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PRELIMINARY EXPERIMENTS USING LIGHT-INITIATED HIGH EXPLOSIVE FOR DRIVING THIN FLYER PLATES

MASTER

R. A. Benham

Sandia National Laboratories

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Printed in the United States of America

Available from:

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy ~~$4.50~~ A03; Microfiche $3.00 A01

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January 1980

ABSTRACT

Light-initiated high explosive, silver acelytide--silver-nitrate (SASN), has been used to produce simulated x-ray blow-off impulse loading on reentry vehicles to study the system structural response. SASN can be used to accelerate thin flyer plates to high terminal velocities which, in turn, can deliver a pressure pulse that can be tailored to the target material. This process is important for impulse tests where both structural and material response is desired. This report summarizes the theories used to calculate the dynamic state of the flyer plate prior to impact. Data from several experiments are presented which indicate that thin flyer plates can be properly accelerated and that there are predictive techniques available which are adequate to calculate the motion of the flyer plate. Recommendations are made for future study that must be undertaken to make the SASN flyer plate technique usable.

Key Words: impulse testing, pressure pulse shaping, x-ray blowoff simulation

*This work was supported by the United States Department of Energy (DoE).

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PRELIMINARY EXPERIMENTS USING LIGHT-INITIATED HIGH EXPLOSIVE FOR DRIVING THIN FLYER PLATES

Introduction

Light-initiated high explosive has been used to produce impulse loads on various structural members including large complex structural systems. Surface areas up to one square metre have been subjected to a simultaneously-applied, distributed impulse load both with and without load discontinuities. The dynamic loading, which is intended to simulate x-ray induced blowoff impulse, has been designed to produce structural response.* In a nuclear encounter, both material and structural response result when the surface material of the structure vaporizes and is blown off. In the past, no attempt has been made to tailor the pressure pulse from the light-sensitive explosive for investigation of combined structural and material response. The light-initiated high explosive (LIHE) technique would be enhanced as a simulation tool if pressure tailoring could be added to its capabilities.

Pressure tailoring has been accomplished in other impulse simulation techniques by driving thin flyer plates to impact the surface of the test structure.[1,2] The mechanics of pressure tailoring of the plate impact pressure pulse are the same regardless of the method of driving the flyer plate. Earlier work[3] has indicated that LIHE can accelerate flyer plates to velocities high enough to produce peak pressure loading of tens of kilobars in typical weapon structure materials.

*A load appears impulsive to a structure if the pressure duration is short compared to the shortest structural response period of the test item.

Also, a preliminary set of experiments has been conducted at Southwest Research Institute[4] which has proven the feasibility of accelerating thin flyer plates (both electrical conductors and nonconductors) with spray-deposited, light-sensitive explosive.

This report summarizes the theories used to calculate the dynamic state of the flyer plate prior to impact. The shock wave mechanics used to predict the actual pressure input to the test surface are not discussed here since the topic is covered in detail elsewhere.[1,2,5] A set of experiments that was conducted at Sandia Laboratories to further investigate the use of light-sensitive explosive to accelerate thin plates is discussed. The most recent explosive formulation and handling techniques were used. The objectives of the experiments were: (1) to reverify experimentally that thin flyer plates could be accelerated to terminal velocity while retaining the proper flatness and orientation; and (2) to evaluate existing explosive behavior theories and flyer plate gap transit theories for predicting the actual behavior during travel to impact. These objectives must be successfully met to allow the design of complex simulation experiments on real structures. The data from these experiments is presented which indicate that thin flyer plates can be properly accelerated and that the predictive techniques are adequate to calculate the motion of the flyer plate. Recommendations are made for future study that must be undertaken to make the LIHE technique experimentally usable.

Technique

The process for this technique starts with the careful formulation of the explosive in the form of a slurry. The explosive is then sprayed onto the test structure, the mass distribution over the surface being controlled by using various combinations of masks and/or overlapping spray passes. The explosive distribution is evaluated using local explosive weight measurements and/or beta backscatter areal density measurements during the spraying operation. The test item is then remotely transported to the test site and positioned in front of a capacitor discharge light source. An intense flash of light initiates the explosive and the resulting gas expansion produces a pressure load on the test structure surface.

In the proposed pressure tailoring experiments, the sprayed structure is a thin flyer plate. The plate is accelerated to a terminal velocity by the pressure pulse from the expanding gas of the explosive detonation. The flyer travels through a gap to impact the test structure. The pressure loading to the structural surface depends on the material and impact velocity of the flyer, on the nature of the air cushion effect, and the material of the test structure.[1-4]

Theory

The phenomena that are considered for calculation of the flyer plate motion are: initiation of a known quantity of explosive, expansion of the explosive products, and compression of the ambient gas between the flyer plate and the target. The important parameters to be calculated are the time of arrival and velocity of the plate at impact. In some cases, the compressed gas between the flyer and target may store enough energy to actually reverse the travel of the flyer plate producing a smooth, nearly-symmetrical pressure pulse in the target. The total momentum delivered to the test surface is dependent on the total change in velocity of the flyer plate, so the rebound condition must be understood. It is the intent of this paper to predict the motion of the flyer plate prior to impact.

For the analysis, it is assumed that the explosive is uniformly initiated by instantly converting the solid explosive mass to the same volume and density of high pressure gas, and that detonation propagation direction has little effect on the process. The explosive products are assumed to expand uniformly with a linear velocity profile across the thickness of the explosive/explosive gas. The pressure at the interface between the explosive products and the flyer plate drives the flyer to the terminal velocity. The terminal velocity magnitude can be determined using the Gurney[6] approach. The velocity is a function of the Gurney velocity ($\sqrt{2E}$)* and the areal density of the explosive (C) and of the flyer (M). Equation 1 shows this relationship.[6] Figure 1 is a sketch of the explosive system showing the geometry and terminology of the Gurney solution.

$$V_{terminal} = \sqrt{2E}\left[\frac{\left(1 + \frac{2M}{C}\right)^3 + 1}{6\left(1 + \frac{M}{C}\right)} + \frac{M}{C}\right]^{-1/2} \qquad (1)$$

This terminal velocity is reached at the end of the explosive push or acceleration phase of the plate motion (when the explosive products' pressure has been reduced to near ambient).

