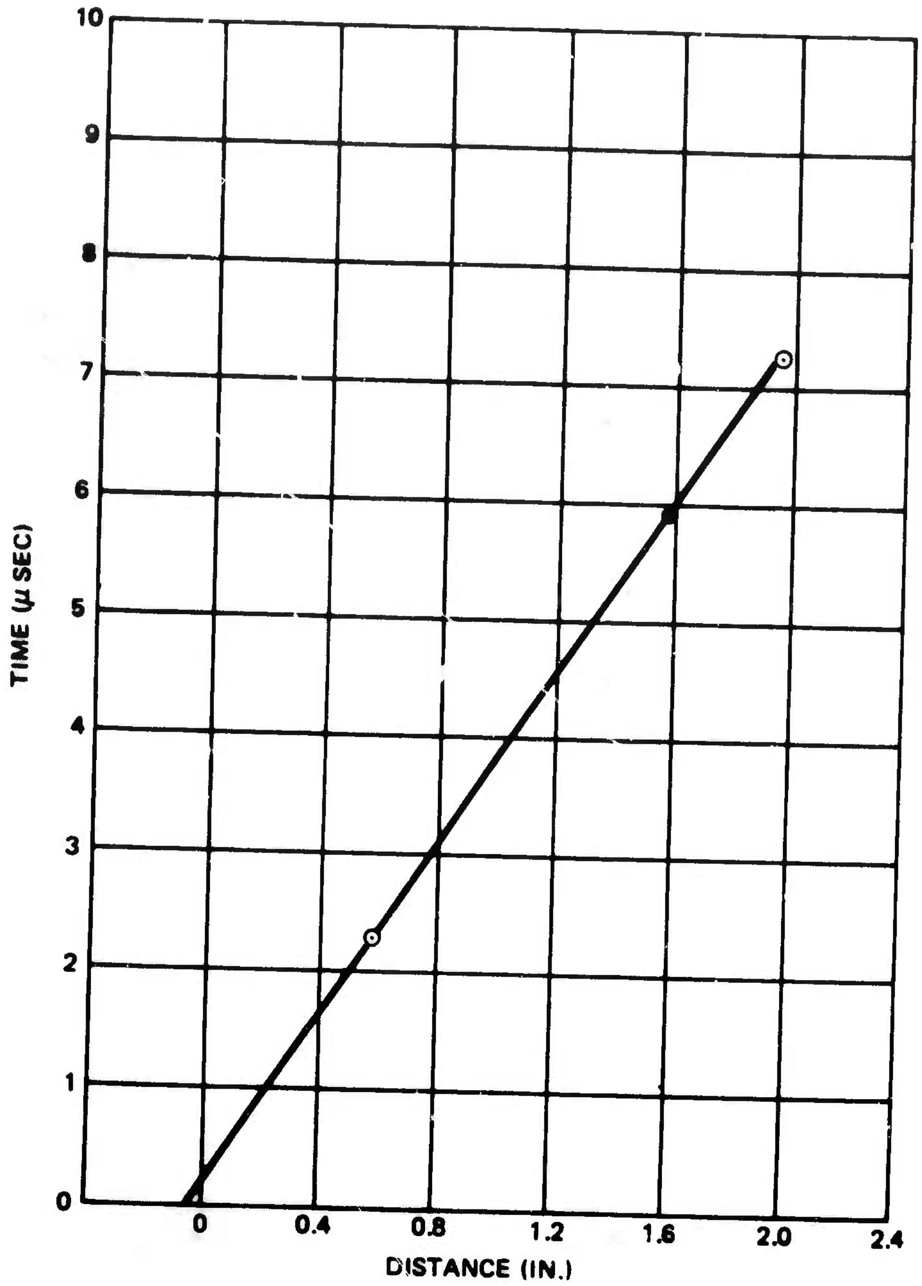


Spray Position vs Time

PLATE NO.	6
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,750 FPS
TARGET CONFIGURATION:	Cd-V-Cd 0.072/3.43/0.125 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.8 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

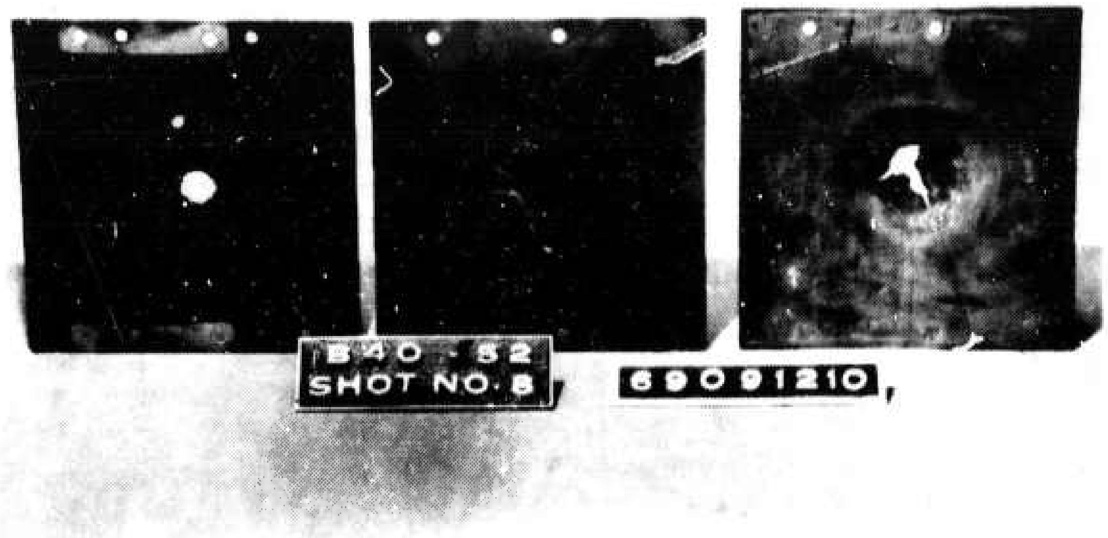

B40-22
SHOT NO. 7
69091107

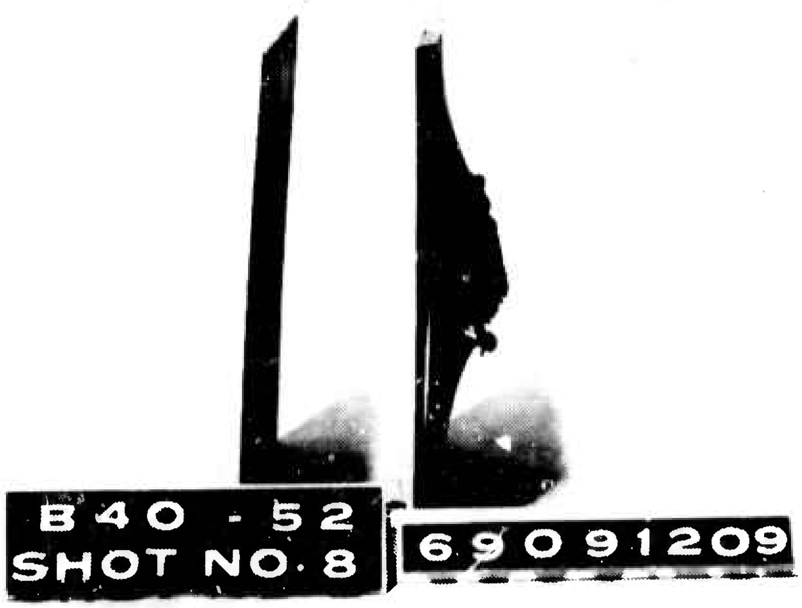

B40-22
SHOT NO. 7
69091108

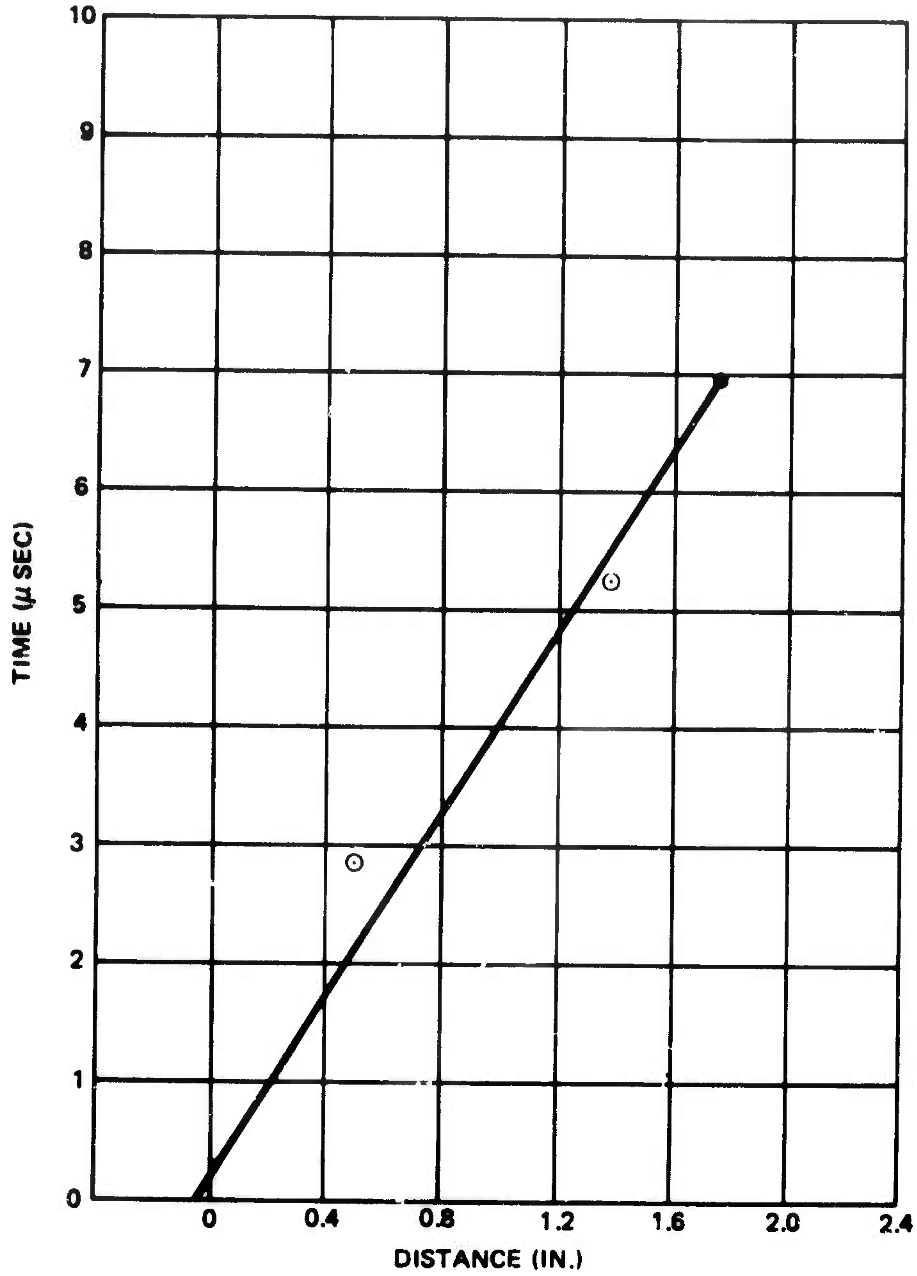


Spray Position vs Time

PLATE NO.	7
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,700 FPS
TARGET CONFIGURATION:	Cd-V-Al(1) 0.072/3.43/0.125 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.85 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	---

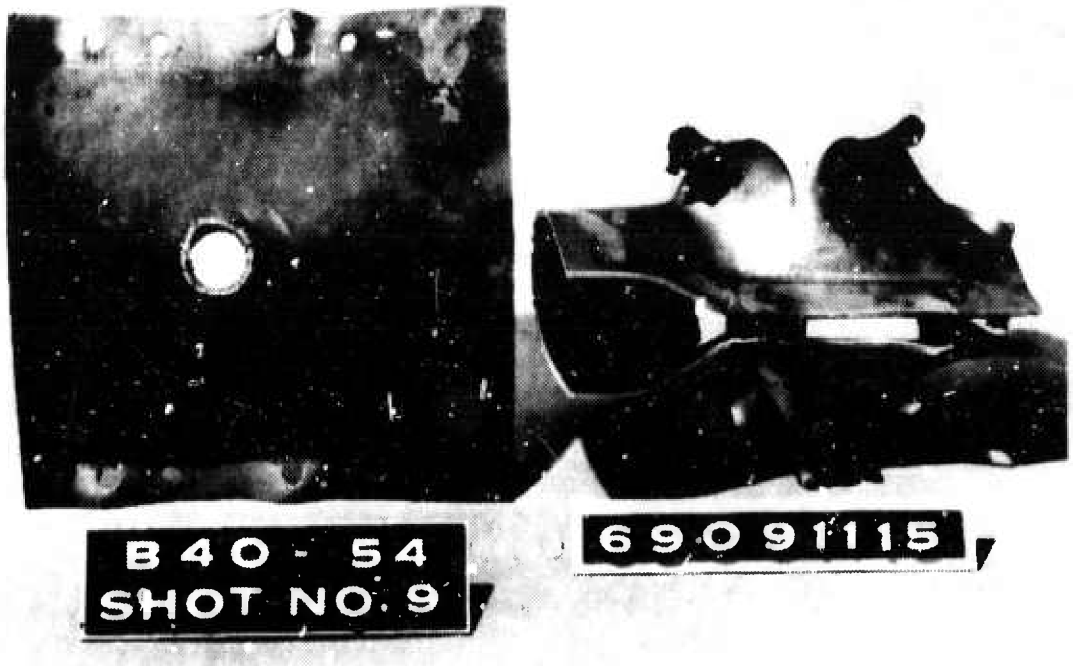

B40 - 52
SHOT NO. 8
69091210


B40 - 52
SHOT NO. 8
69091209

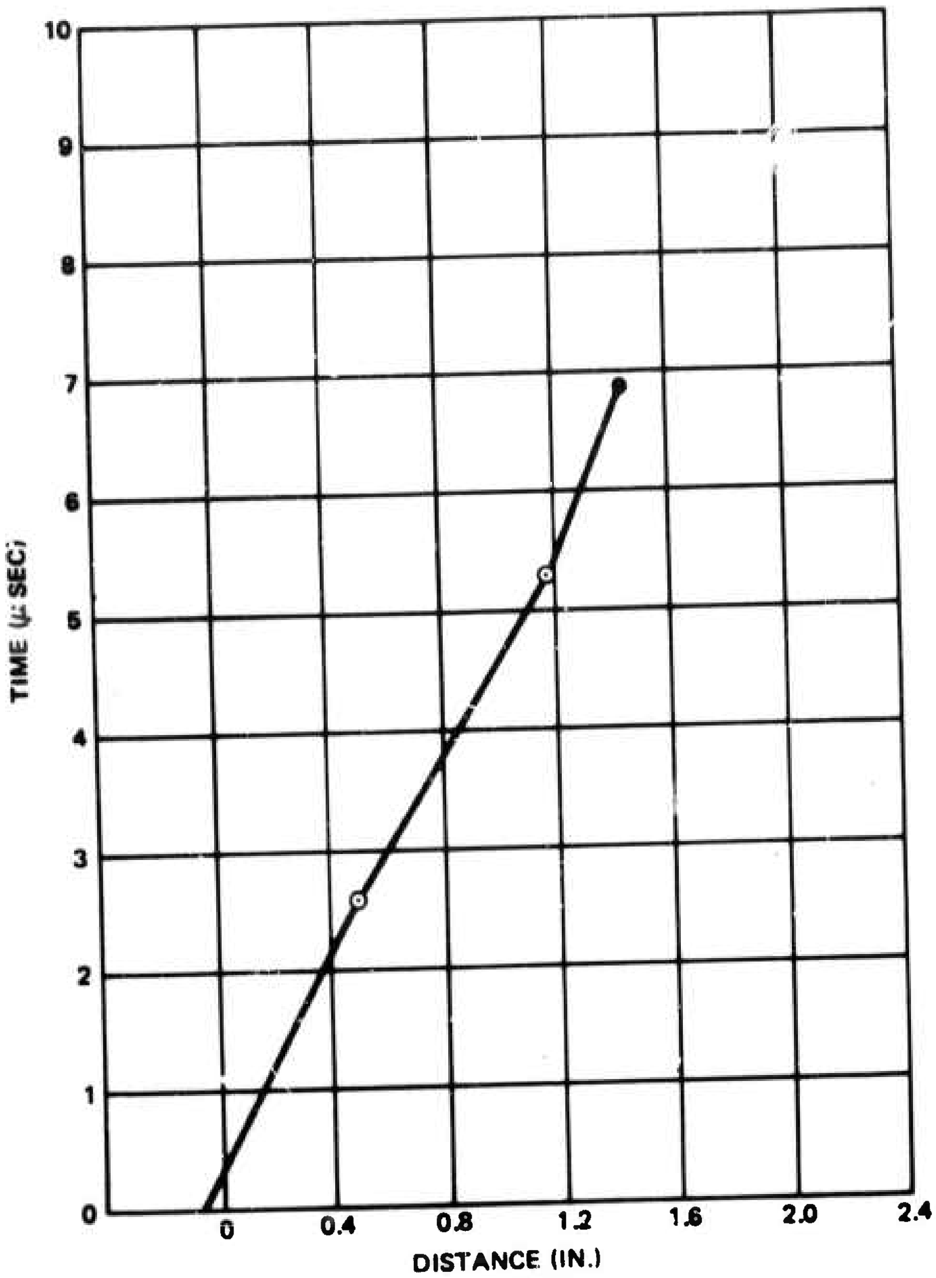


Spray Position vs Time

PLATE NO.	8
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,250 FPS
TARGET CONFIGURATION:	Cd-V-Fe-Pb 0.072/2.29/0.070/0.250 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.85 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	1.5 IN.

