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# TARGET RESPONSE TO EXPLOSIVE BLAST



Final Report  
By  
George H. Custard  
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Falcon Research and Development Company  
Denver, Colorado

September 1970

PREPARED FOR

ARMED SERVICES EXPLOSIVE SAFETY BOARD  
FORRESTAL BUILDING  
WASHINGTON, D. C.  
Contract No. DAHC04-69-C-0095

# FALCON

RESEARCH AND  
DEVELOPMENT

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The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry, no matter how small, should be recorded to ensure the integrity of the financial statements. This includes not only sales and purchases but also expenses and income. The document also highlights the need for regular reconciliation of bank statements and the company's records to identify any discrepancies early on.

In addition, the document provides a detailed breakdown of the accounting cycle, from identifying the accounting event to preparing the financial statements. It explains how each step contributes to the overall accuracy and reliability of the financial data. The document also includes a section on the importance of internal controls, which are designed to prevent errors and fraud, and to ensure that the company's assets are protected.

The document concludes by stressing the importance of transparency and accountability in financial reporting. It encourages the company to adhere to the highest standards of ethical conduct and to provide clear and concise information to all stakeholders. The document also includes a list of references and a glossary of key terms to help readers understand the concepts discussed in the document.

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John R. Thayer

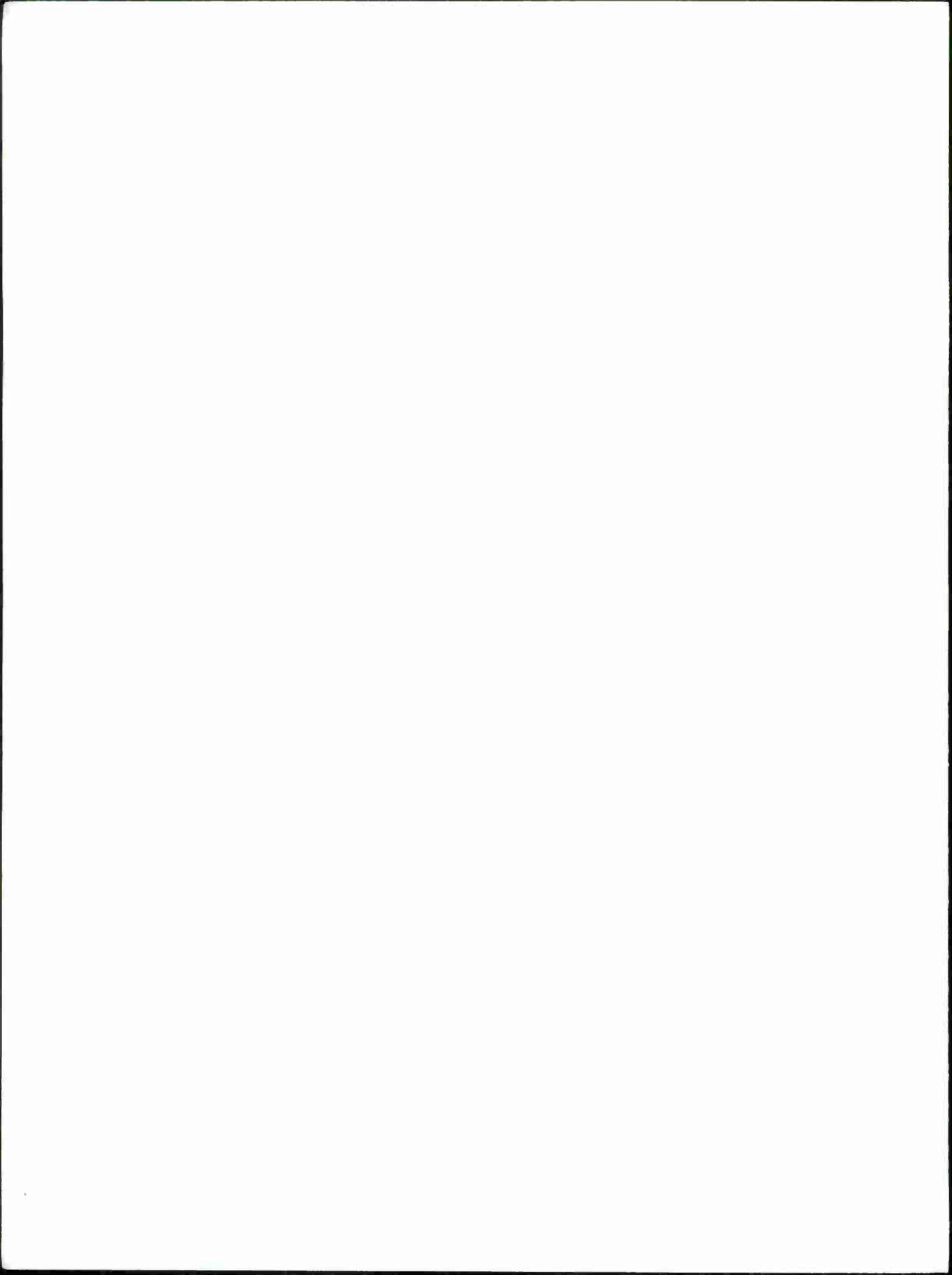
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## FOREWORD