The Gurney velocity, $\sqrt{2E}$, for the light sensitive explosive is found experimentally by measuring the impulse delivered to a rigid wall (i.e. M/C 71). Using equation 1 with M/C 71 and defining the rigid wall impulse as the mass of the flyer times the terminal velocity the following is obtained.

$$\sqrt{2E} = \frac{I_{rigid\ wall}}{C}\sqrt{\frac{4}{3}} \qquad (2)$$

A calibration curve relating the impulse and the explosive areal density has been determined for LIHE.[7] The combination of the calibration curve and equation (2) leads to a description of $\sqrt{2E}$ as a function of explosive areal density, C.[7]

The time required to reach the terminal velocity can be calculated using the polytropic expansion process PV^n = constant

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*The Gurney velocity is a property of the explosive which indicates the effectiveness of the explosive in propelling material.

for the gas and PA = $M\ddot{X}$ for the flyer. A is the area over which the pressure acts, M is the mass of the flyer, $\ddot{X}$ is the acceleration of the flyer and n is the expansion process exponent. The value of n is to be discussed later.

Integrating this equation twice and putting in the values for the initial condition gives the expression (3) for time, t, as a function of position, X.

$$t = \left[\frac{(n-1)M}{2P_o X_o^n g}\right]^{1/2} \int_{xo}^{x} \frac{dx}{\left(\frac{1}{X_o^{n-1}} - \frac{1}{X^{n-1}}\right)^{1/2}} \qquad (3)$$

P_o, X_o, g, M are initial pressure, initial explosive half thickness, gravity constant, and flyer areal density respectively. The flyer terminal velocity can be determined from this approach and is $V_{term} = \frac{2P_o X_o g}{(n-1)M}$.[8] Using equation (3), one can determine the time for the flyer to reach position X by integrating from the starting position, X_o, to position X. The value X_o is the distance between the flyer plate surface and the plane in the explosive of zero particle motion (from the assumption of a linear velocity profile of the explosive debris). This reference plane occurs at different locations within the thickness of the explosive depending upon the exact configuration. For the open face sandwich configuration under consideration here, X_o can be found from

$$\frac{T-X_o}{X_o} = 1 + 2M/C \ , \qquad (4)$$

where T is the explosive thickness[8] (see Figure 1).

A sensitivity study of the effect of changing the exponent n on the flyer transit time through the gap has been conducted. Table 1 shows a small part of this study.

TABLE 1. EFFECT OF EXPANSION EXPONENT n ON FLYER MOTION

n	Gap	Flyer Areal Density (M)	Explosive Areal Density (C)	Gap Transit Time	% of Maximum Flyer Momentum at Impact
1.4	.057 cm	.089gm/cm^2	.020gm/cm^2	7.25μsec	83.6
3	.057 cm	.089gm/cm^2	.020gm/cm^2	5.35μsec	99.6

Transient time through gap for constant velocity = 5.16μsec

The flyer is assumed to be traveling in a vacuum.

Maximum flyer momentum = 987 taps (terminal flyer velocity of 11036 cm/sec).

If n is low, then the acceleration time is long. Terminal velocity was not reached at impact for n = 1.4 of Table I. If n is high, then the energy from the expanding gas is delivered to the plate in a much shorter distance resulting in higher accelerations.

Since simultaneity of loading is important. Experiments are currently underway at Sandia to evaluate the explosive expansion process.

The flyer plate must travel through a finite gap before impacting the test surface. Air, if any, between the flyer and test surface compresses to form a cushion prior to plate impact. This cushion effect will minimally cause a smooth pressure precursor prior to impact shock delivery or maximally cause the flyer to reverse direction without actually impacting the test surface (a symmetrical pressure pulse with double the flyer plate momentum being delivered). The air cushion effect has received considerable attention[1,2,4,5]; therefore the theory will not be described here.

The ideal experimental condition for flyer plate impulse delivery is to have the flyer plate reach terminal velocity before the gap has been traversed so that there is not a gradient in flyer velocity as a function of distance in the region of the impact. Ideally, the cushion effect should not be appreciable during the acceleration phase of the transit, thus allowing decoupling of the acceleration calculations from the cushion calculations.

In the first attempt at calculating the flyer transit of a gap, the flyer was assumed to be at the terminal velocity after having traveled some specified distance across the gap. The air cushion equations were then used to predict the continuation of the flyer on to impact or rebound. A computer program based on the previously cited work has been written which predicts the motion of the, air cushioned, driven flyer plate. A refinement to this method includes calculation of the motion of the flyer through the acceleration phase.[9]

EXPERIMENTAL EVIDENCE

A series of four experiments was conducted in June 1977 to provide data for accessing the utility of the technique. The main purposes were:

1) Verify that a thin (.033 cm thick) aluminum flyer plate can be accelerated in a plane, uniform manner.
2) Evaluate measurement techniques for measuring flyer plate condition and displacement history.
3) Evaluate predictive techniques of terminal flyer velocity and air cushion effect.

The data collected to achieve the above listed purposes were: 1) the physical condition of the post test flyer; 2) flash X-ray shadow graphs of the flyer, and 3) non-contacting (eddy current) displacement gage measurements.

The experimental setup consisted of a .033 cm thick aluminum flyer plate 7.62 cm in diameter that was attached to a phenolic support ring by means of a layer of paper stretched across the diameter of the ring. The phenolic ring was positioned in a gage holding fixture. Figure 2 shows a cross-section of the test setup and Figure 3 shows a photograph of the actual hardware. Detonation timing crystals were attached to the holder for determination of time initiation (Figure 4). The explosive on the outside of the assembly (see Figure 2) was initiated, by the flash of light from a capacitor bank discharge,[10] thus driving the flyer plate through the gap toward the displacement gage. A gap between the flyer and the gage of 1.27 cm was chosen to allow measurement of flyer motion after the electrical system recovered from the capacitor bank noise black out and to allow sufficient travel for obtaining flash X-ray exposures of the flyer plate during transit. Flash X-ray exposures were taken as the flyer traveled through the gap to show flyer velocity and condition at various times after initiation. Figure 5 shows the flash X-ray setup and Figure 6 shows the test assembly in front of the light source. The output from the displacement gage was recorded on an oscilloscope for the first test and on a disc recorder with 1 MHz frequency response for the second and third test. The detonation timing crystal signals were also recorded on an oscilloscope.