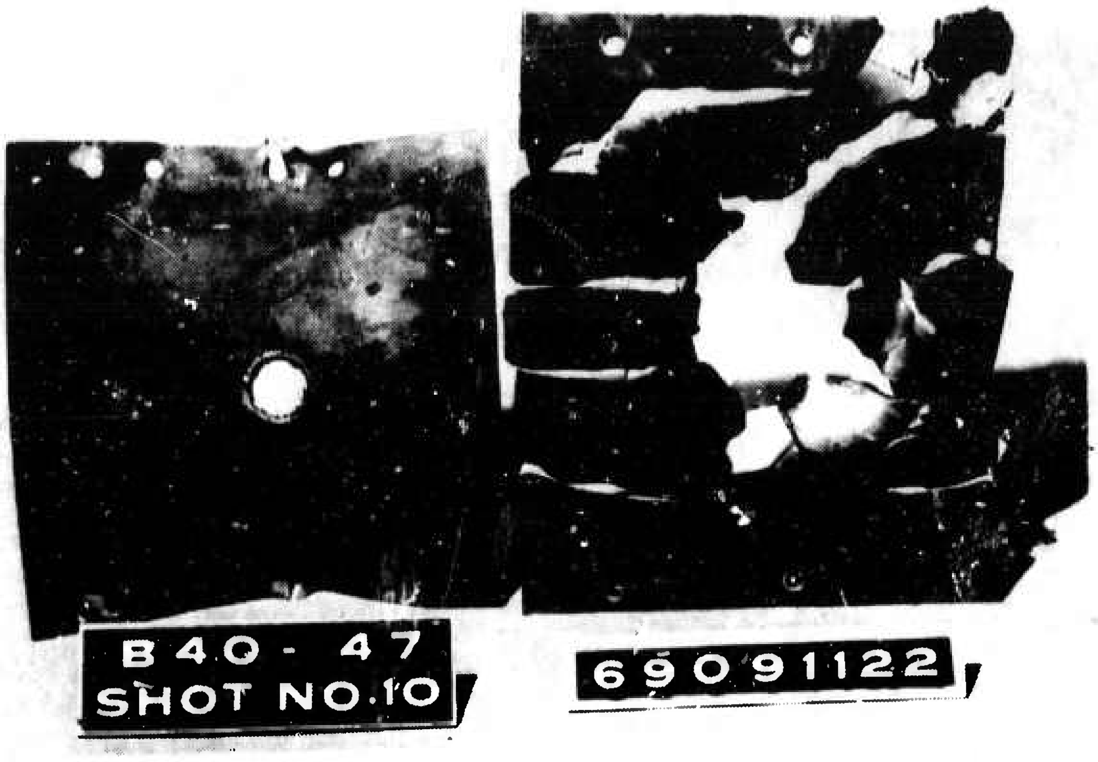

B40 - 54
SHOT NO. 9
69091115


B40 - 54
SHOT NO. 9
69091116

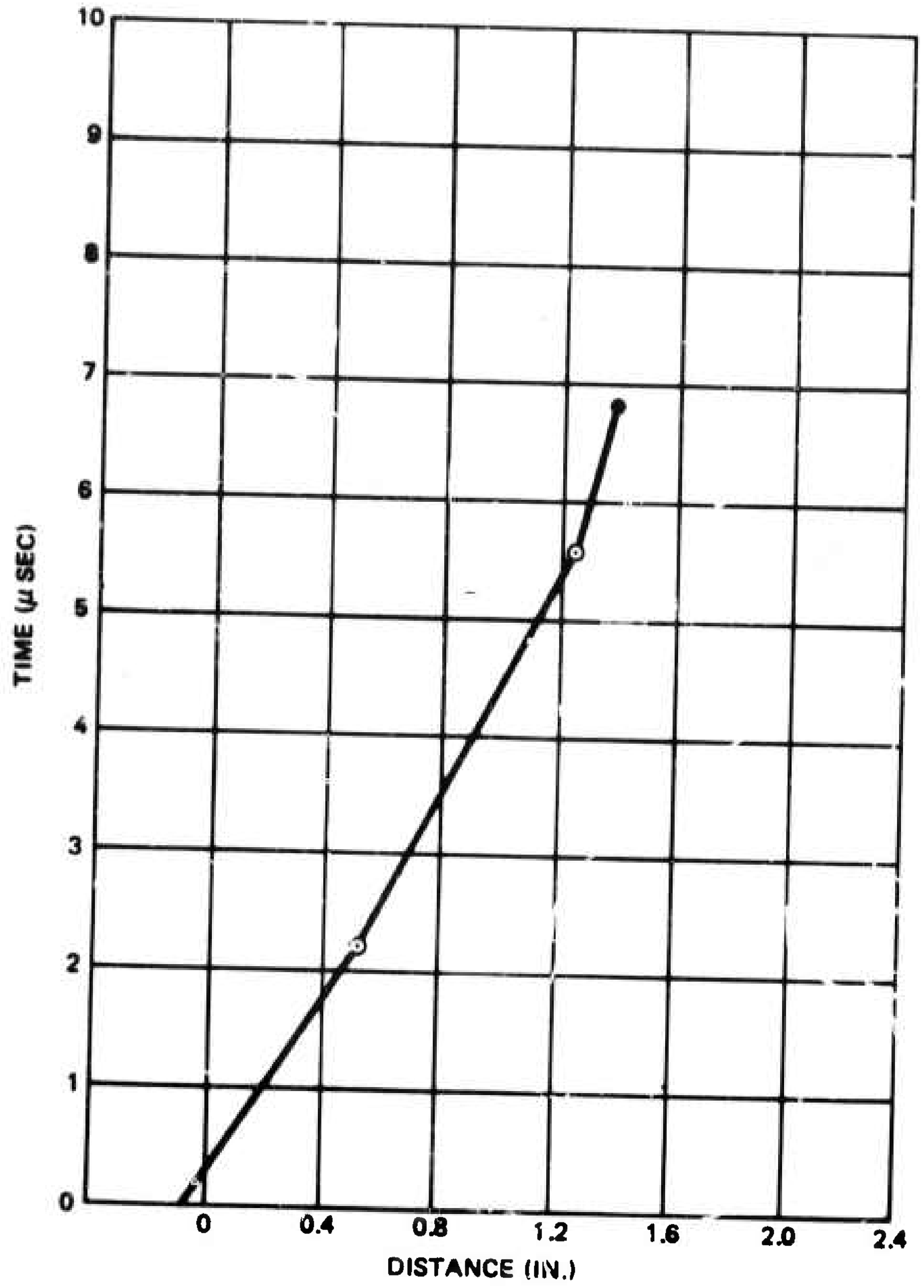


Spray Position vs Time

PLATE NO.	9
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,300 FPS
TARGET CONFIGURATION:	Cd-f-Al(1) 0.072/2.29/0.125 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	5.0 IN.

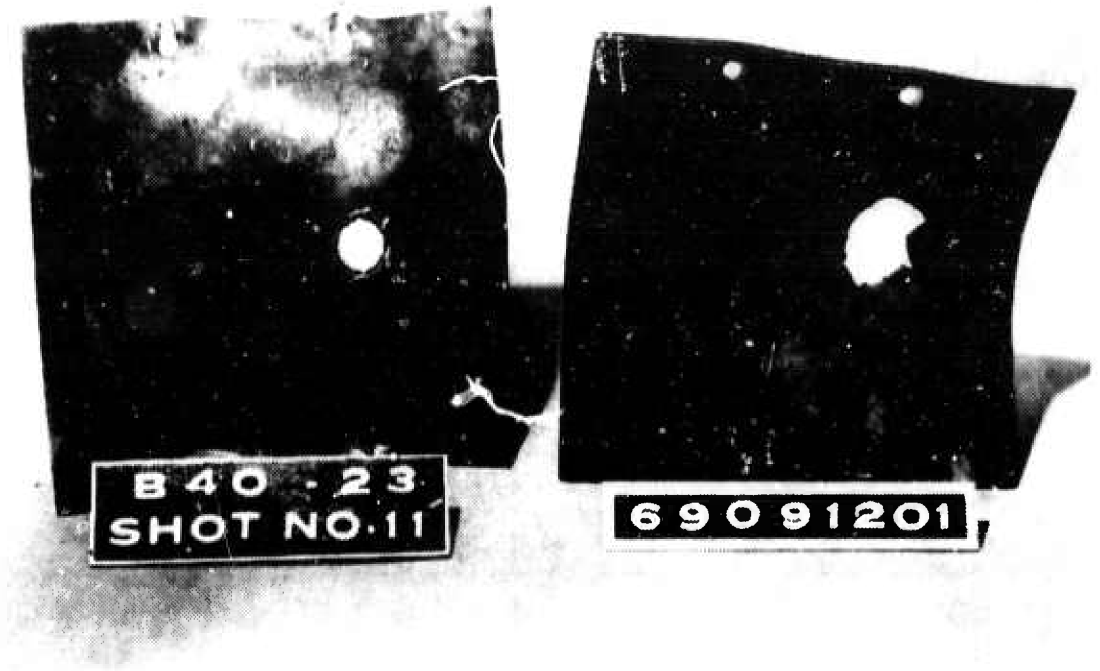

B40 - 47
SHOT NO.10
69091122

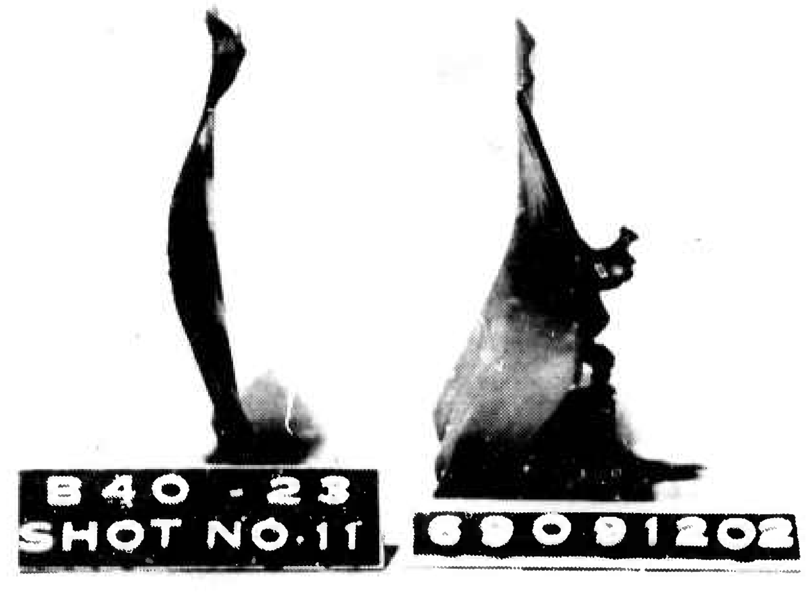

B40 - 47
SHOT NO.10
69091121

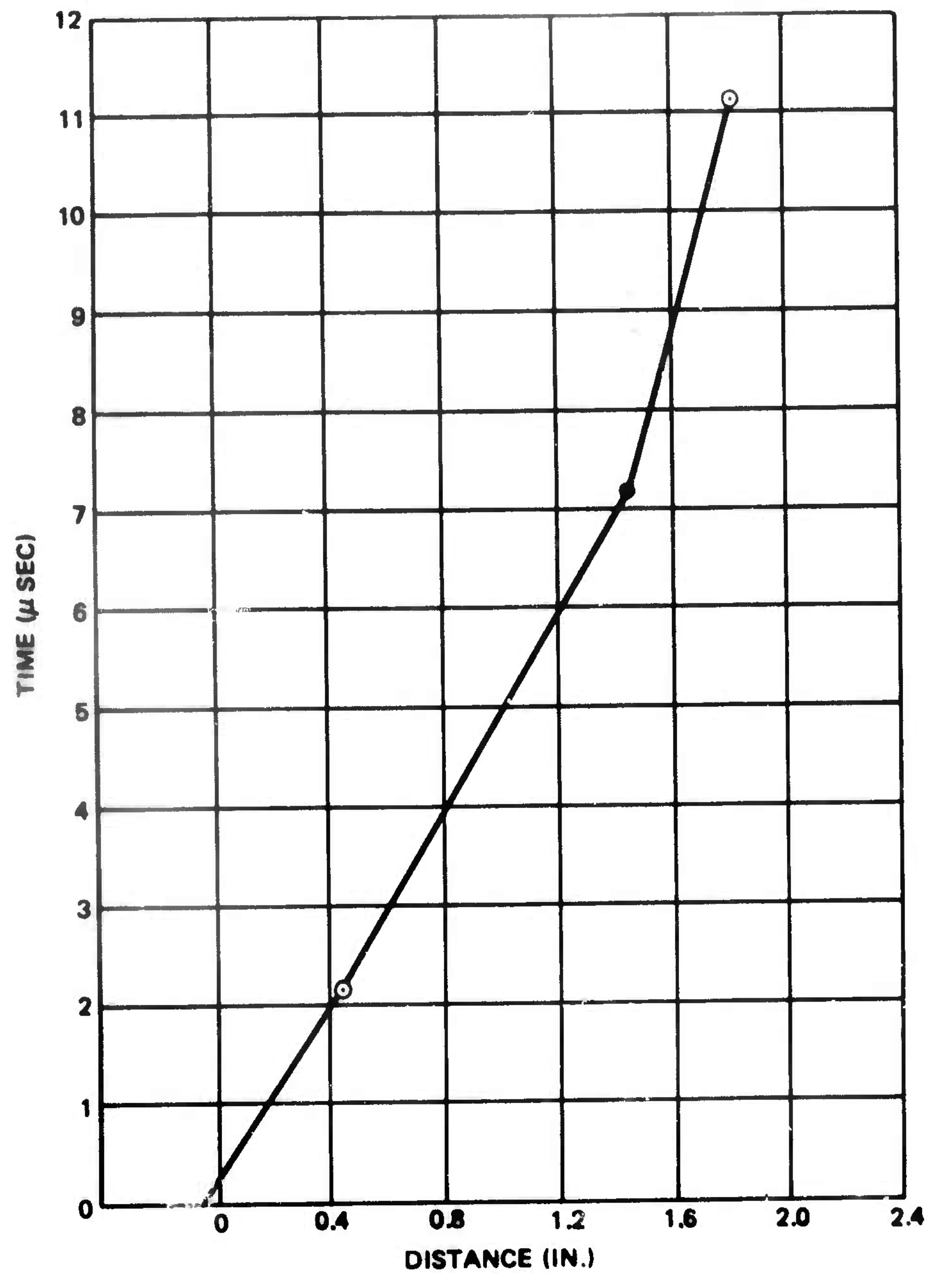


Spray Position vs Time

PLATE NO.	10
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,550 FPS
TARGET CONFIGURATION:	Cd-f-Al(2)
	0.072/2.29/0.125 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

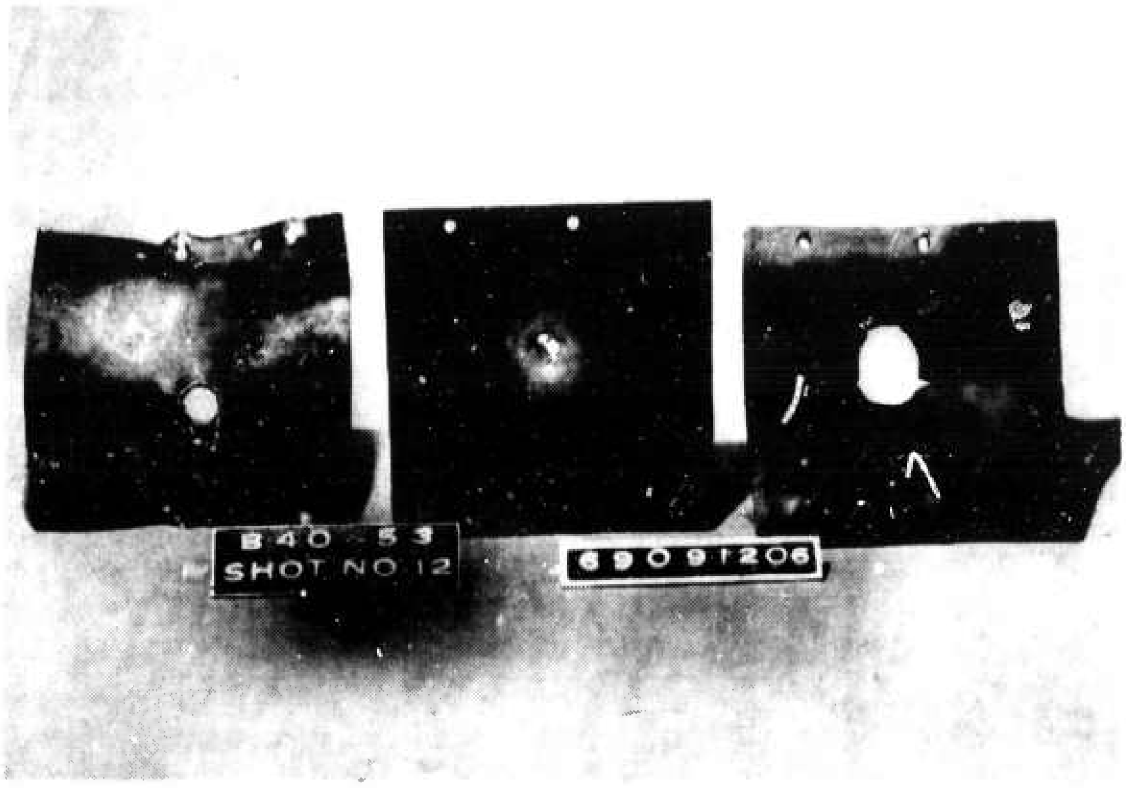

B40 - 23
SHOT NO. 11
69091201


B40 - 23
SHOT NO. 11
69091202

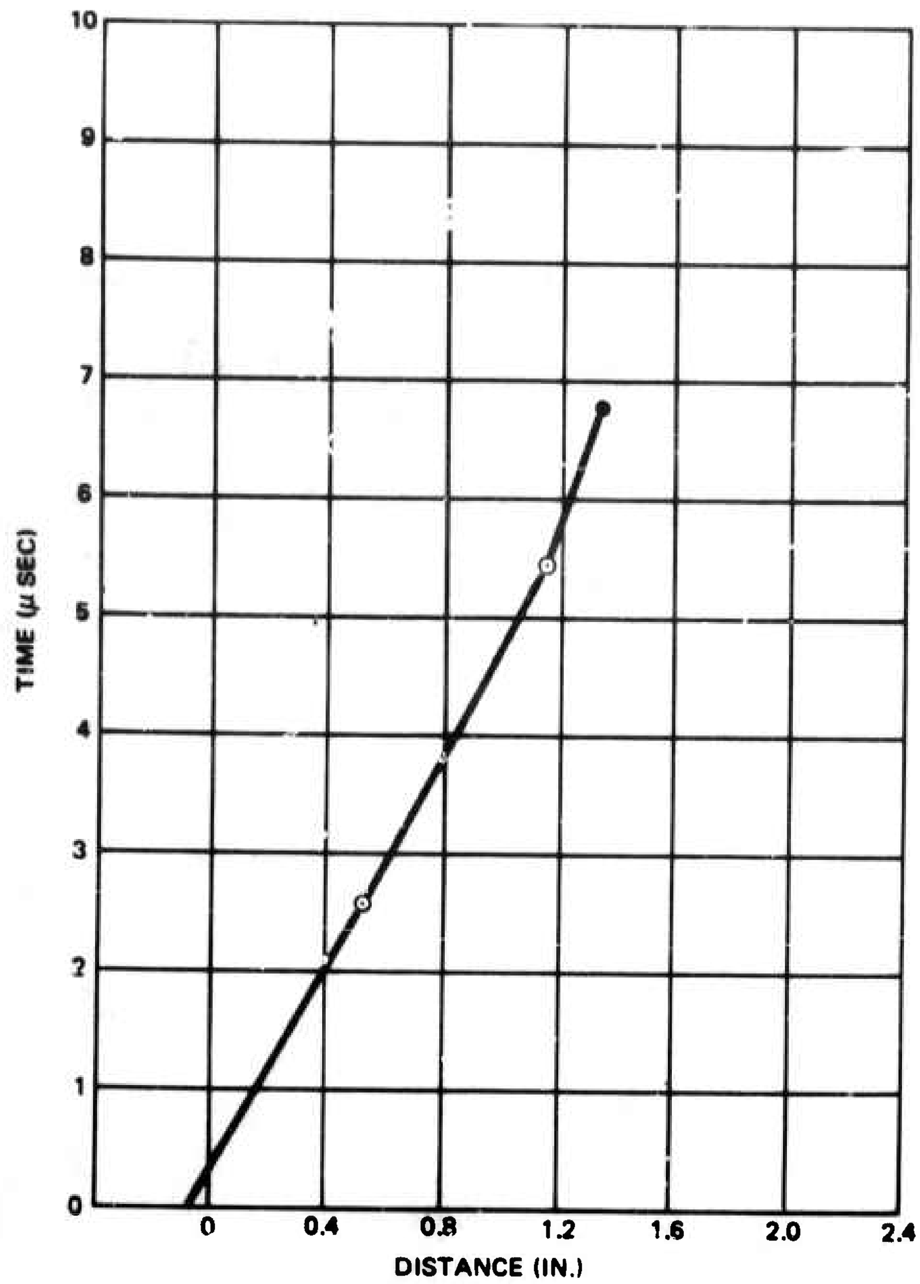


Spray Position vs Time

PLATE NO.	11
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,450 FPS
TARGET CONFIGURATION:	Cd-f-Fe 0.072/2.29/0.125 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	1.75 IN.