The work summarized in this report was conducted under Contract DAHC04-69-C-0095 during the period 1 March 1970 to 30 September 1970. The project was completed under the direction of the Chairman of the Armed Services Explosive Safety Board, Col. William Cameron, III. Technical guidance was provided by Mr. Russel G. Perkins, Contract Monitor and Dr. Thomas A. Zaker.

The study was conducted by the Falcon Research and Development Company under the guidance of Mr. Arthur M. Krill, President. Mr. George H. Custard served as Project Supervisor and was ably assisted by Mr. John Thayer, Mr. William L. Baker and Mr. Donald C. Saum. Other persons assisting in the project at the Falcon Research and Development Company include Mr. Charles E. Eppinger and Mr. Howard Iwata.

The tests conducted at the U. S. Naval Weapons Center, China Lake, California, were performed with the assistance and cooperation of Mr. Fred Weals and Mr. Al Sound of the NWC staff.

The tests performed at the Suffield Experiment Station, Ralston, Alberta, Canada were guided by Mr. John H. Keefer, U. S. Technical Director for Event Dial Pack and Mr. Ralph Reisler, U. S. Program Director for Air Blast Projects. Support services for the Dial Pack tests were provided by Mr. A. P. R. Lambert of the Canadian General Electric Company. Other assistance in these tests was provided by Major William J. Shepard, DASA Project Officer, Mr. Jack Kelso of the DASA staff, Mr. Louis Giglio-Tos of the Ballistics Research Laboratory, and Mr. George Pratt of the U. S. Air Force Audio-Visual Center.

## ABSTRACT

The work covered by this report extended the knowledge of blast interactions with two types of targets and achieved a fuller understanding of the requirements for protecting personnel exposed to stored explosives. The specific targets were a 1/4 inch plate glass window and a bus. These tests were performed because of a general lack of earlier experimental data relative to the response of these particular target elements.

Plate glass windows were exposed to blast pressures of 0.65 and 1.09 psi peak incident pressure from a surface burst charge. Bus vehicles were exposed, side on to the blast wave, to provide maximum opportunity to overturning at blast pressures of 7, 8, and 9 psi peak incident pressure. High speed photographic coverage was provided on all tests to document target response.

It was shown that plate glass fragments as large as 1500 grams (3.3 lbs.) are produced under threshold breakage conditions and that approximately 40 percent of the window may break into fragments, each weighing a pound or more. The only velocity vector of importance, under these conditions, is the one provided by the force of gravity.

Bus vehicles were shown to be somewhat more resistant to overturning by blast than a simple model had indicated. It was concluded that window areas do not effectively transmit blast energy to the bus for overturning and that the suspension system acted to inhibit overturning in these test exposures.