RESULTS

Figures 7 through 10 show reproduction of the flash X-ray data. Table 2 is a summary of the test data. Figures 11 and 12 show the flyers after the test. The large buckles were caused when the flyer rebounded out of the assembly and impacted the light array.

After each of the first three tests, it was noticed that the rebound of the flyer was lower than expected, so the fourth test was conducted with only the X-ray to verify that the edges of the flyer were impacting the fixture while over the gage the compressed air did not allow impact. See Figure 13. Figure 10 shows the X-ray of the rebounded flyer plate.

The flatness of the flyer plate in Figures 7, 8, and 9 is sufficient for impact experiments. In actual experiments, transit gaps will be held to less than .254 cm so that flatness and tilt will be typically better than shown in the first exposure.

The displacement gage was susceptible to electrical noise, as mentioned above, and so was saturated by the electrical noise of the capacitor bank light source for early times. The initiation timing crystals were used to determine the start of flyer motion. Final flyer velocity and air cushion effect could be easily determined using the displacement gages.

The most complete displacement data was obtained from the second test. The explosive initiation time was delayed the longest, causing the signal to start later in the noise blackout time. Figures 14 and 15 show the predicted motion history and pressure at the target face using the above-mentioned model and computer program.* Figure 16 shows the comparison between the prediction and measurement for test #2. Agreement is good up to the point of maximum gas compression. Edge relief of the compressed gas caused the edges to be retarded less than the center and impact the gage holder causing energy to leave the flyer and therefore rebound at a lower than expected velocity.

CONCLUSIONS AND RECOMMENDATIONS

At least one class of flyer plates (.033 cm thick aluminum) can be accelerated with spray deposited light HE with sufficient planarity and predictability to be used in pressure pulse tailoring impulse experiments. Impact conditions (velocity, time) can be predicted fairly well with existing approximations to the gas expansion process. Design of a complex experiment will require better understanding of the explosive behavior. A better resolution transducer (fibre optics, capacitance gages) should be used to observe the acceleration history of a flyer plate to define the explosive expansion process to a better degree.**

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*The computer program listing is not included in this report but is available from Division 1533.

**The experimental work and an analytical model have been accomplished and are soon to be published.[9]

experiments on flat configurations should be conducted to verify tailored pressure shape and amplitude for both contact and cushioned experiments. Pressure transducer technology will currently allow this investigation. Experiments to extend the range of impulse levels should be conducted. Methods of physical support of the flyer for full system experiments must be developed, as well as a program to use the calculational elements of this report to design a complete system load with impulse, pressure and simultaneity controlled.

ACKNOWLEDGMENT

The author would like to express appreciation to D. L. Shirey who conducted the explosive experiments, to B. D. Duggins who provided the displacement measuring scheme and assisted in computer programming, to P. B. Higgins who assisted with instrumentation and facility operation, to Walter Gill for his comment on this report and to Anna Marie Carroll for preparing the text

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Test	Explosive Areal Density Mg/cm² (C)	Explosive Initiation Time (Crystals) μsec	Effective Flyer Thickness cm	Flyer Areal Density Mg/cm² (M)	Gurney Predicted Velocity mm/μs	Measured Velocity mm/μs: Displ. Gage Slope	Measured Velocity mm/μs: X-ray Velocity (V_{12})	Flatness	$\frac{V_{meas.\ avg}}{V_{predicted}}$
1	.0217±5%	42[1]	.0366	.099	.11140	-[2]	.12100	No measurable wrinkle or tilt in first .5 cm	1.086
2	.0225±5%	53	.0376	.1019	.11372	.11999	.11965	"	1.051
3	.0225±5%	38.5	.0373	.1012	.11440	-[2]	.11723	"	1.025
4[4]	.0206±5%	31, 32, 34	.0368	.100	.10386	-[3]	.11293	"	1.087

[1] Explosive initiation is controlled by distance between the explosive surface and the light source

[2] Initial slope difficult to measure because the explosive initiated during electrical "blackout" time from light source capacitor discharge