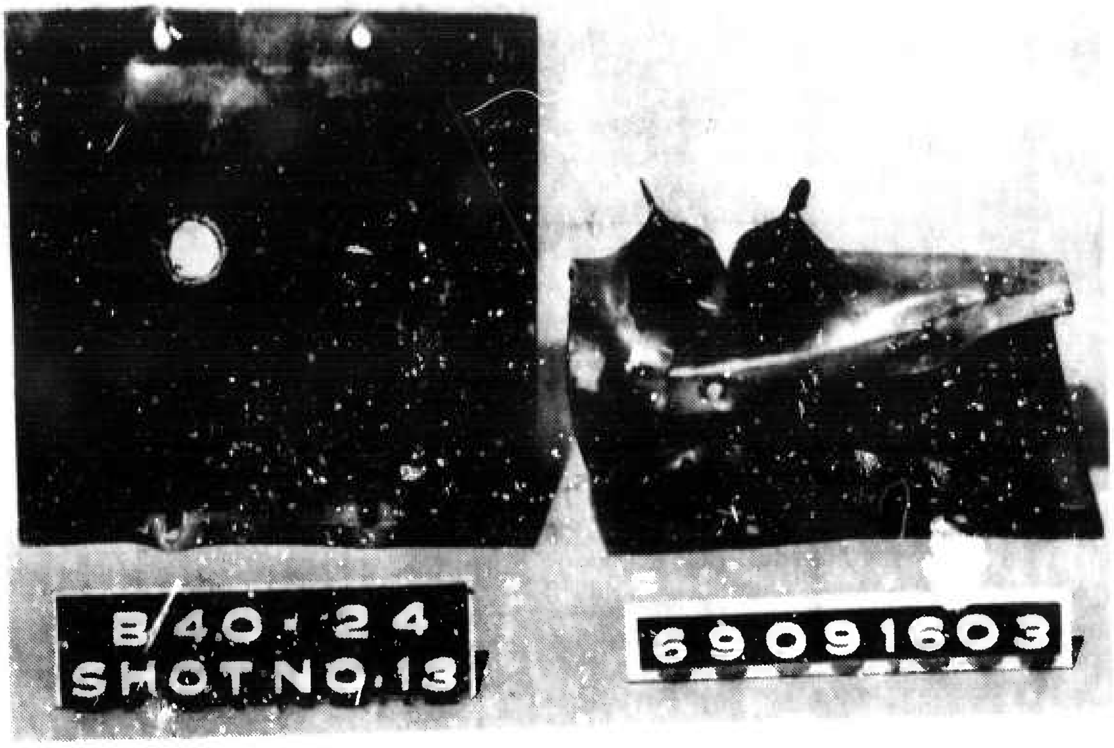

B40-53
SHOT NO 12
6909I206

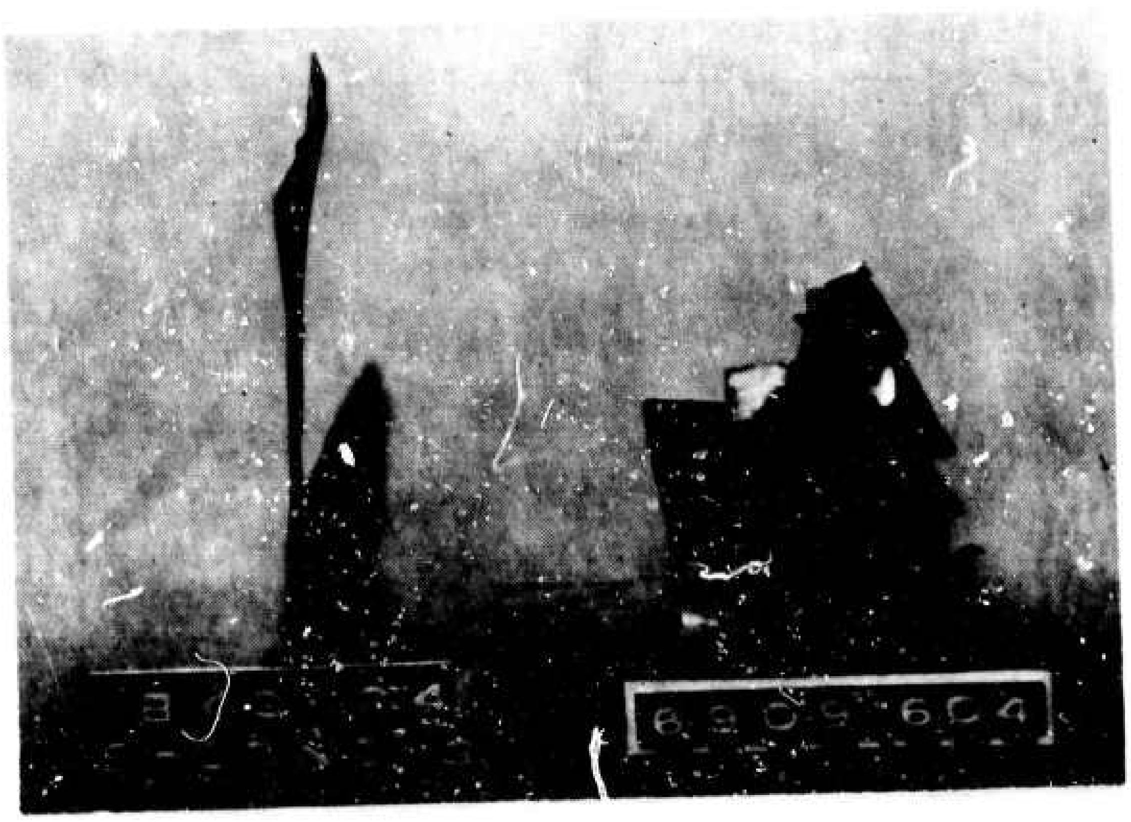

B40-53
SHOT NO.12
6909I205

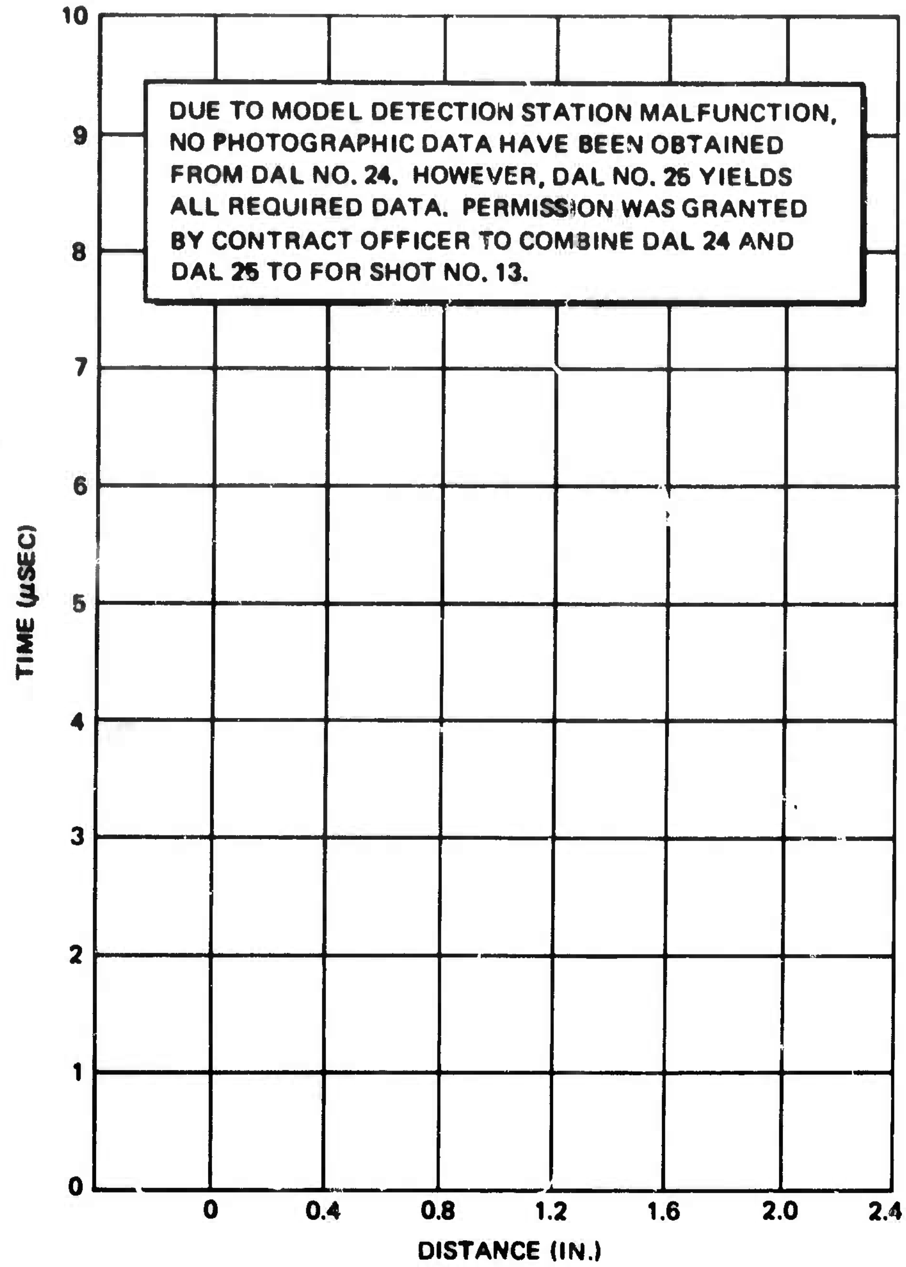


Spray Position vs Time

PLATE NO.	12
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,250 FPS
TARGET CONFIGURATION:	Cd-f-Fe-Pb 0.072/2.29/0.070/0.250 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	2.0 IN.

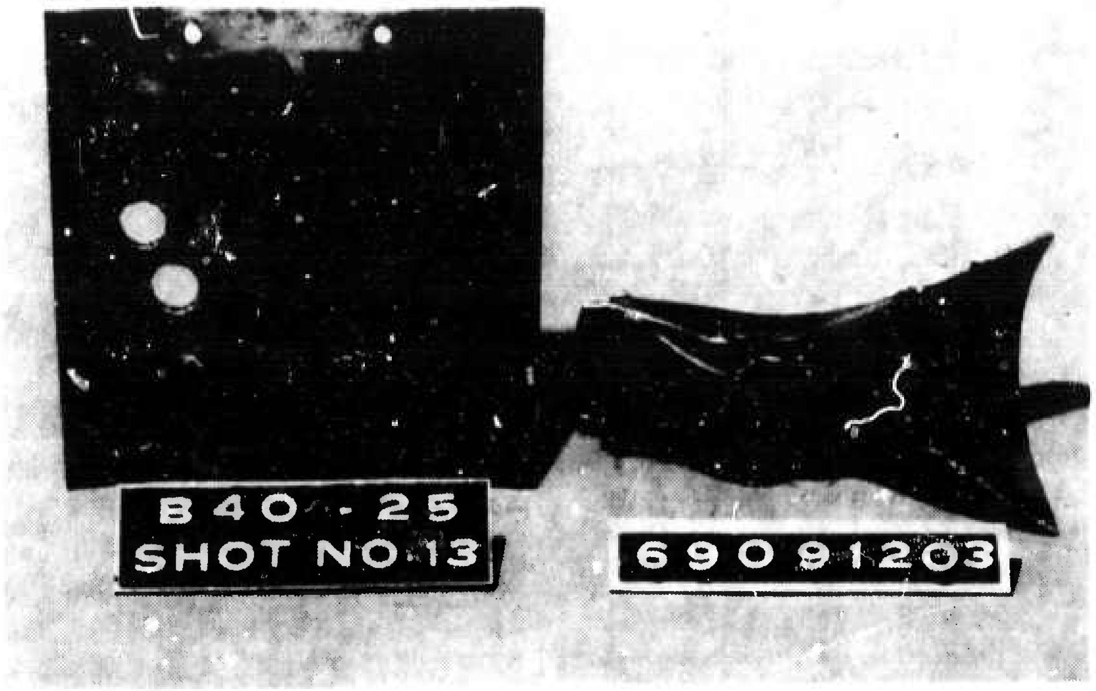

B40-24
SHOT NO.13
69091603

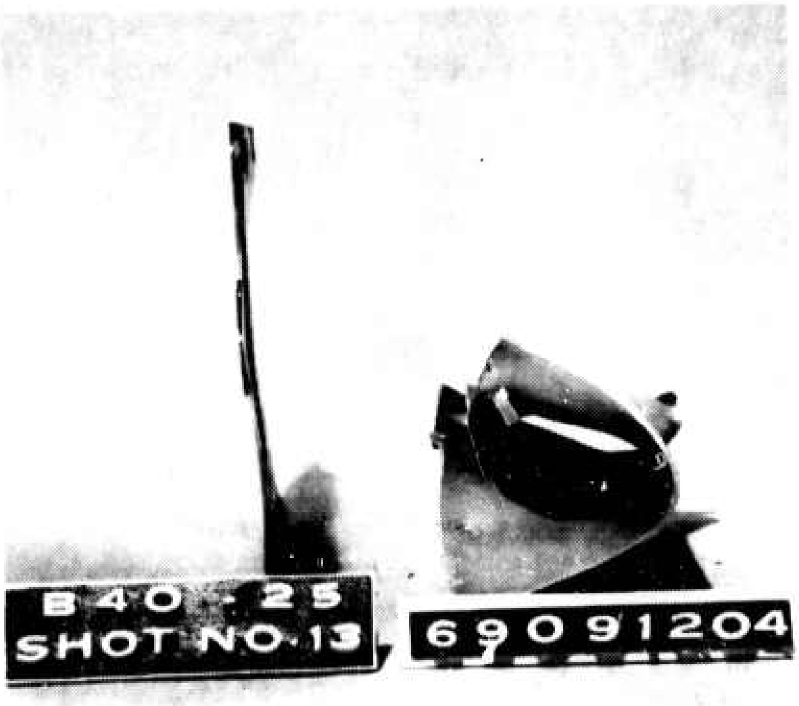


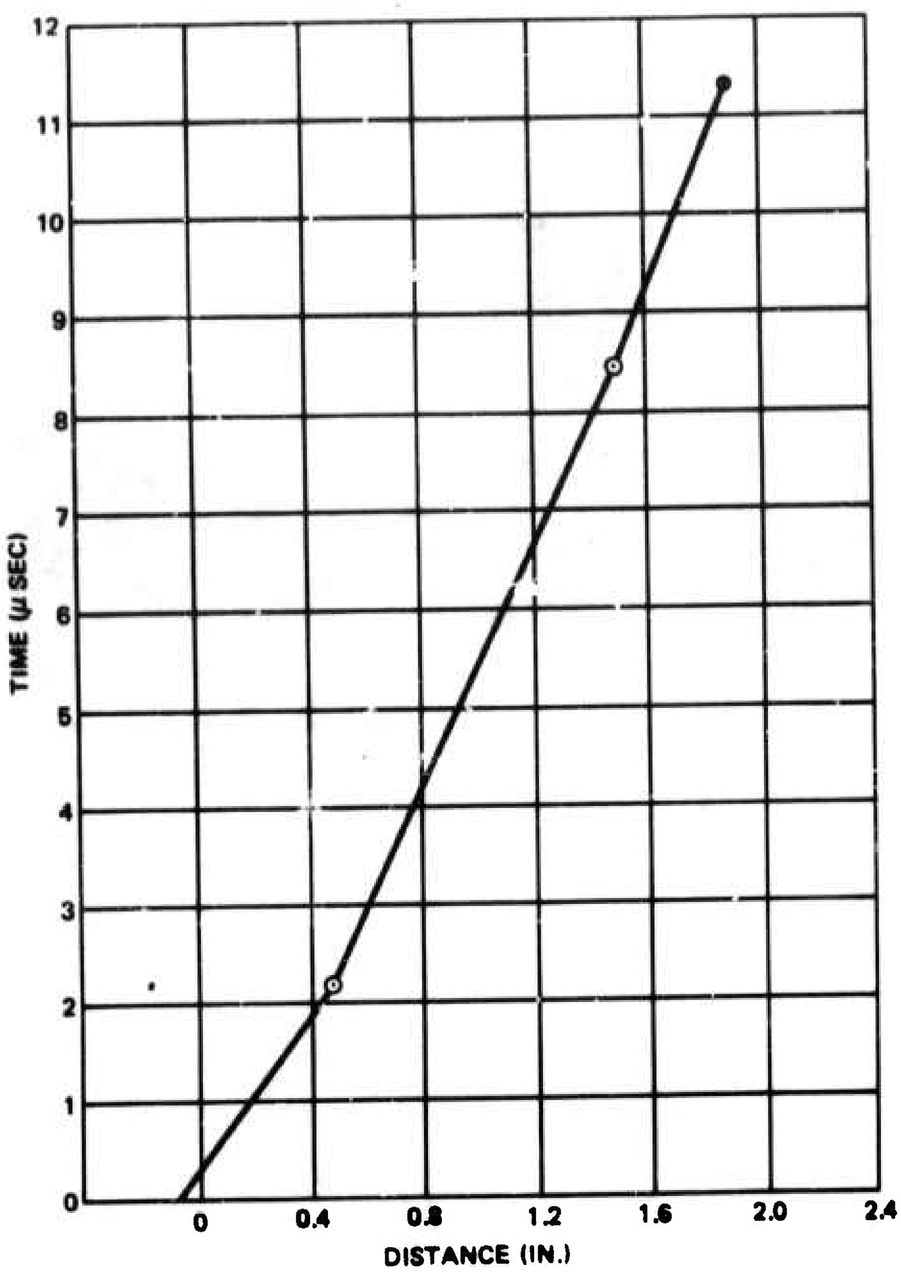


Spray Position vs Time

PLATE NO.	13
PROJECTILE:	CAOMIUM SPHERE
IMPACT VELOCITY:	–
TARGET CONFIGURATION:	Cd-f-Al(1) 0.072/3.43/0.125 IN.
FOAM OENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE OIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	4.0 IN.


B40 - 25
SHOT NO 13
69091203


B40 - 25
SHOT NO 13
69091204

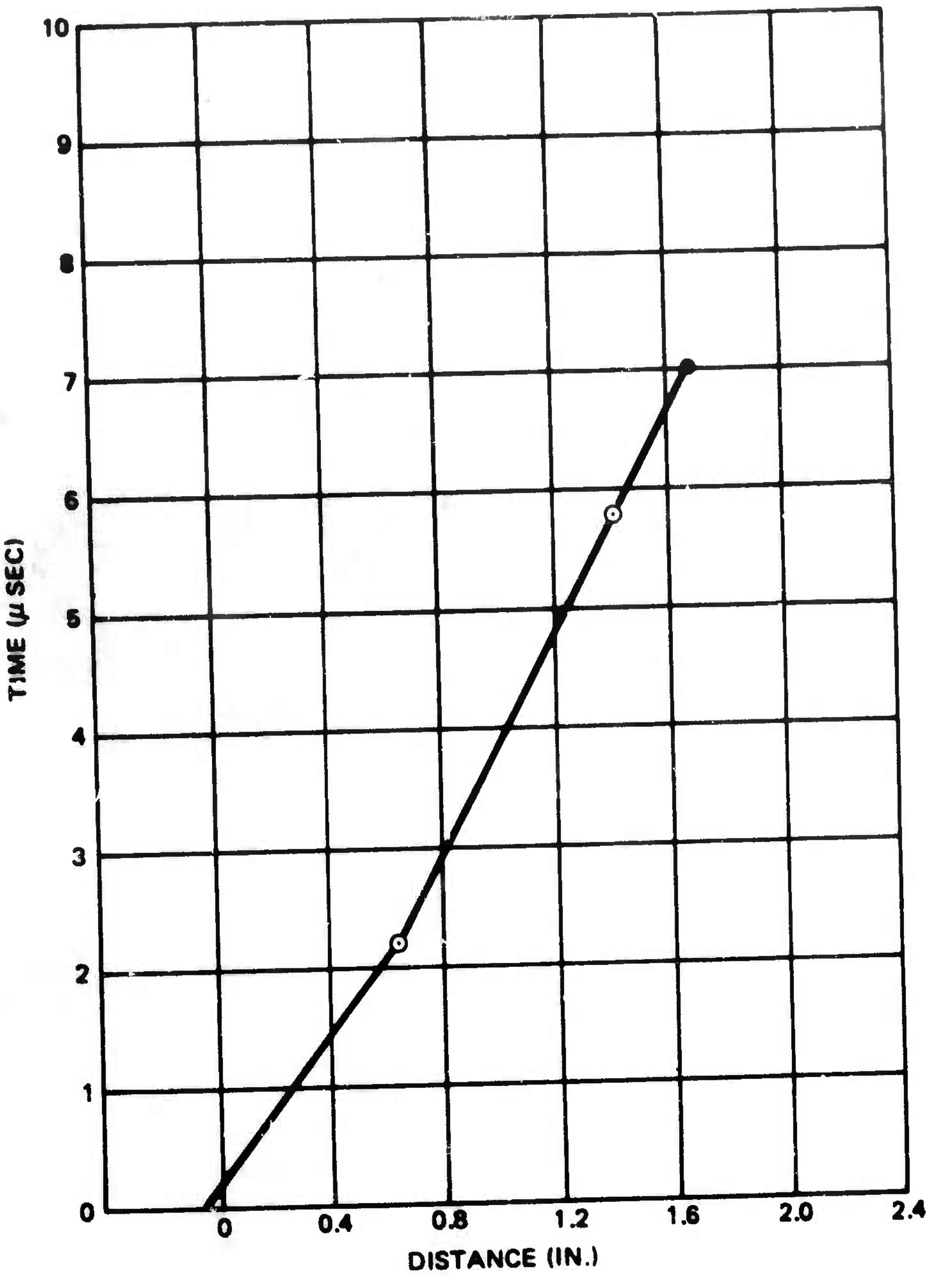


Spray Position vs Time

PLATE NO.	13A
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,600 FPS
TARGET CONFIGURATION:	Cd-f-Al(1) 0.072/3.43/0.125 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.8 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	2.5 IN.

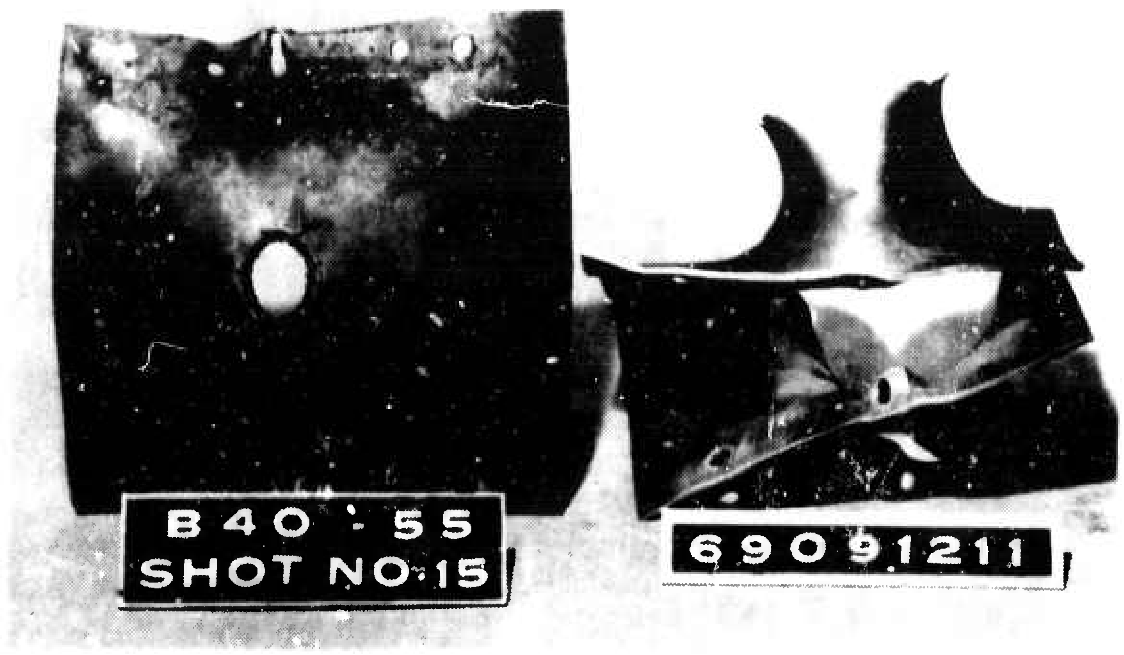

B 40 - 35
SHOT NO.14
69091114

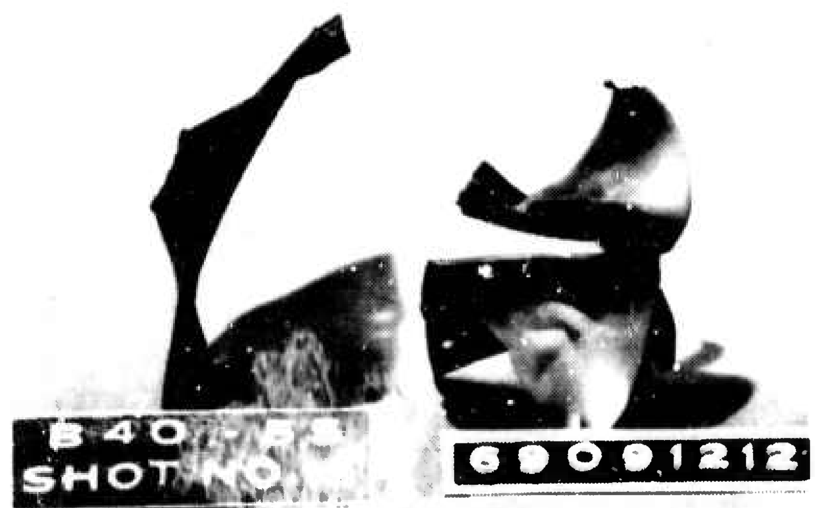

B 40 - 35
SHOT NO.14
69091113

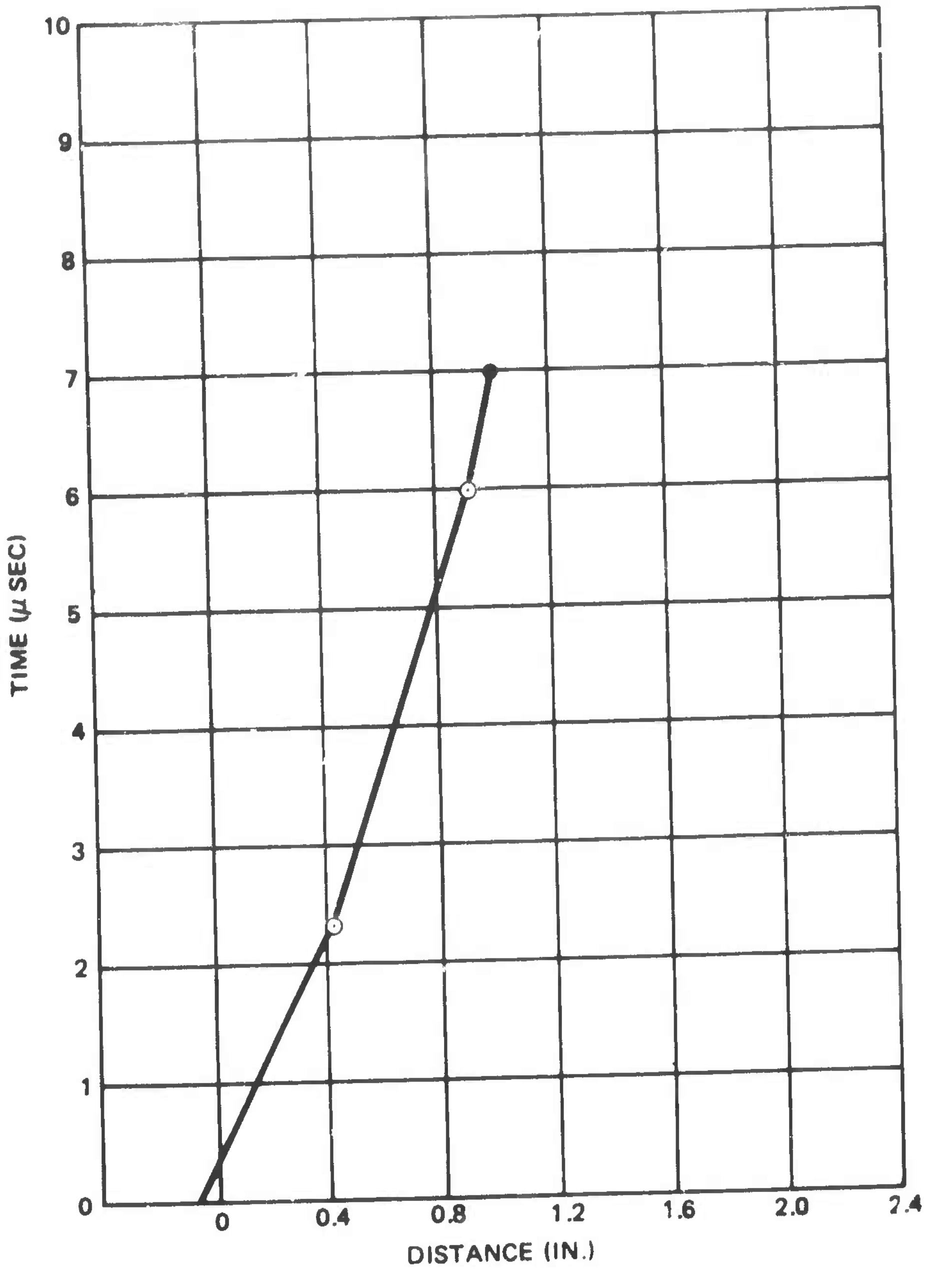


Spray Position vs Time

PLATE NO.	14
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,500 FPS
TARGET CONFIGURATION:	Cd-f-Al(1) 0.072/2.29/0.064 IN.
FOAM DENSITY:	0.05 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.85 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B40 - 55
SHOT NO 15
69091211


SHOT
69091212

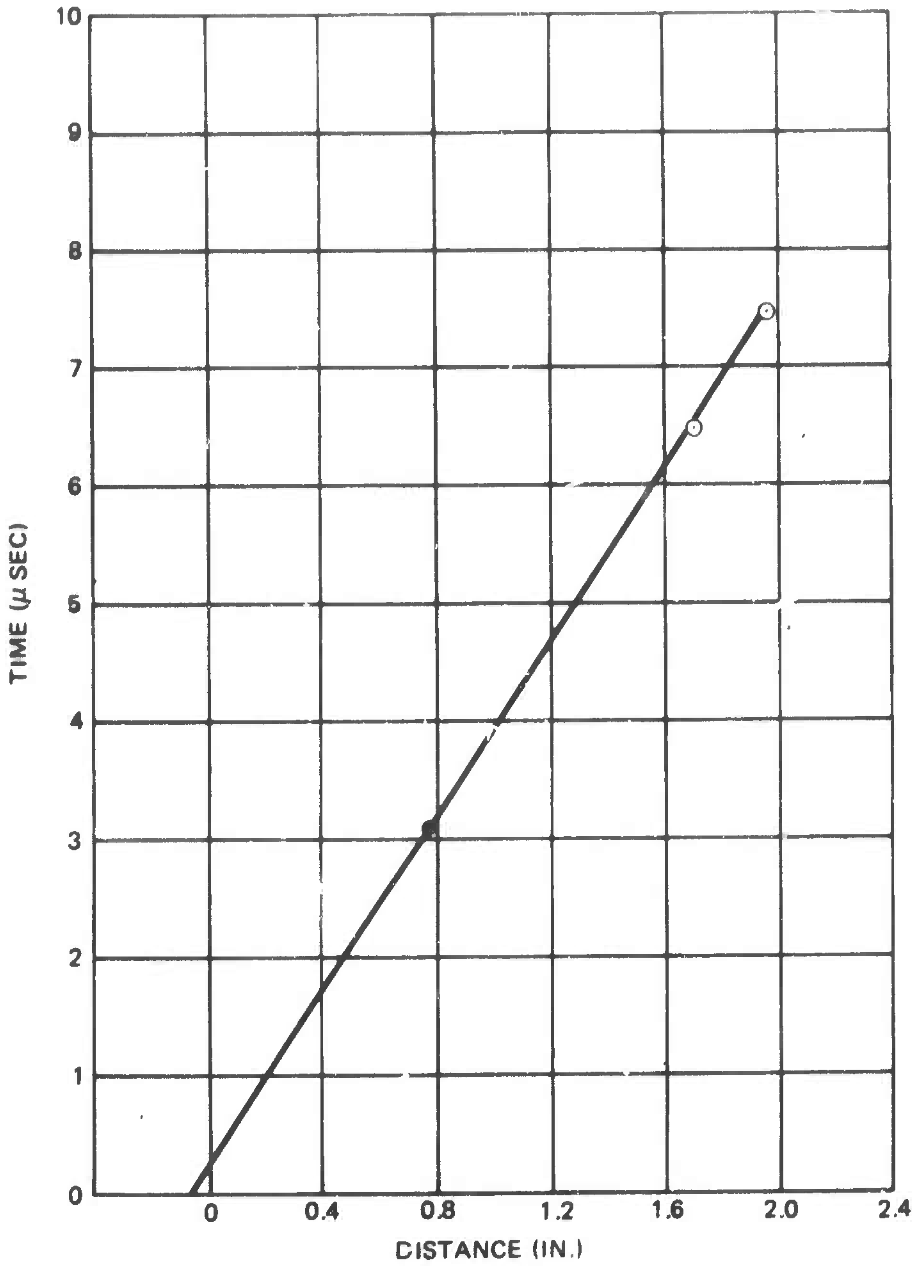


Spray Position vs Time

PLATE NO.	15
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,300 FPS
TARGET CONFIGURATION:	Cd-f-Al(1) 0.072/2.29/0.125 IN.
FOAM DENSITY:	0.5 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.15 IN.
REAR PLATE MAXIMUM HOLE DIAMETER	4.9 IN.


B40-14
SHOT NO.16
69091101


B40-14
SHOT NO.16
69091102

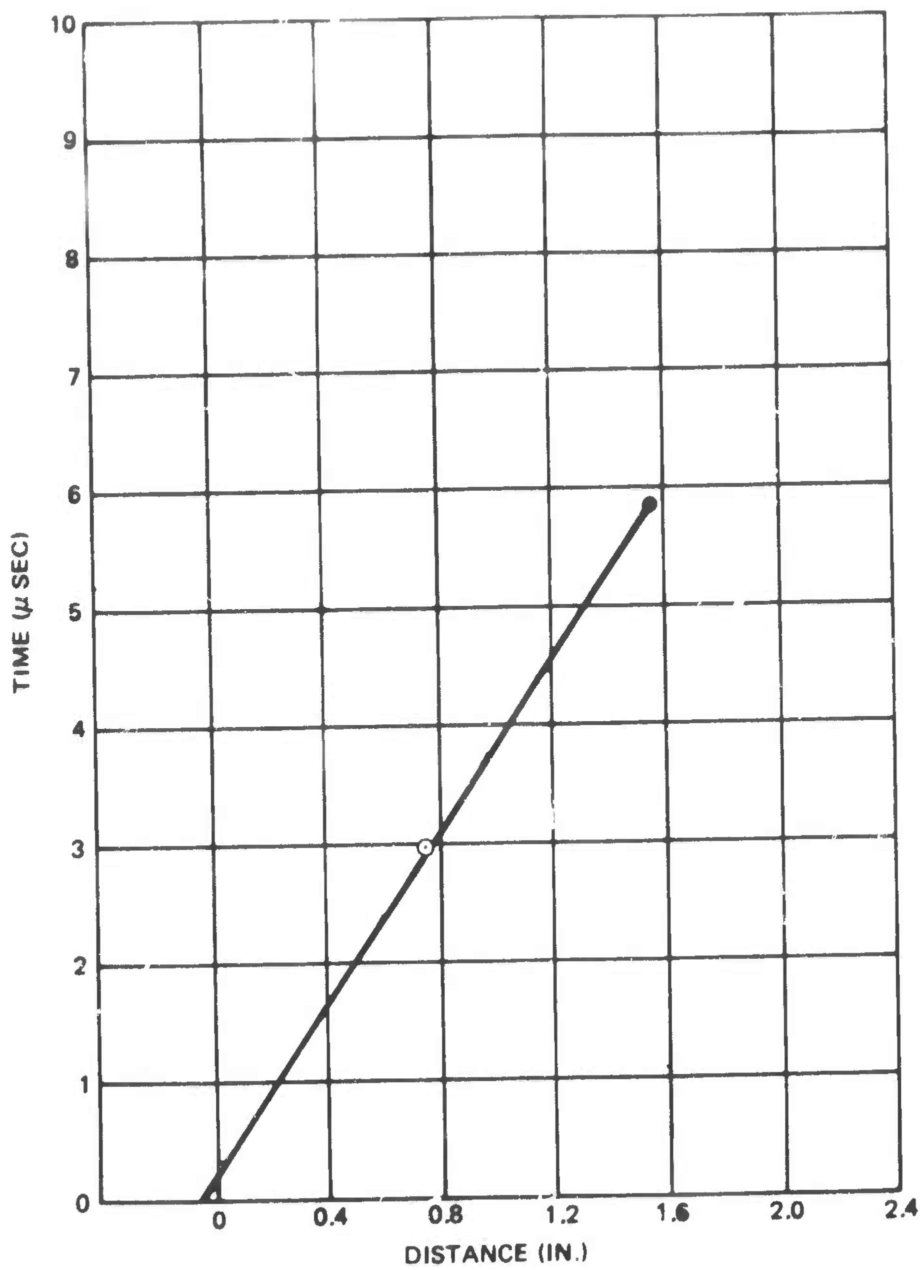


Spray Position vs Time

PLATE NO.	16
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	25,000 FPS
TARGET CONFIGURATION:	Cd-V-Al-Fe 0.072/2.29/0.064/0.070 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.95 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	3.7 IN.


B 40-18
SHOT NO.17
69091104

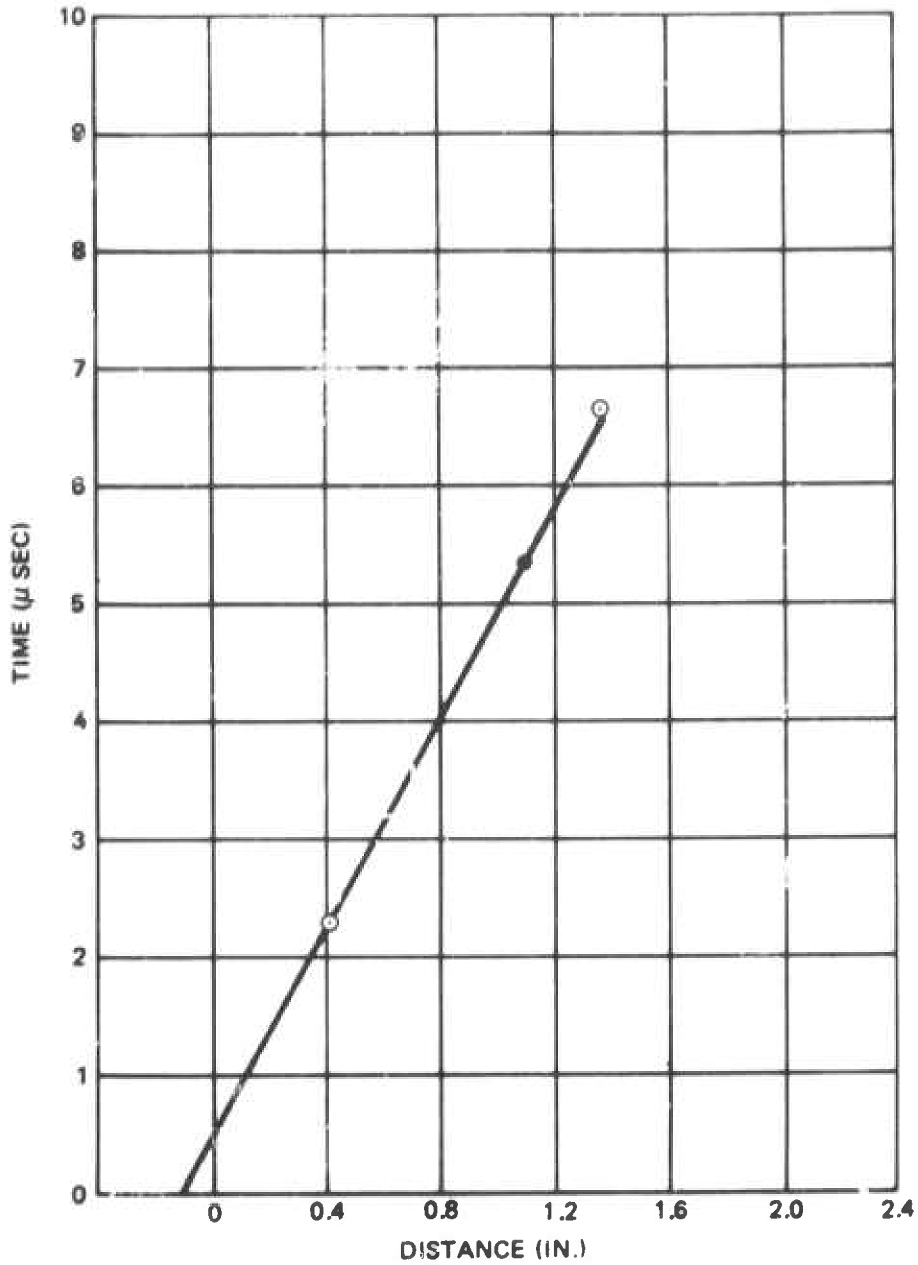

B 40-18
SHOT NO.17
69091103



Spray Position vs Time

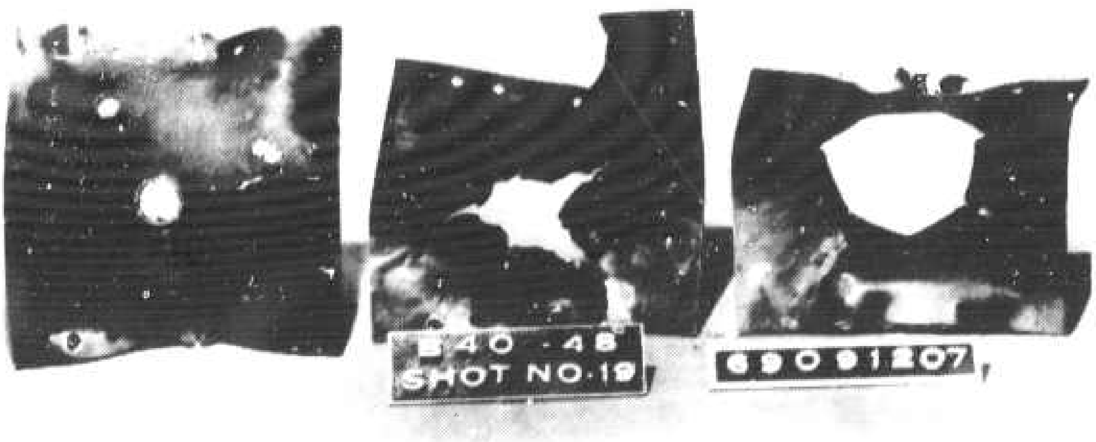
PLATE NO.	17
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,000 FPS
TARGET CONFIGURATION:	Cd-V-Al-Fe 0.072/3.43/0.064/0.070 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.85 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B 40-19
SHOT NO.18
69091105