[3] No displacement gages used

[4] Conducted to observe flyer after impact with the surface

TABLE 2. FLYER PLATE EXPERIMENTAL RESULTS

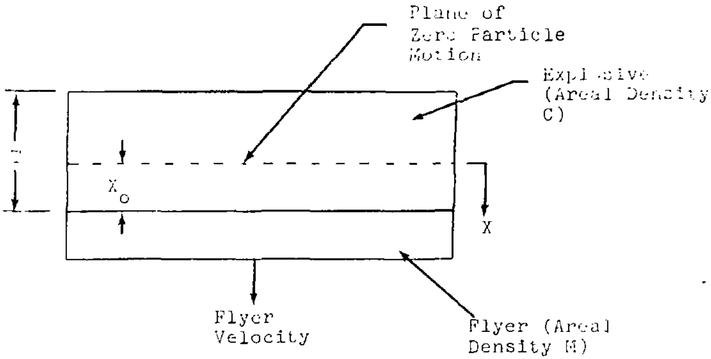

FIGURE 1. EXPLOSIVE CONFIGURATION

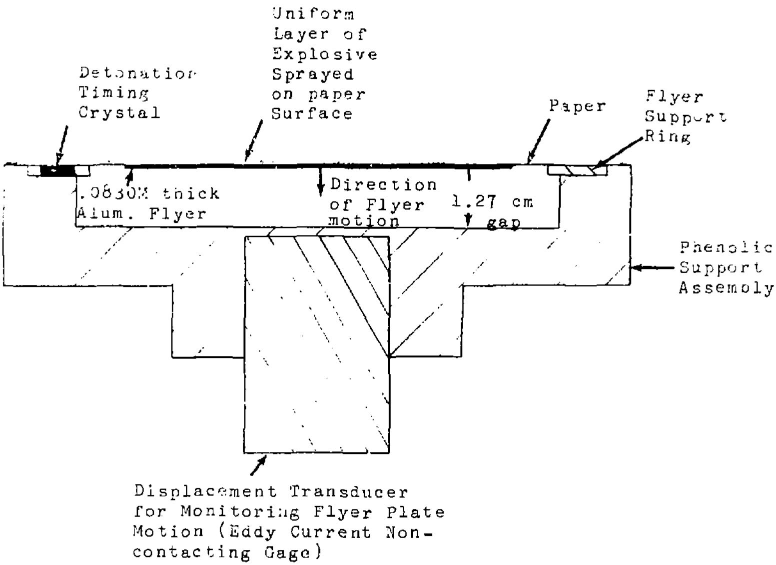

FIGURE 2. SKETCH OF EXPERIMENTAL SETUP