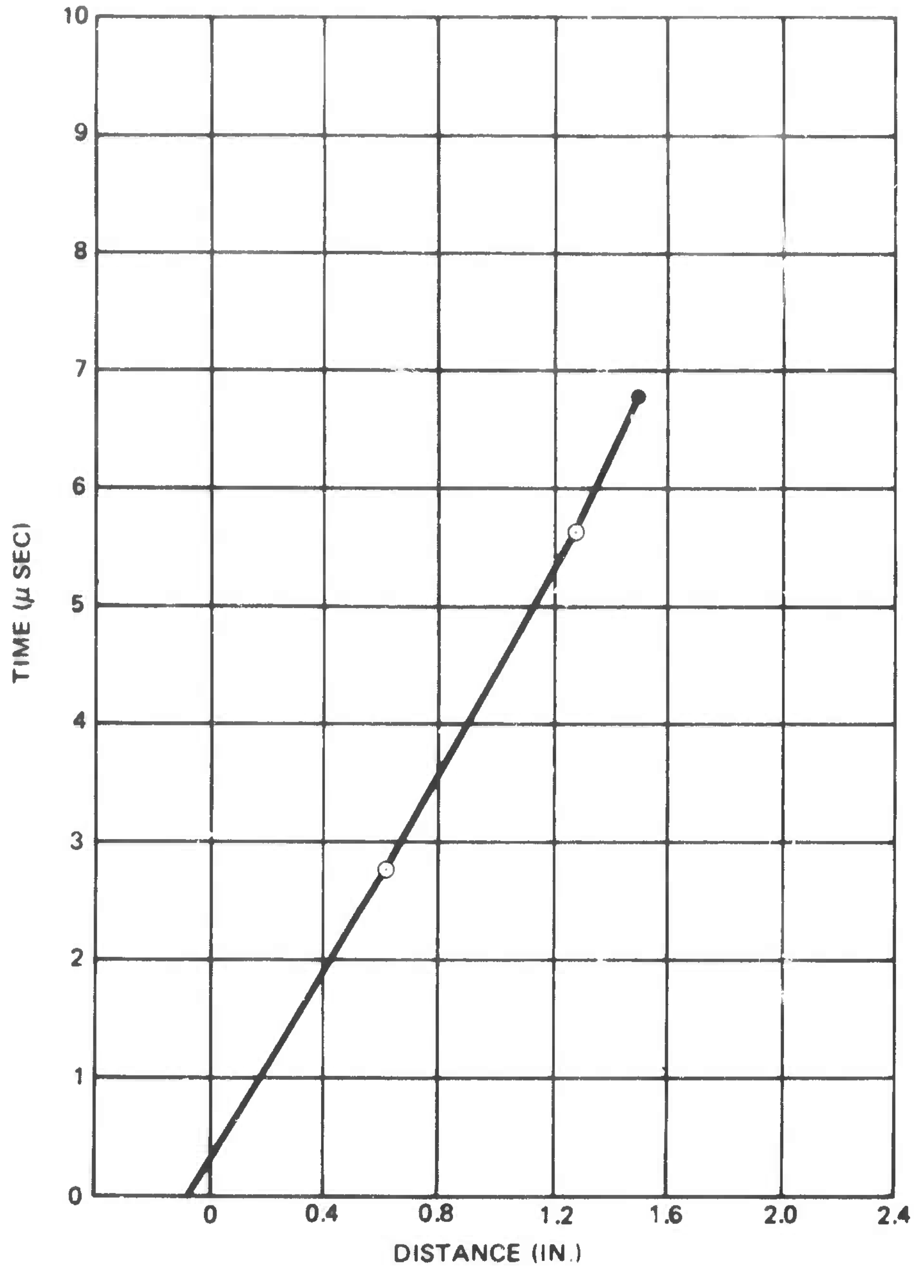


Spray Position vs Time

PLATE NO.	18
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,600 FPS
TARGET CONFIGURATION:	Cd-V-Al-Fe 0.125/2.29/0.064/0.070 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.3 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	1.5 IN.

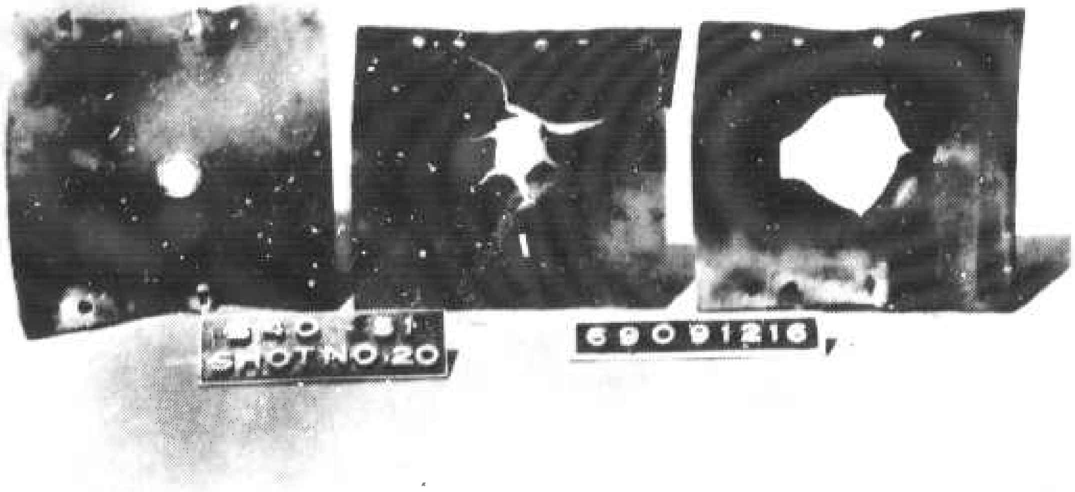

B40 - 48
SHOT NO-19
69091207

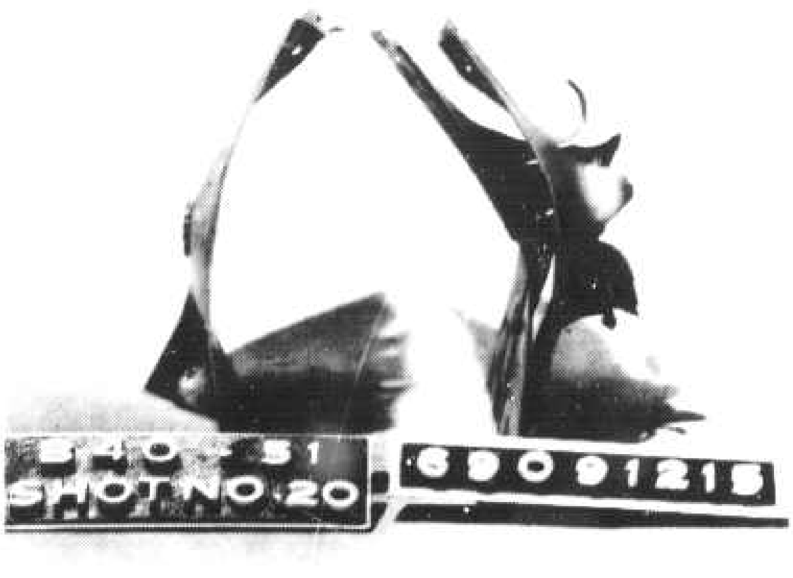

B40 - 48
SHOT NO-19

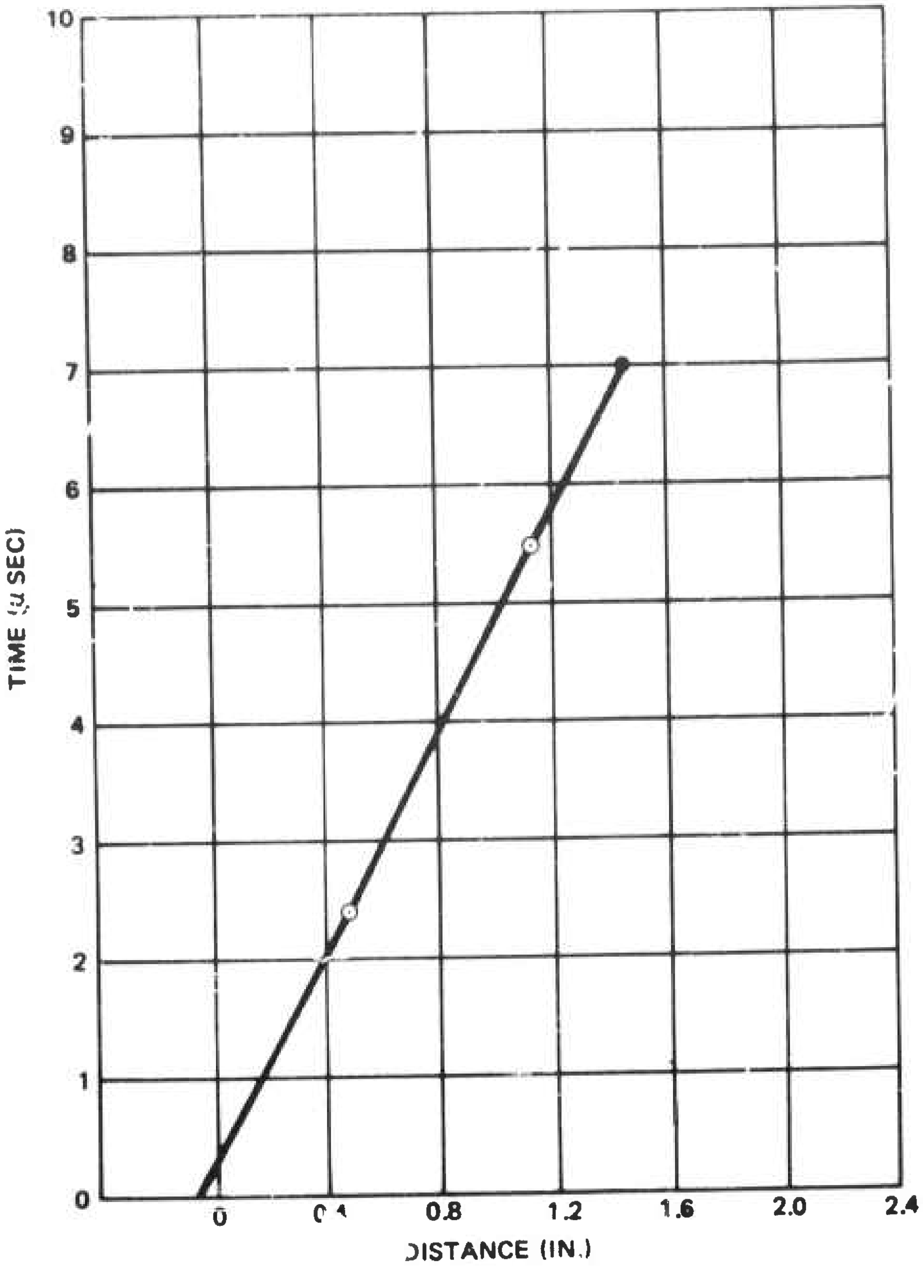


Spray Position vs Time

PLATE NO.	19
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,600 FPS
TARGET CONFIGURATION:	Cd-f-Al-Fe 0.072/2.29/0.063/0.070 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.95 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	4.0 IN.

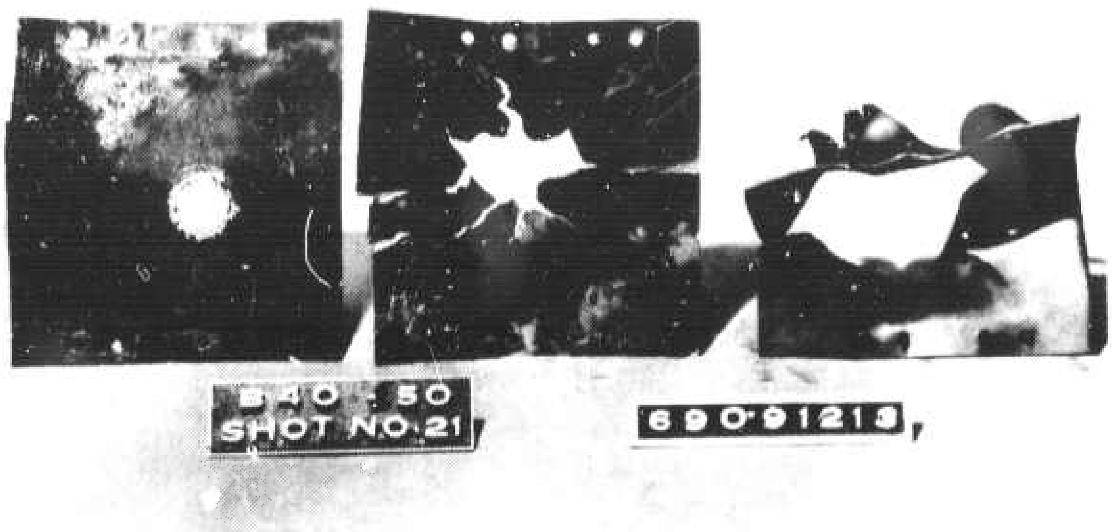

SHOT NO 20
69091216

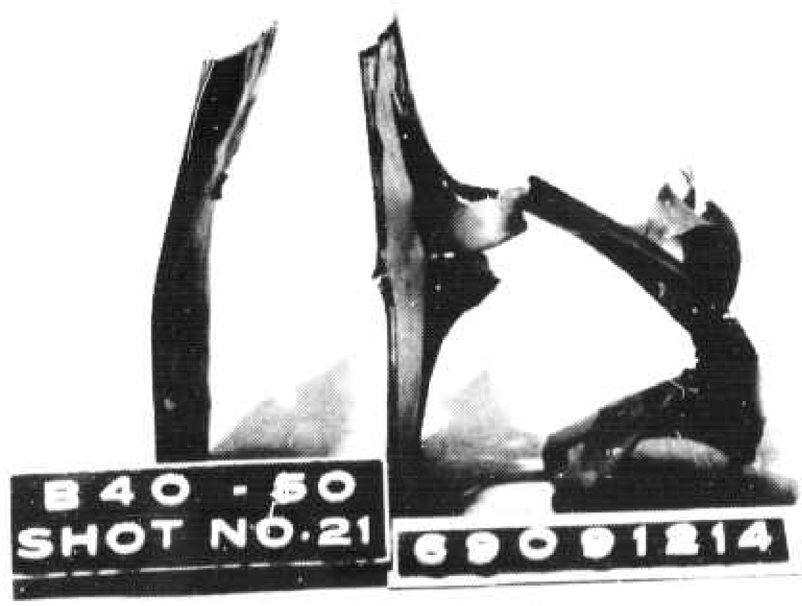

SHOT NO 20
69091215

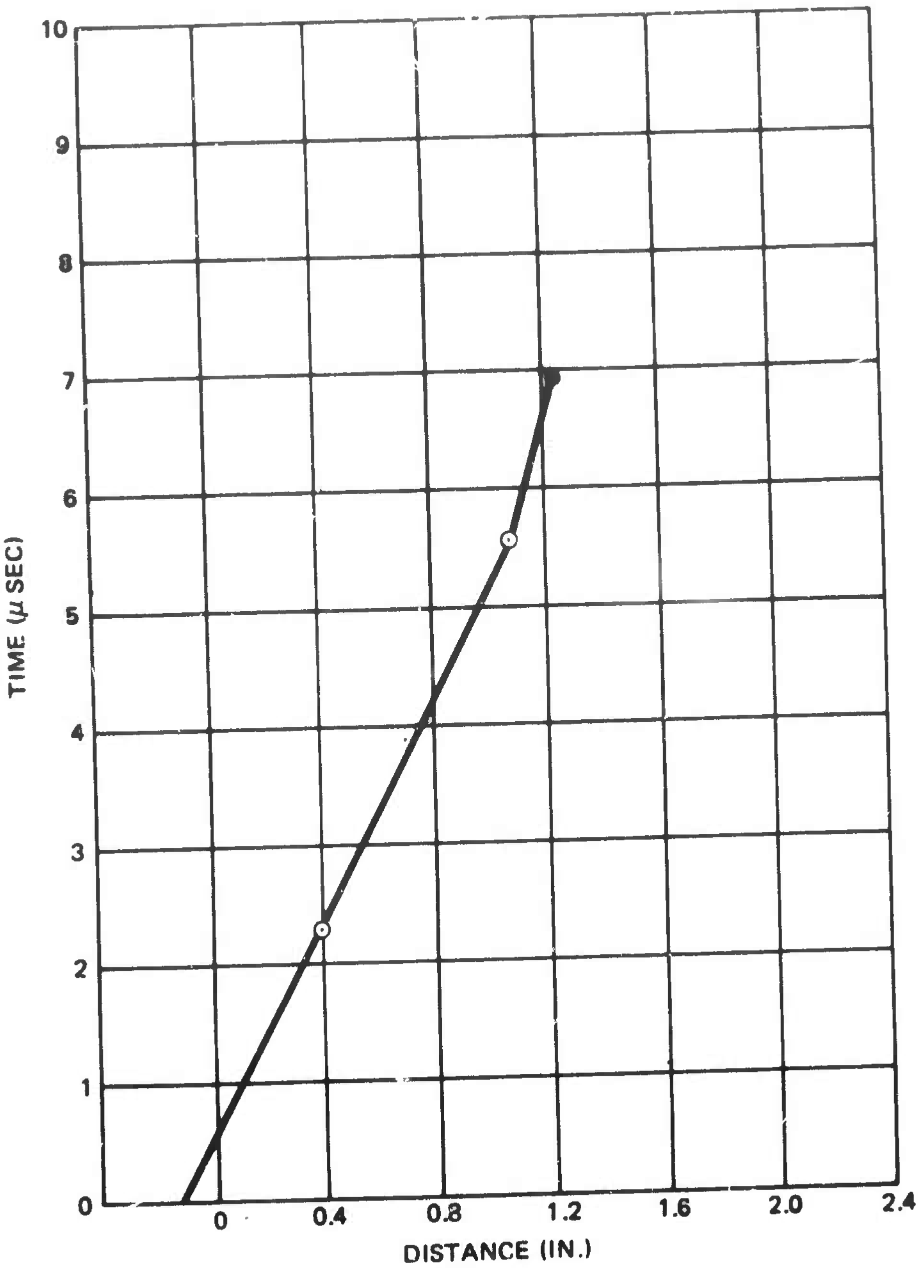


Spray Position vs Time

PLATE NO.	20
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,550 FPS
TARGET CONFIGURATION:	Cd-f-Al-Fe 0.072/3.43/0.063/0.070 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	3.5 IN.