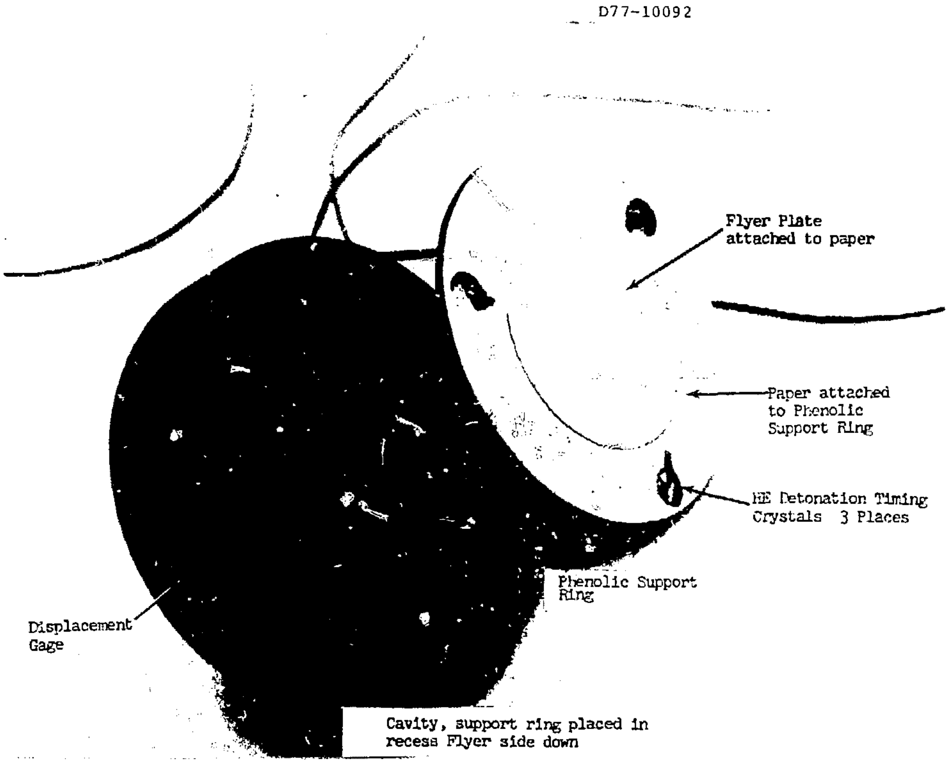

FIGURE 3. EXPERIMENTAL SETUP

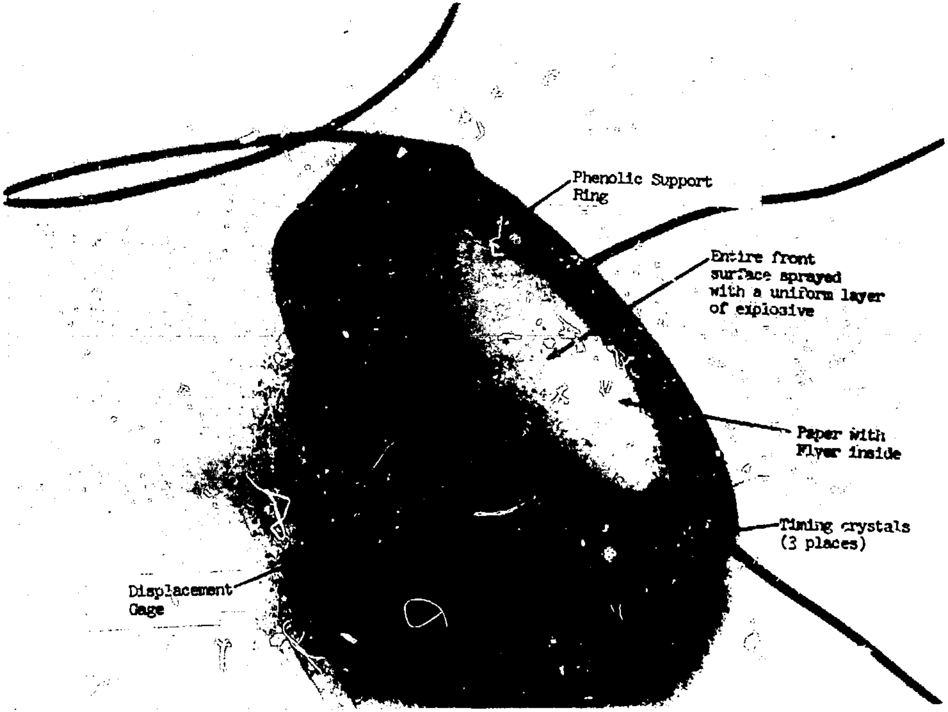

FIGURE 4. ASSEMBLED TEST FIXTURE

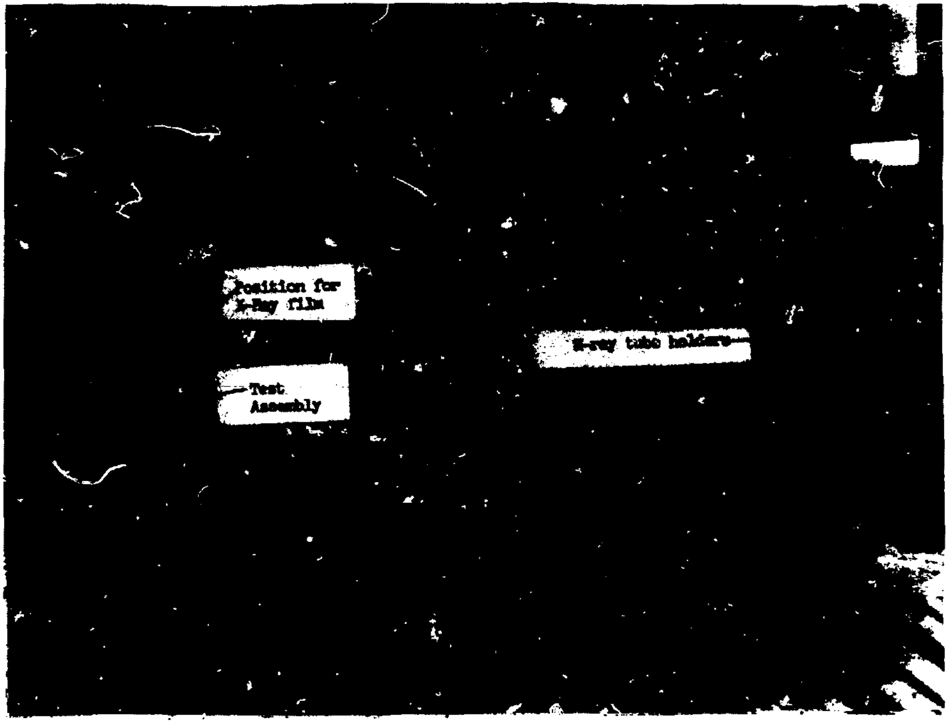

FIGURE 5. FLASH X-RAY SETUP

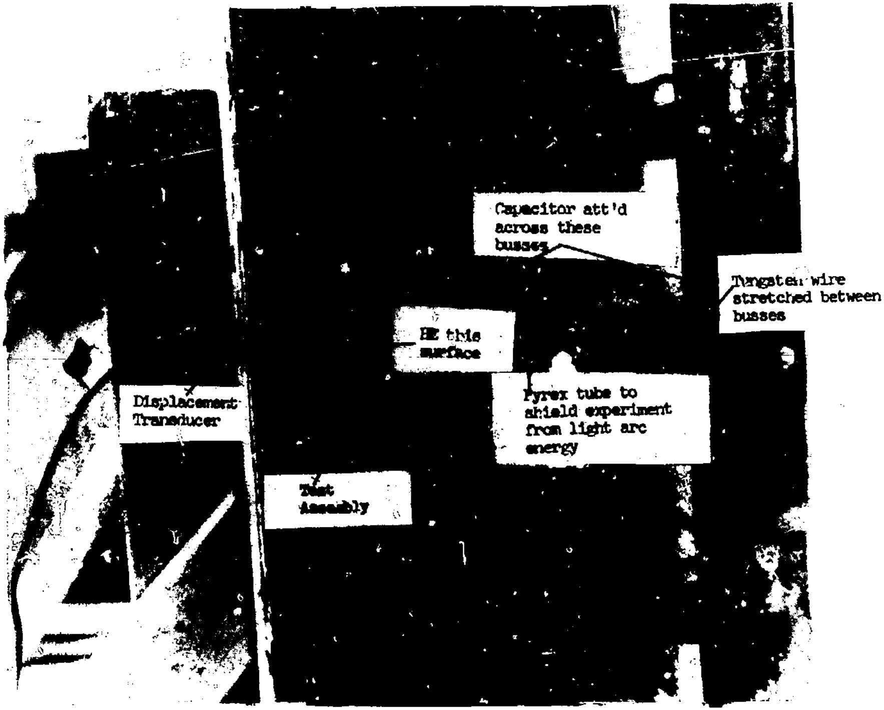

FIGURE 6. TEST ASSEMBLY IN FRONT OF LIGHT ARRAY