B40-50
SHOT NO.21
69091213

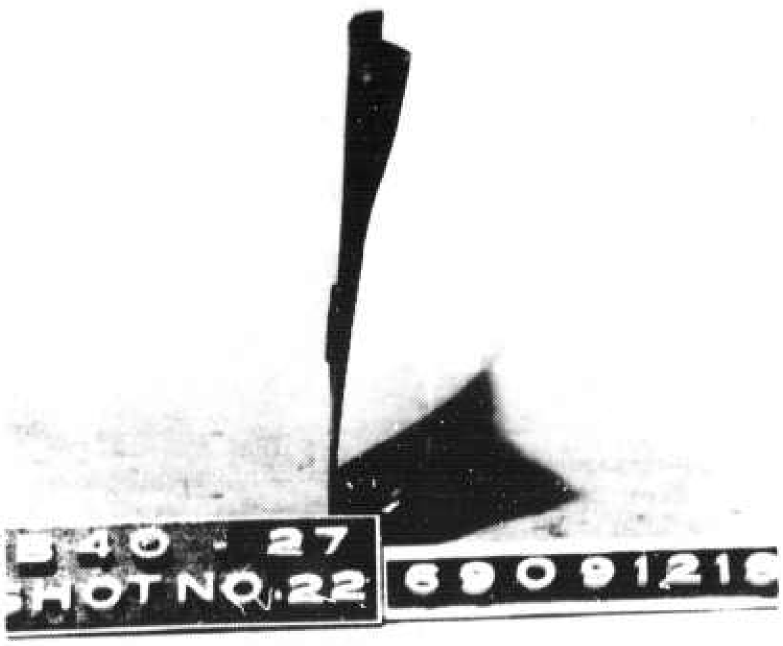

B40-50
SHOT NO.21
69091214

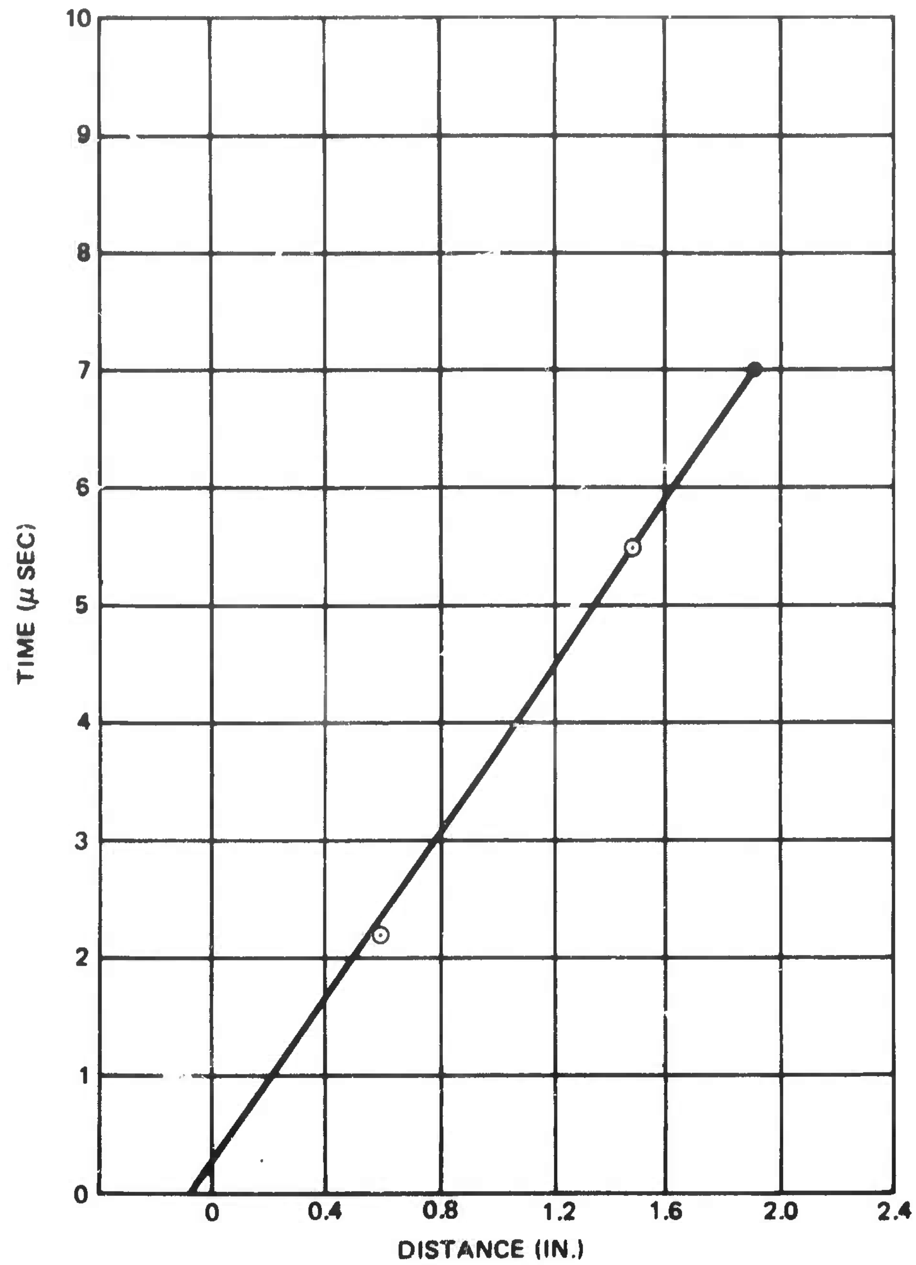


Spray Position vs Time

PLATE NO.	21
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,560 FPS
TARGET CONFIGURATION:	Cd-f-Al-Fe 0.125/2.29/0.063/0.070 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.2 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	5.4 IN.

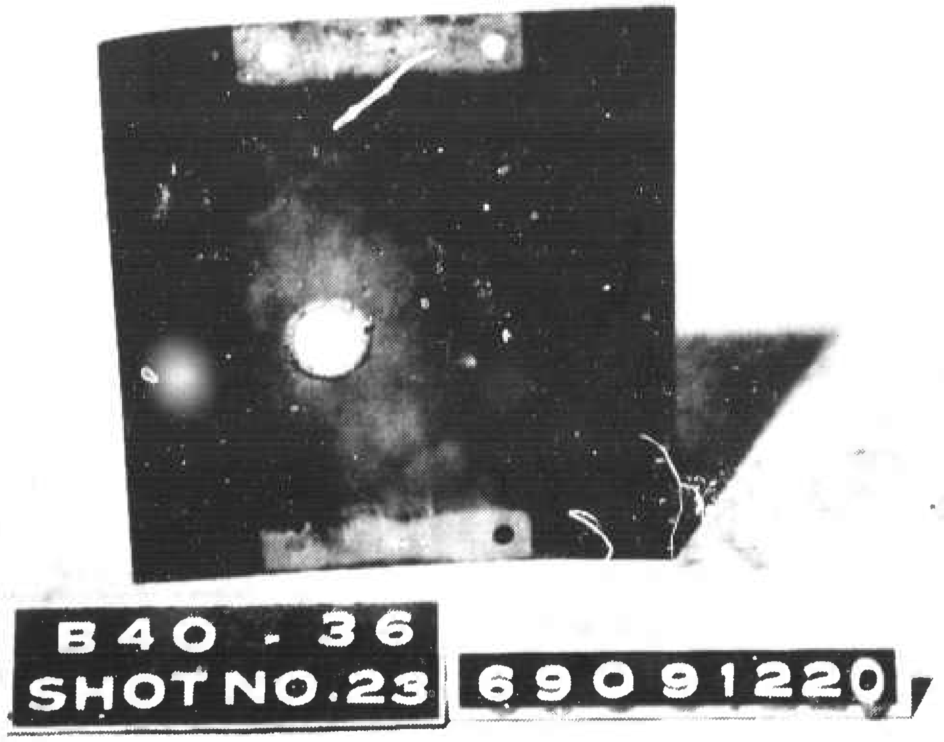

B40-27
SHOT NO.22
69091217

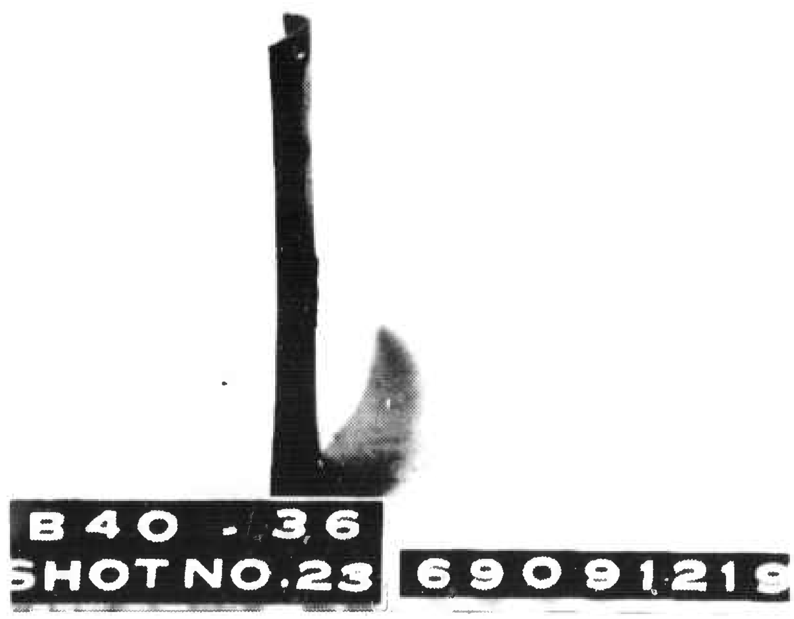

B40 - 27
SHOT NO.22

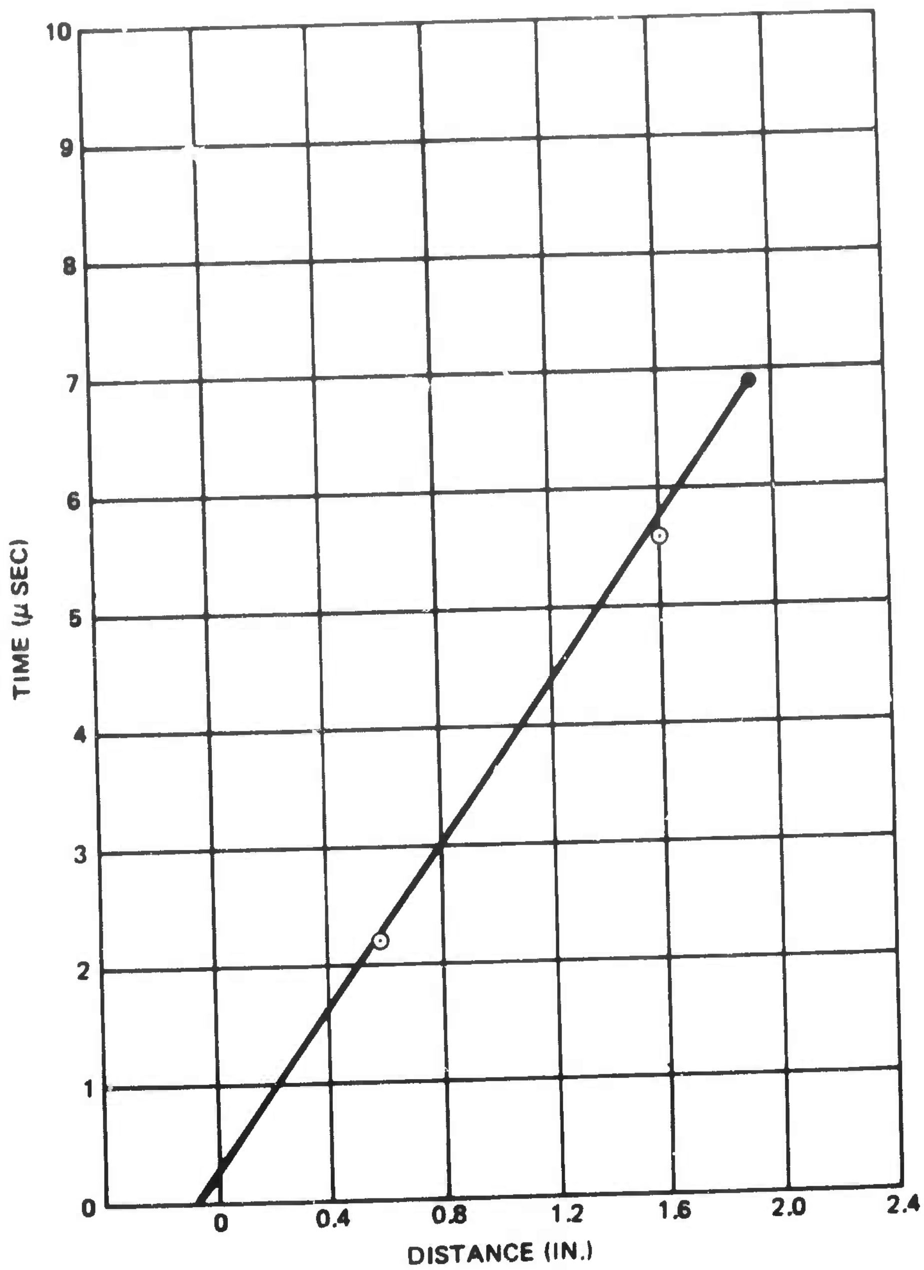


Spray Position vs Time

PLATE NO.	22
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,700 FPS
TARGET CONFIGURATION:	Cd-V-Pr 0.072/2.29/0.5 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.0 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

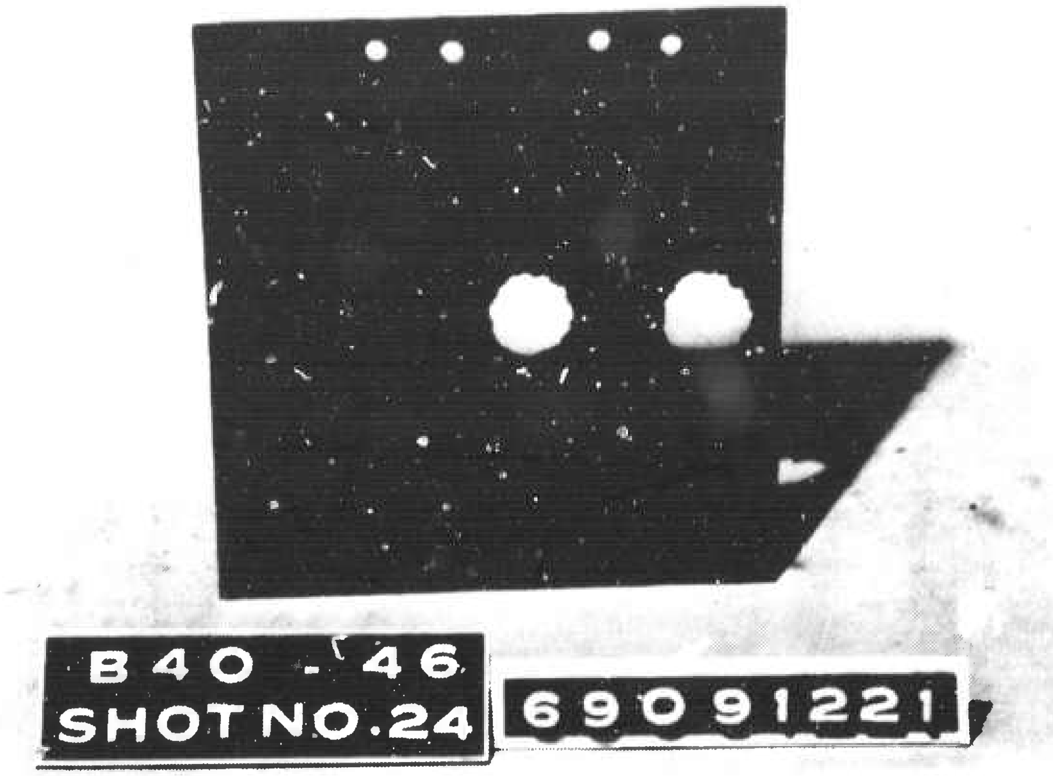

B40 - 36
SHOT NO.23
69091220

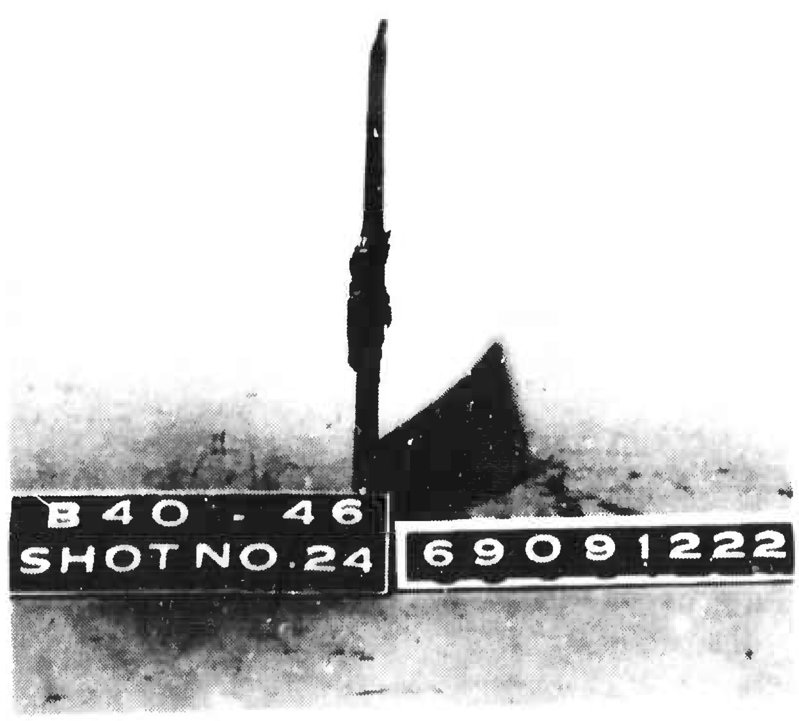

B40 - 36
SHOT NO.23

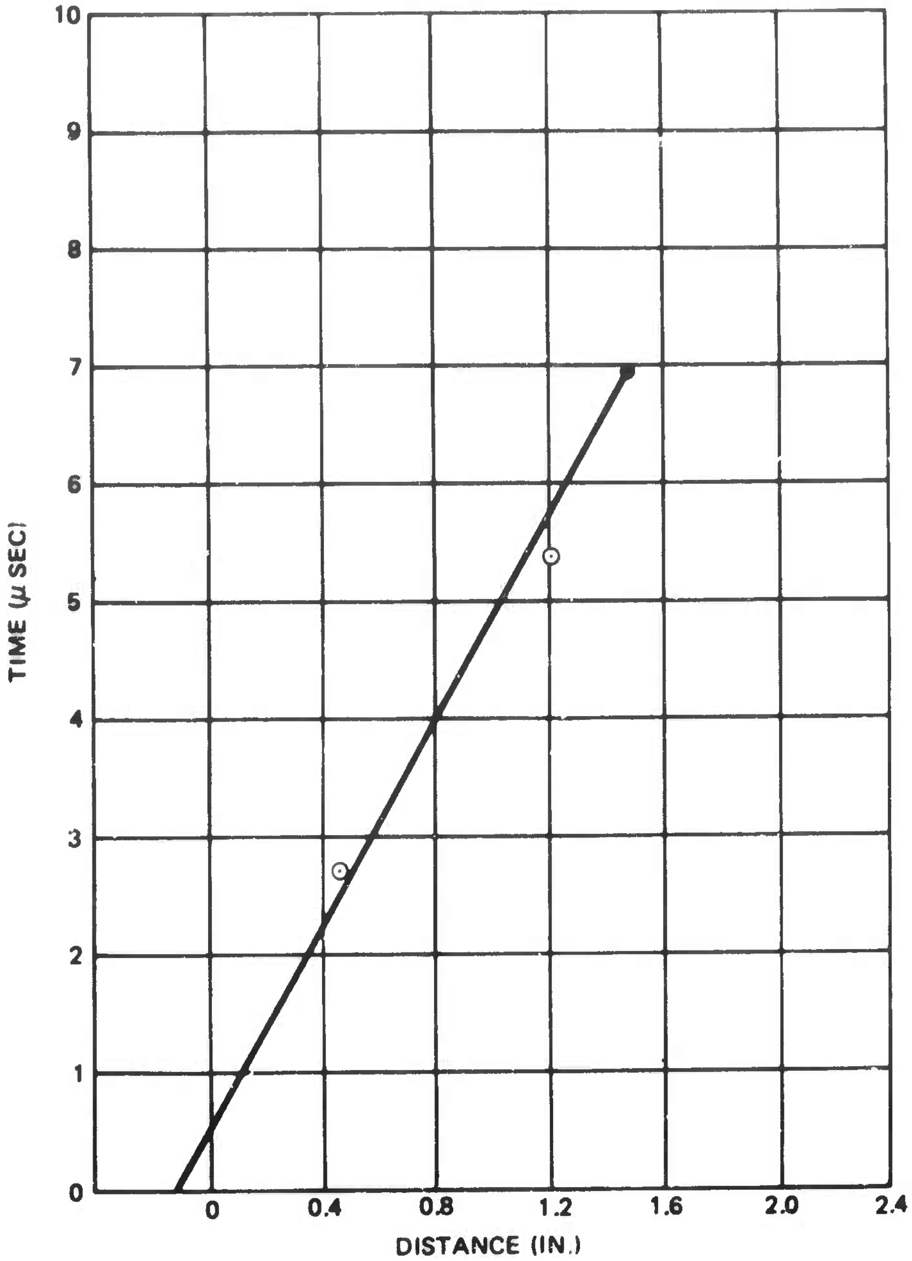


Spray Position vs Time

PLATE NO.	23
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,700 FPS
TARGET CONFIGURATION:	Cd-V-Pr 0.072/3.43/0.5 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.95 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

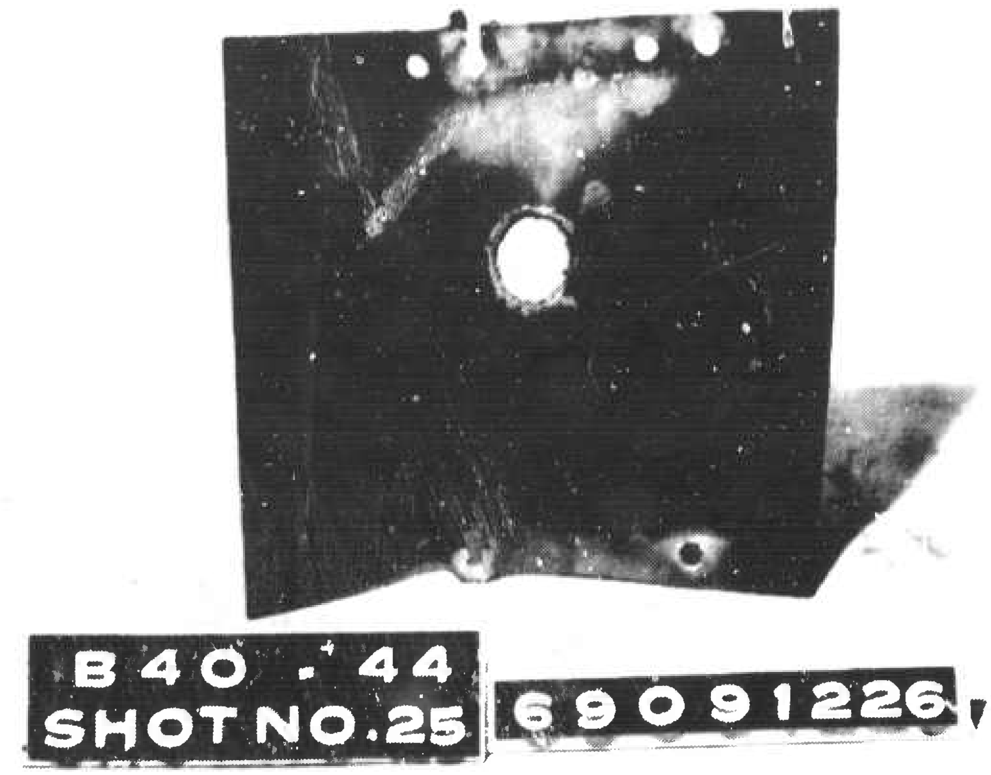

B40 - 46
SHOT NO.24
69091221


B40 - 46
SHOT NO.24
69091222

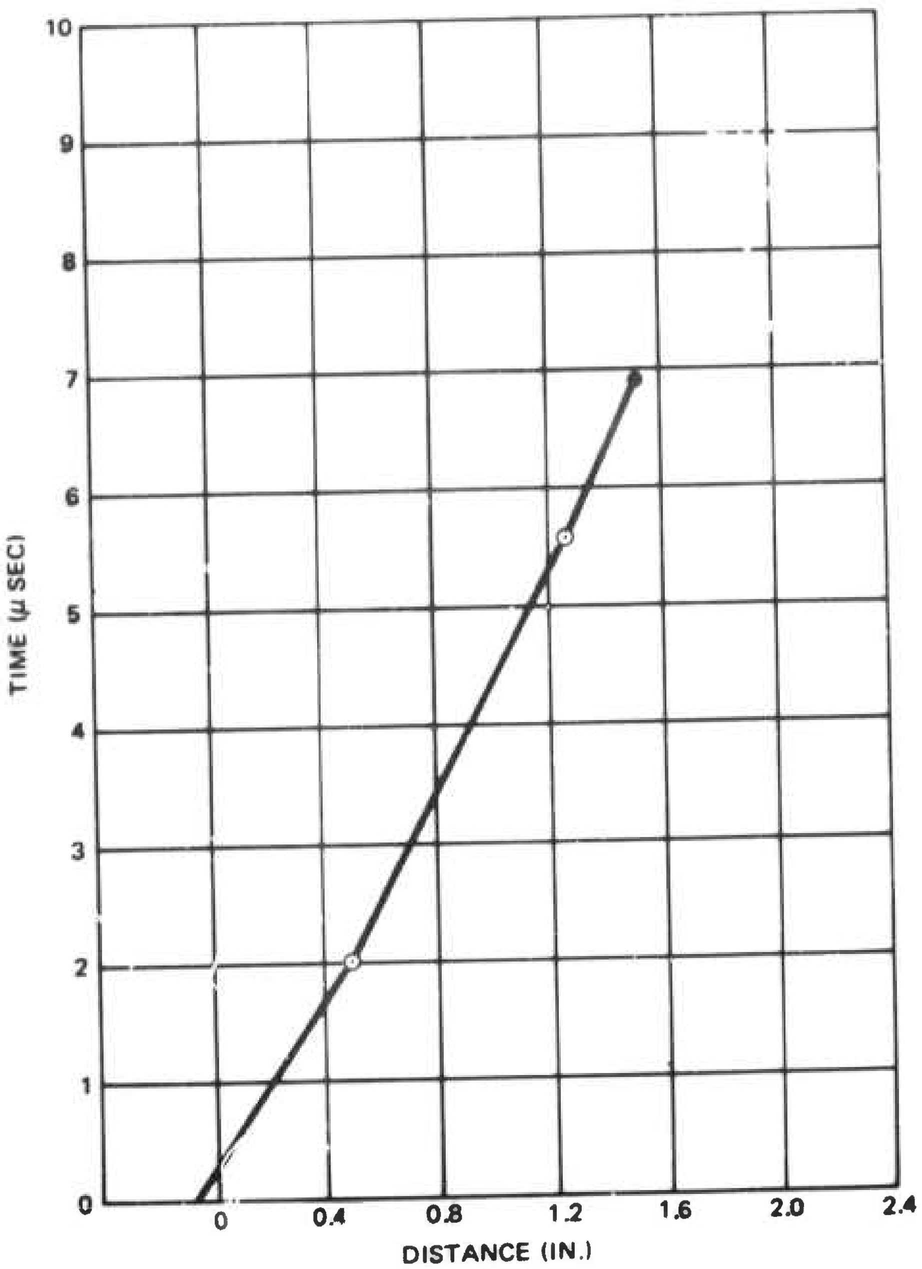


Spray Position vs Time

PLATE NO.	24
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,600 FPS
TARGET CONFIGURATION:	Cd-V-Pr 0.125/2.29/0.5 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.3 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B40 - 44
SHOT NO. 25
69091226


B40 - 44
SHOT NO. 25
69091227

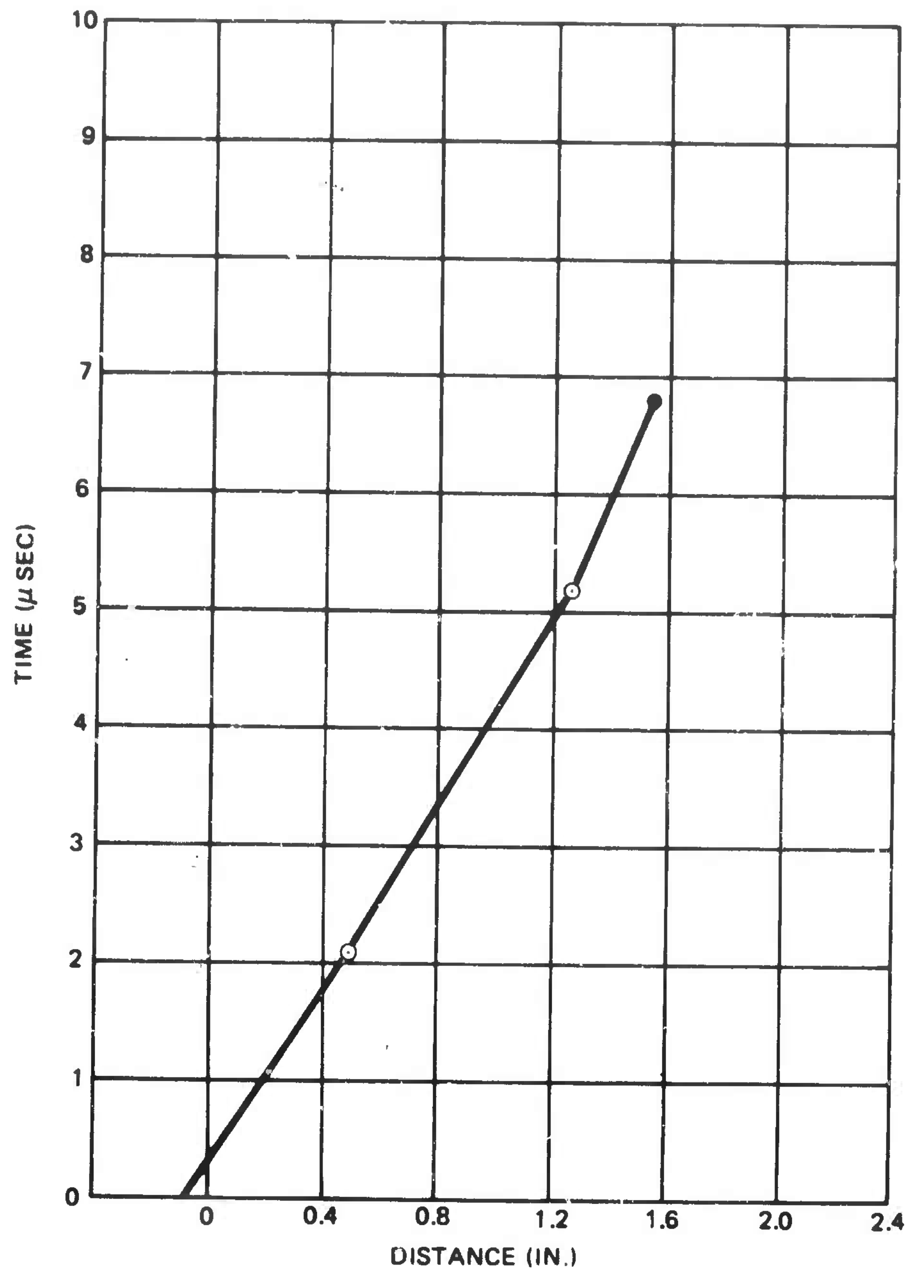


Spray Position vs Time

PLATE NO.	25
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,800 FPS
TARGET CONFIGURATION:	Cd-f-Pr 0.072/2.29/0.5 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.05 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

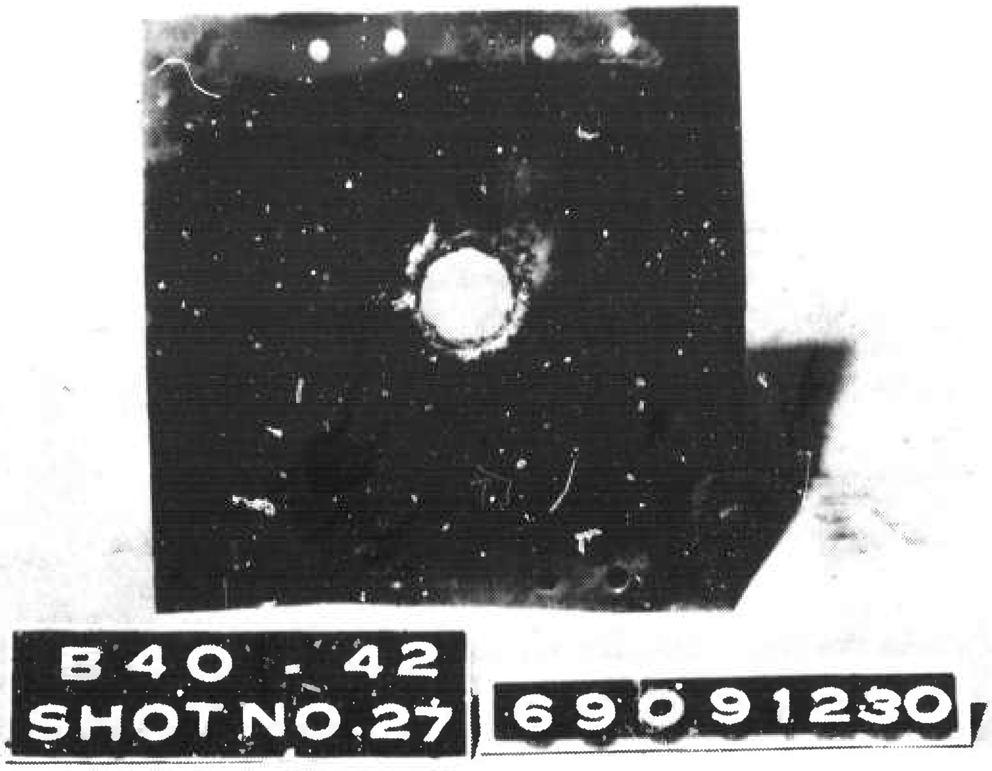

B40 - 41
SHOT NO. 26
69091229


B40 - 41
SHOT NO. 26

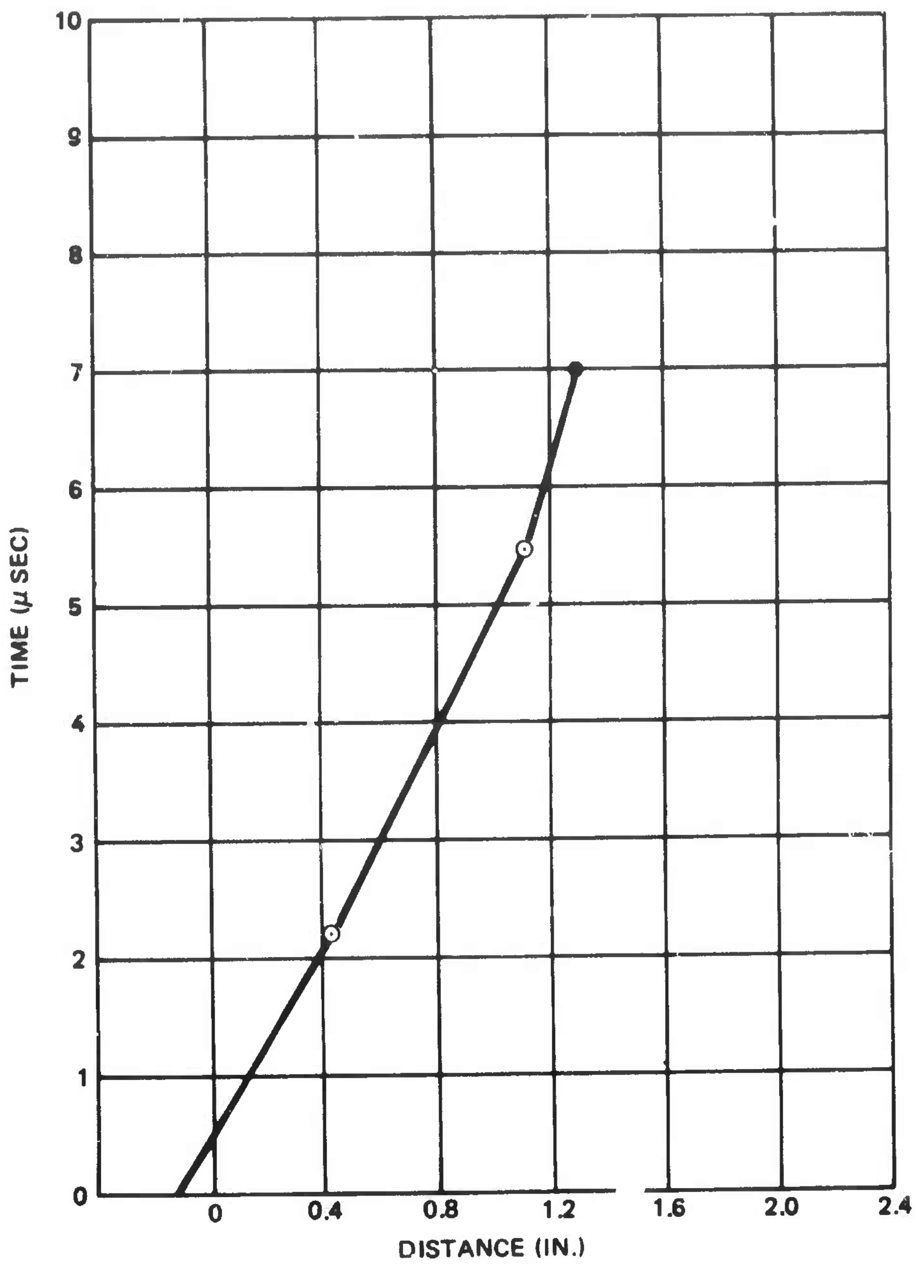


Spray Position vs Time

PLATE NO.	26
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,600 FPS
TARGET CONFIGURATION:	Cd-f-Pr 0.072/3.43/0.5 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