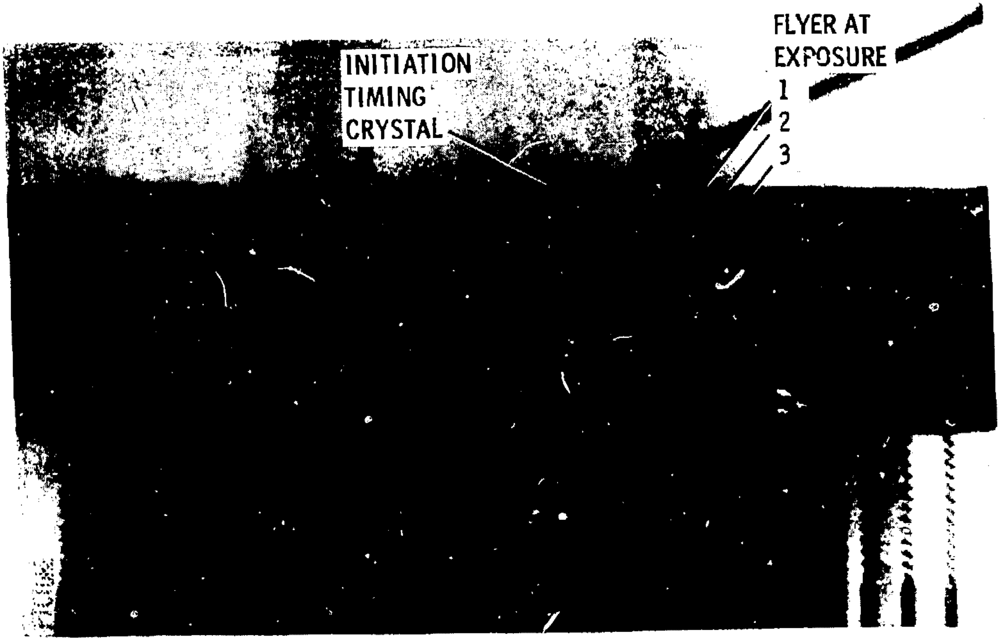

FIGURE 7. FLASH X-RAY DATA FROM TEST #1

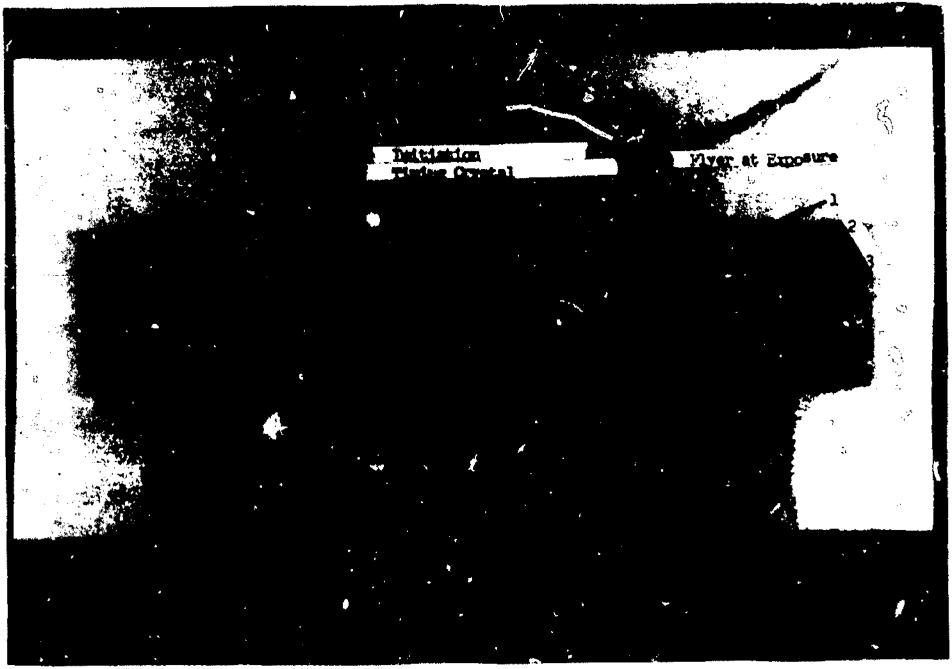

FIGURE 8. FLASH X-RAY DATA FROM TEST #2

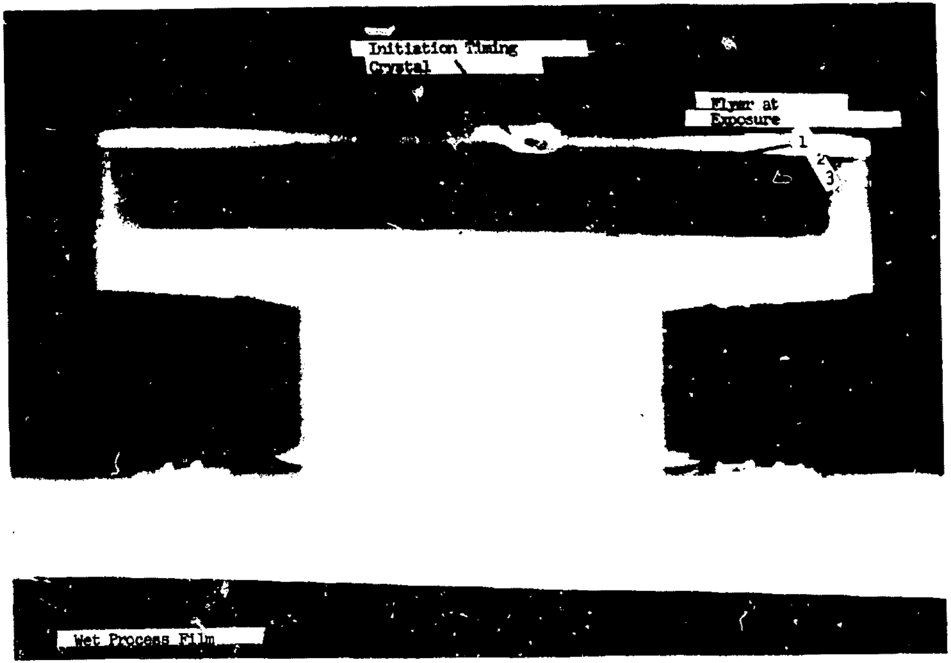

FIGURE 9. FLASH X-RAY DATA FOR TEST #3

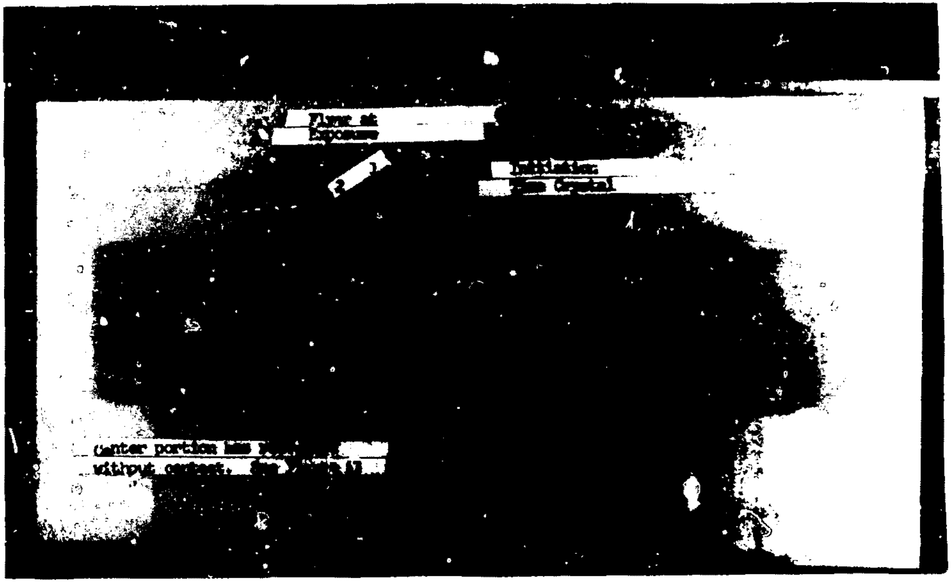