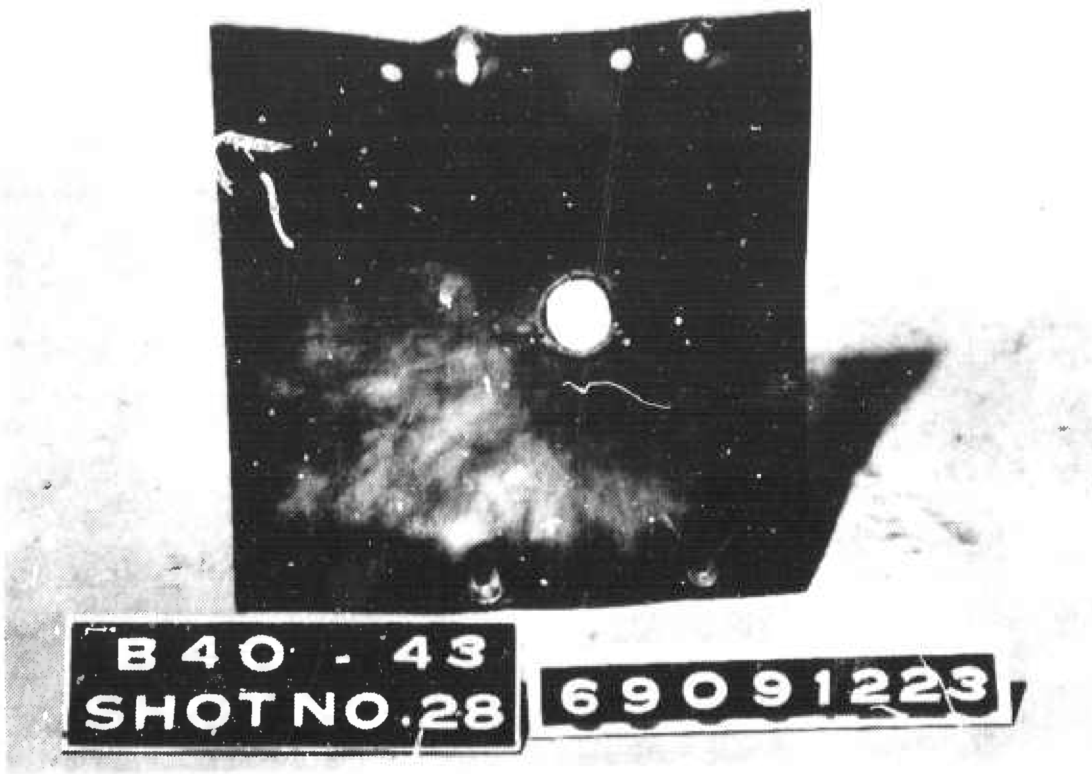

B40 - 42
SHOT NO. 27
69091230


B40 - 42
SHOT NO. 27
69091231

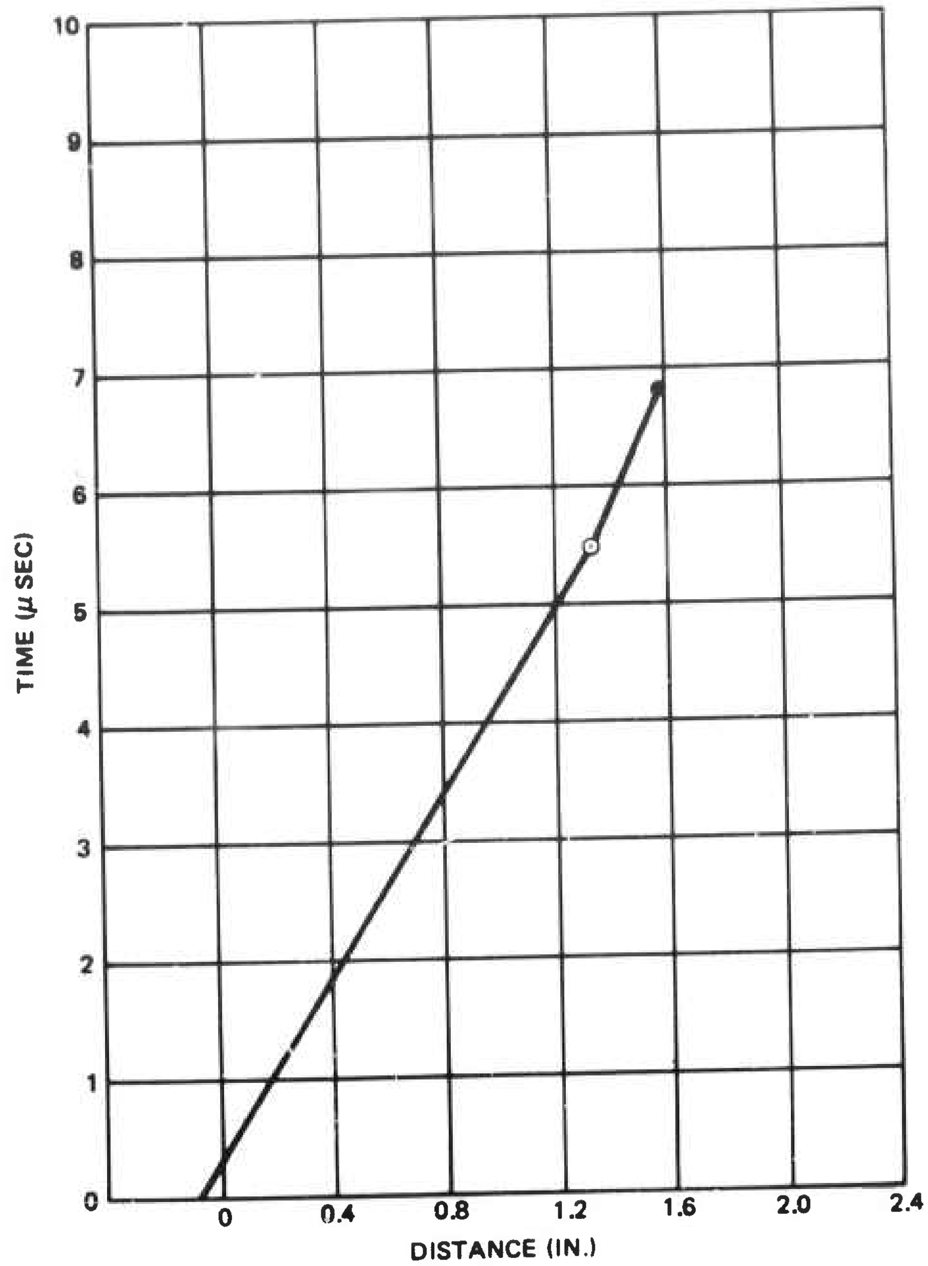


Spray Position vs Time

PLATE NO.	27
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,750 FPS
TARGET CONFIGURATION:	Cd-f-Pr 0.125/2.29/0.5 IN.
FOAM DENSITY:	0.1 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.25 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B40 - 43
SHOT NO. 28
69091223


B40 - 43
SHOT NO. 28
69091224

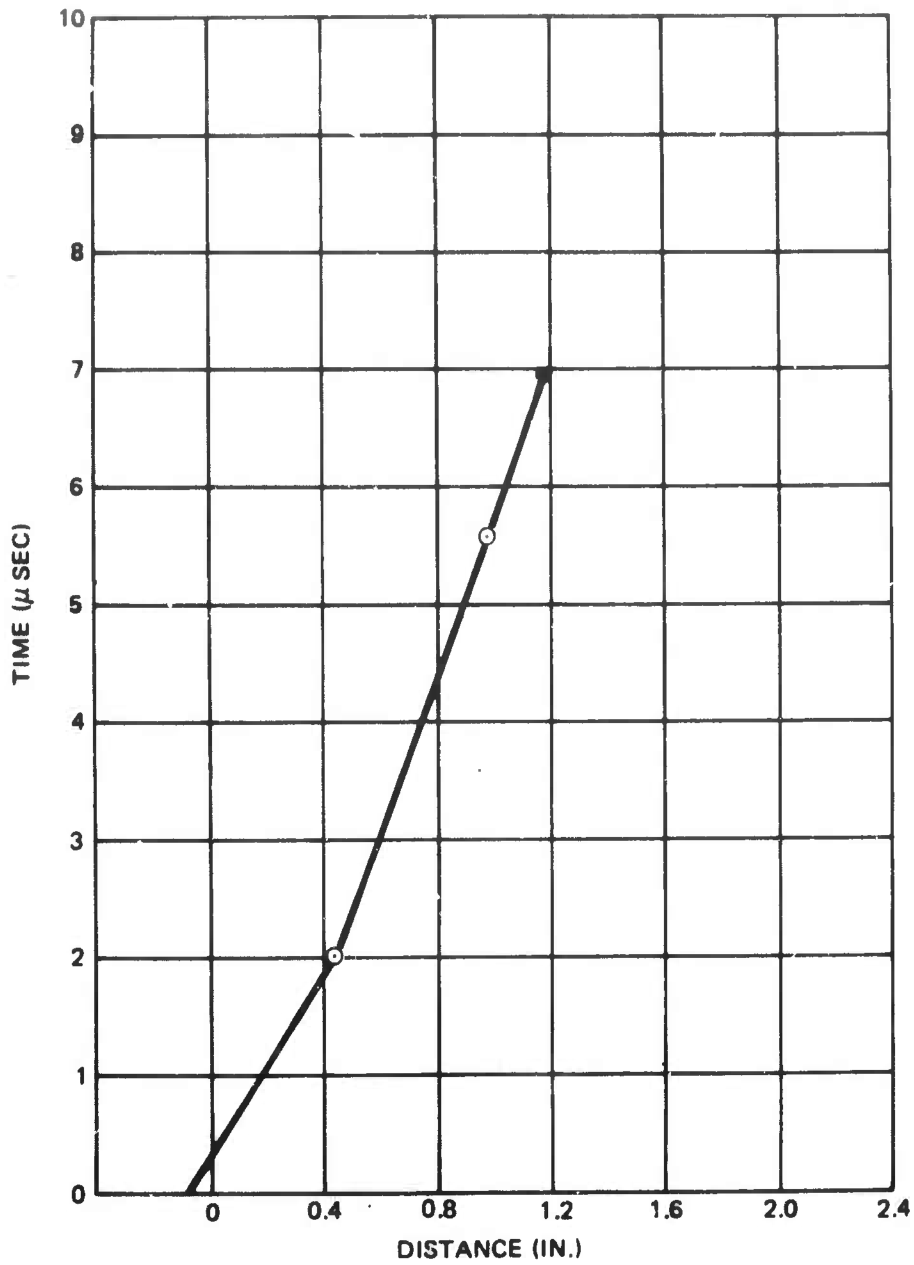


Spray Position vs Time

PLATE NO.	28
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,550 FPS
TARGET CONFIGURATION:	Cd-f-Pr 0.072/2.29/0.5 IN.
FOAM DENSITY:	0.05 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –

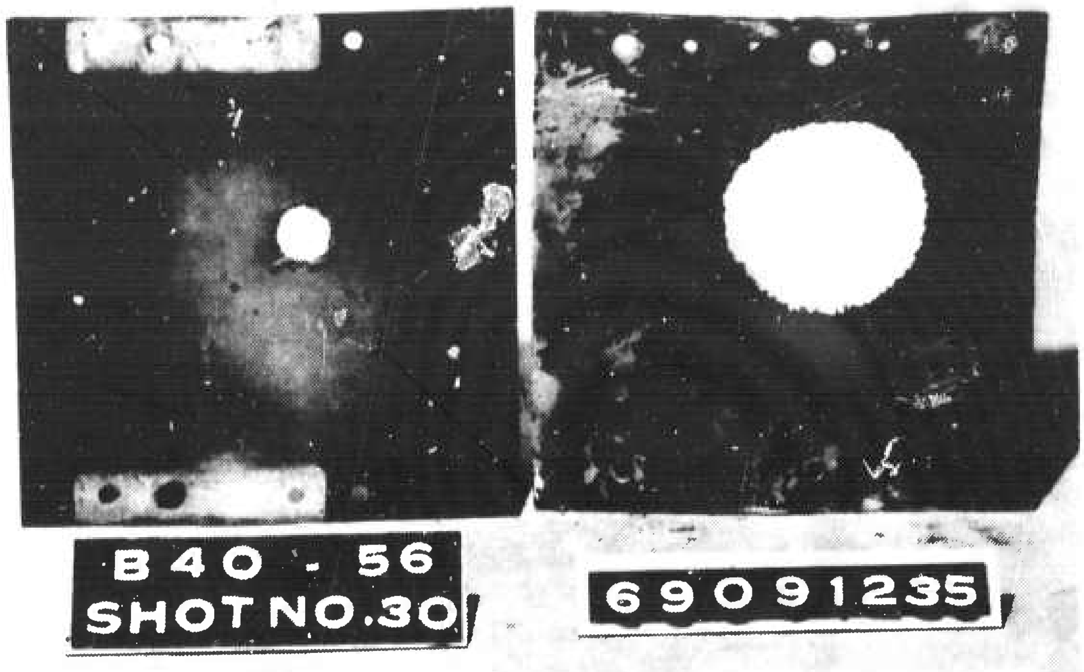

B40 - 45
SHOT NO. 29
69091233

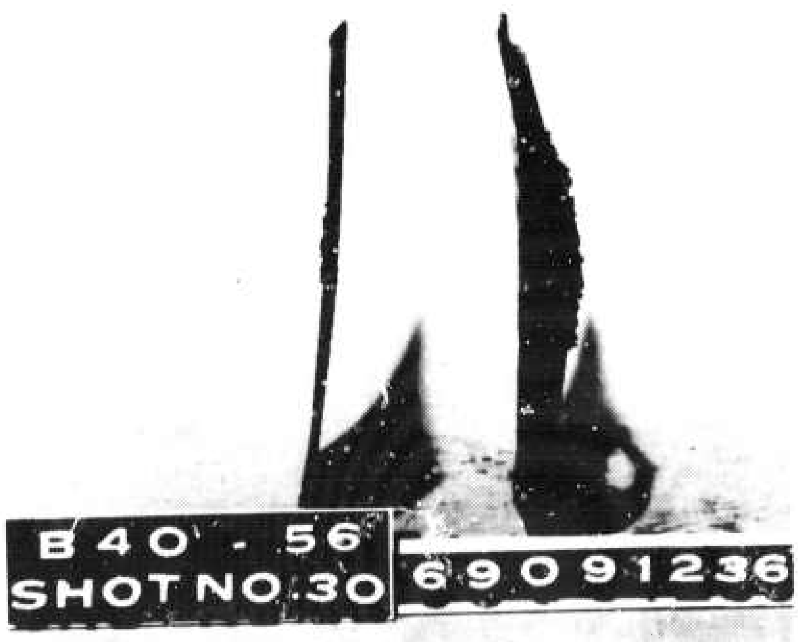

B40 - 45
SHOT NO. 29
69091234

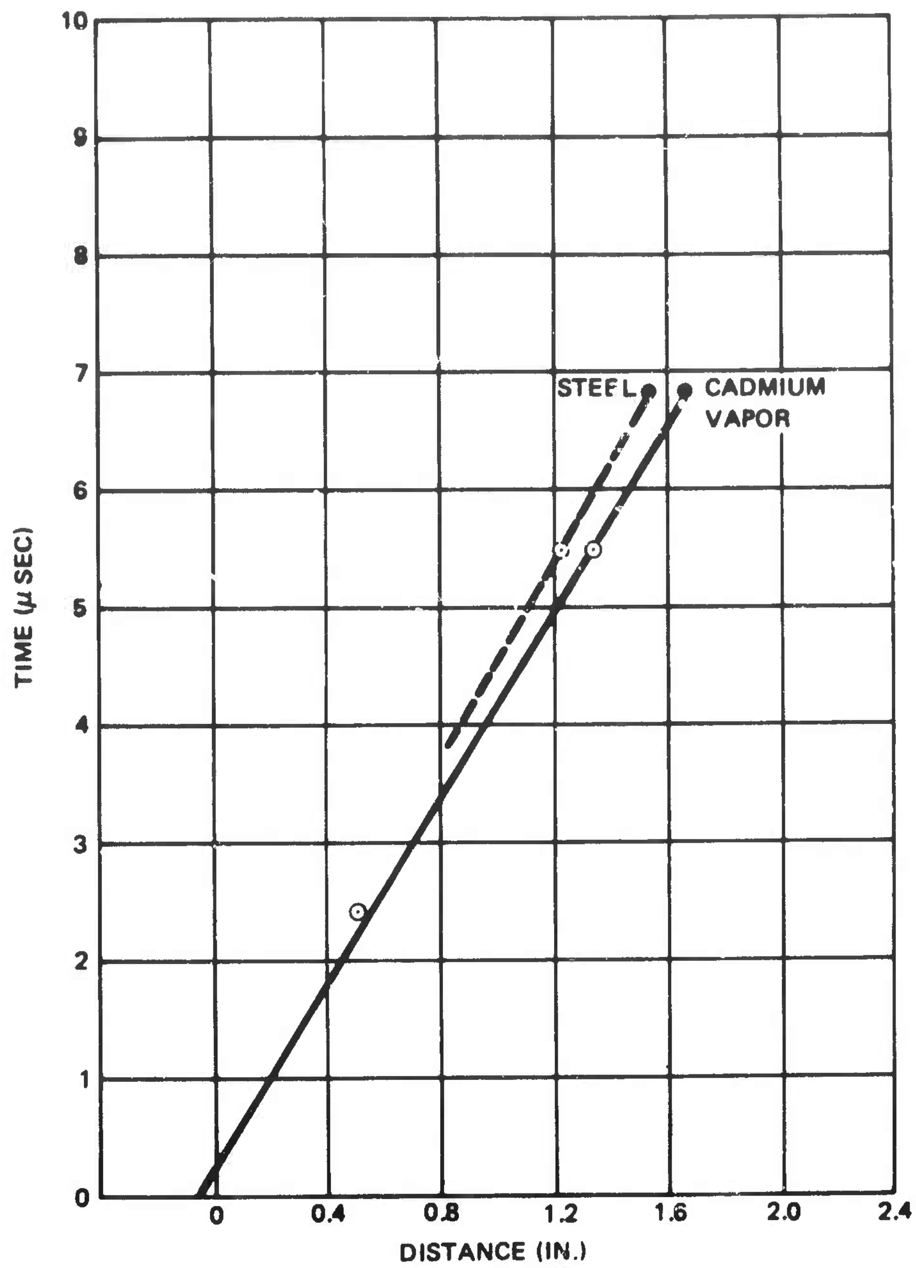


Spray Position vs Time

PLATE NO.	29
PROJECTILE:	CADMIUM SPHERE
IMPACT VELOCITY:	24,700 FPS
TARGET CONFIGURATION:	Cd-f-Pr 0.072/2.29/0.5 IN.
FOAM DENSITY:	0.5 gm/cm^3
FRONT PLATE MAXIMUM HOLE DIAMETER:	1.1 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	– – –


B40 - 56
SHOT NO.30
69091235


B40 - 56
SHOT NO.30
69091236



Spray Position vs Time

PLATE NO.	30
PROJECTILE:	STEEL SPHERE
IMPACT VELOCITY:	23,800 FPS
TARGET CONFIGURATION:	Cd-V-Al(1)
	0.072/3.43/0.125 IN.
FRONT PLATE MAXIMUM HOLE DIAMETER:	0.9 IN.
REAR PLATE MAXIMUM HOLE DIAMETER:	3.4 IN.

REFERENCES

1. Teng, R. N., R. C. Curtis, and J. R. Mastandrea. Descriptions and Capabilities of the Douglas Ballistic Ranges. Douglas Report SM-49090, April 1966.

2. Curtis, J. S. An Accelerated Reservoir Light-Gas Gun. NASA TN D-1144, February 1962.

3. Teng, R. N. Advances in Light-Gas Gun Model Launching Techniques. Douglas Paper No. 4253, November 1967, published in AIAA Journal, Volume V, No. 11, November 1967.

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1 April-3 September 1969

5. AUTHOR(S) (First name, middle initial, last name)

Robert N. Teng

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

(Distribution Limitation Statement No. 2)

Quantitative information on hypervelocity impact dynamics was obtained from 30 shots. Cadmium spheres projected at a velocity of 25,000 fps impacted against various multiplate targets. Instrumentation used during the test includes five channels of flash X rays, high-speed framing camera, model detectors, impact pressure probes, laser stress-wave sensors, and photostress analyzer. However, data from the pressure measurements and the stress-wave analysis are not included in this report. Some preliminary conclusions made from the test and a few remarks on the experimental techniques are included in this report.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hypervelocity						
Impact dynamics						
Cadmium spheres						
Multiplate targets						
Hydrodynamic theory						
Strength-dependent relationships						
Light-gas gun						
Vaporization						
Front-plate damage						
Debris bubble						
Debris velocity						
Debris spray angle						
Rear-plate damage						
Sabot						
Projectile						
Launch tube						
Lexan sabot						
Sabot trap						
Target plates						
Projectile deformation						
Pellet						
Particle impact						