FIGURE 10. FLASH X-RAY DATA FROM TEST #4

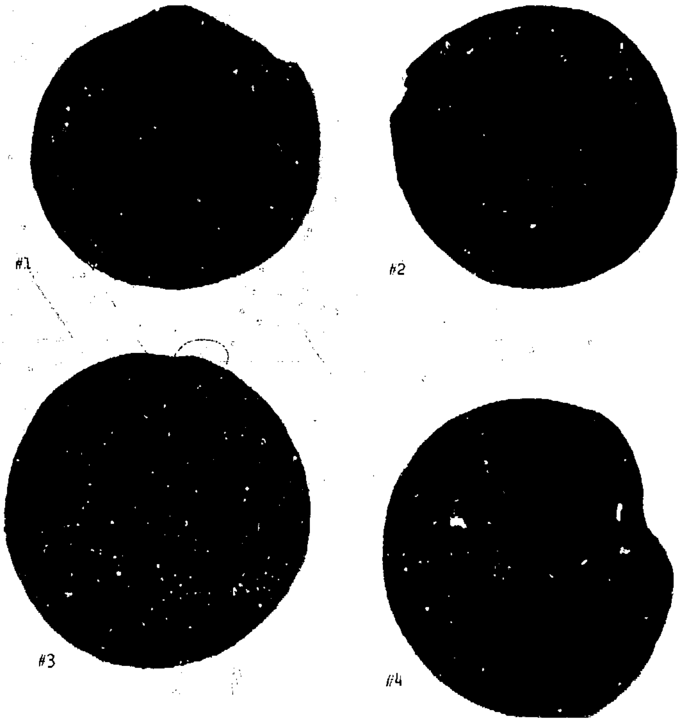

FIGURE 11. POST-IMPACT FLYER, EXPLOSIVE SIDE

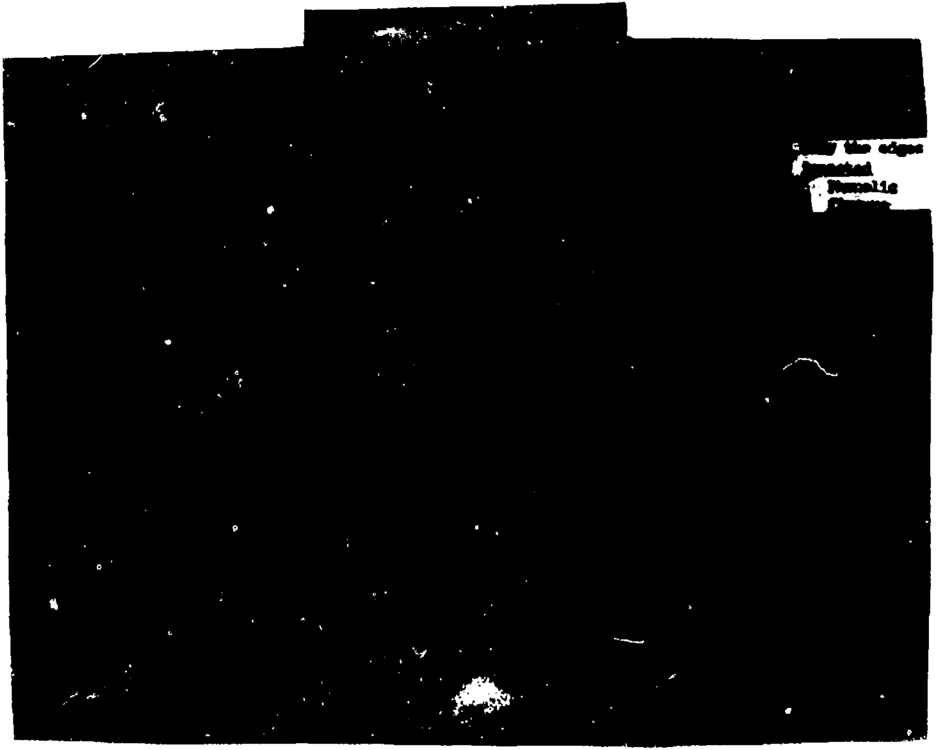

FIGURE 12. POST-IMPACT FLYER, IMPACT SIDE

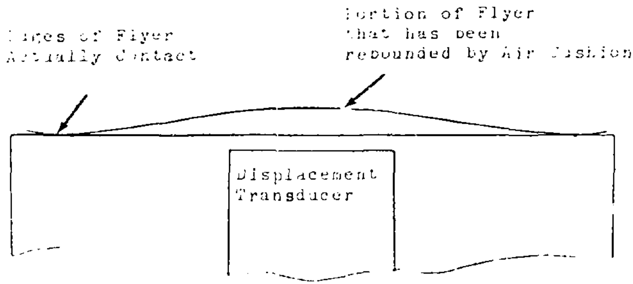

FIGURE 13. PROFILE OF FLYER PLATE AFTER CUSHION EFFECT HAS CAUSED REBOUND

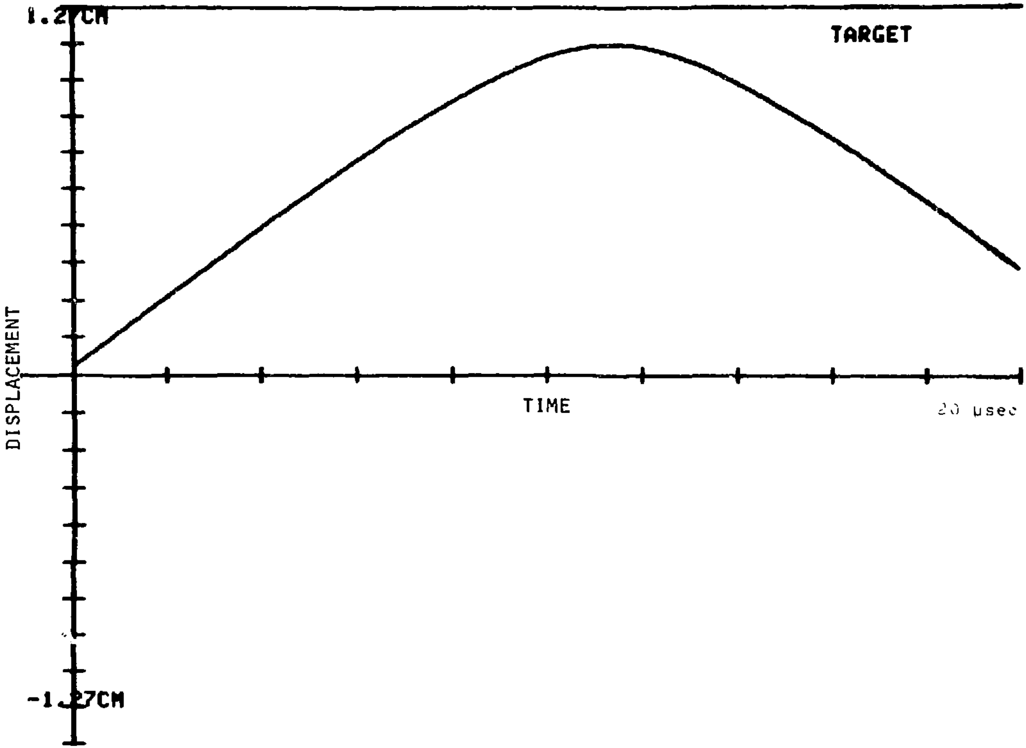

FIGURE 14. PREDICTED MOTION OF FLYER

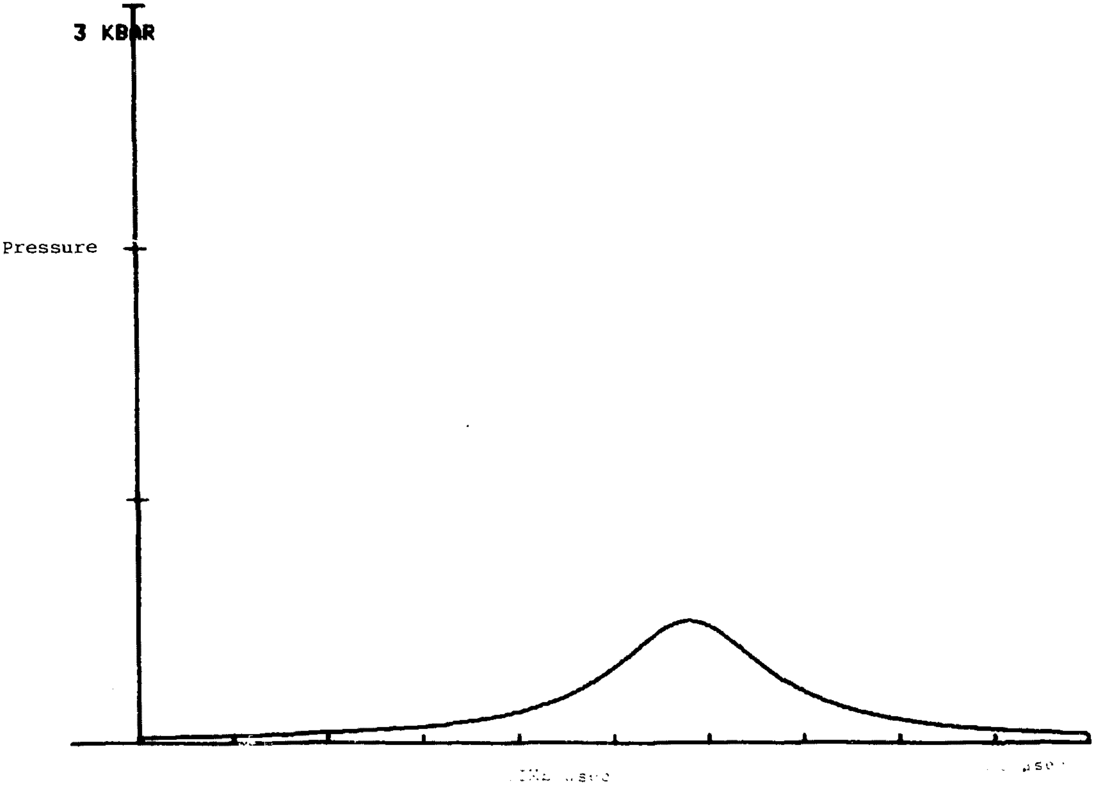

FIGURE 15. PREDICTED PRESSURE DEVELOPED AT THE TARGET SURFACE

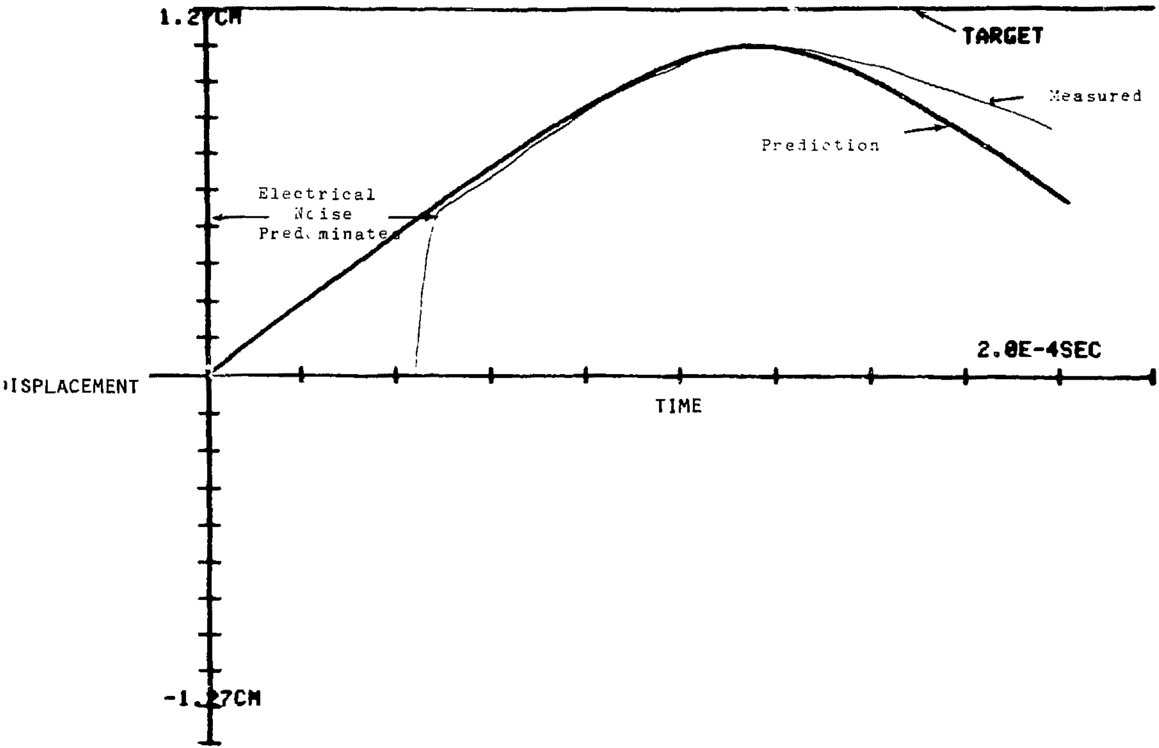

FIGURE 16. COMPARISON BETWEEN PREDICTION AND MEASUREMENT FOR TEST #2