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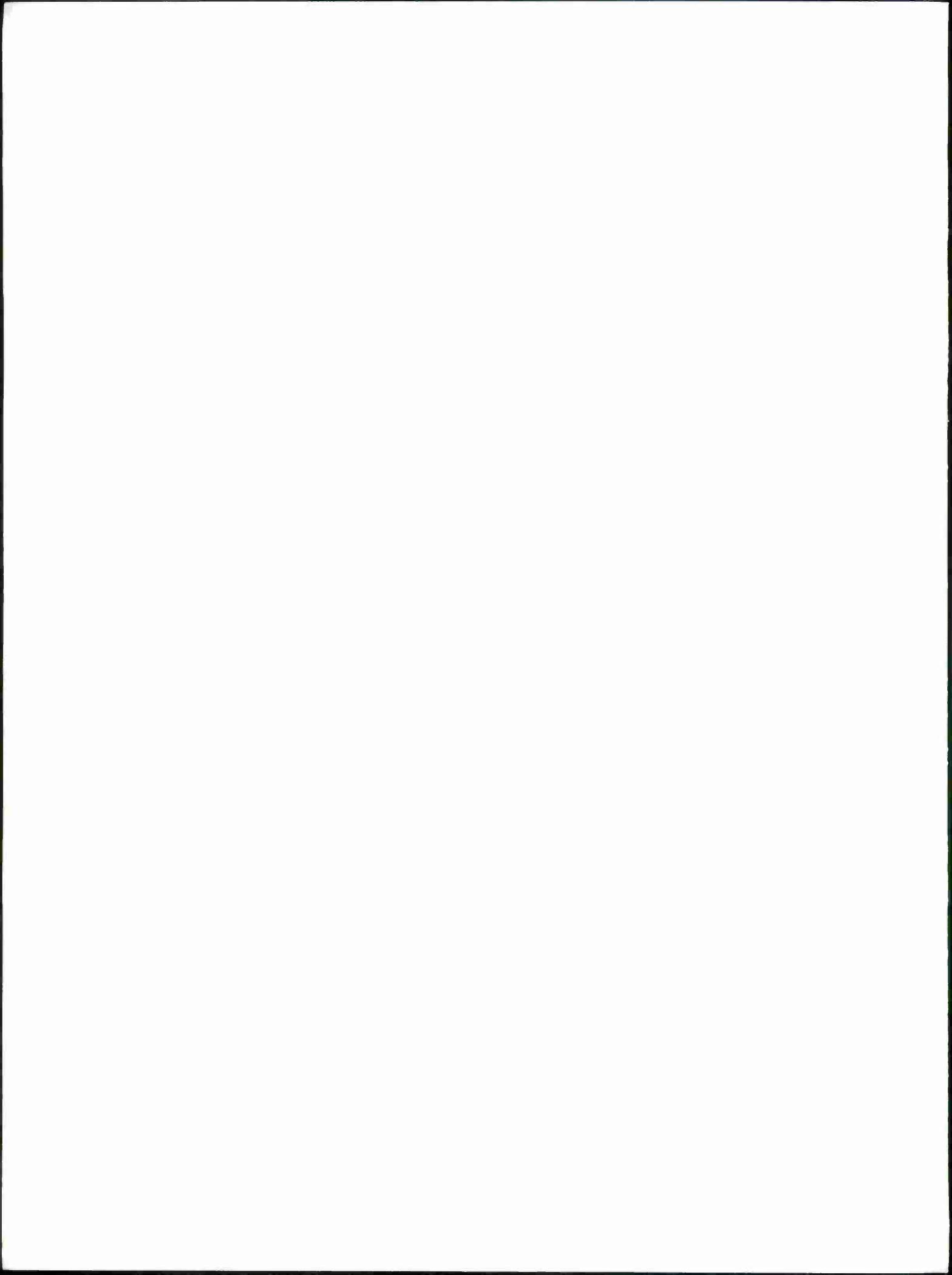
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## I. INTRODUCTION

The protection afforded to personnel in vehicles on public highways and in public or private buildings is of continuing concern to the Armed Services Explosive Safety Board. A recent analytical evaluation of explosive storage safety criteria<sup>1</sup> indicated a need for additional experimental evidence in several areas relating to target response to blast. The tests reported here were performed to meet two of these specific needs.

Most explosive accidents produce a substantial number of broken windows and some injuries from glass fragments. Some glass breakage and the concomitant injuries to exposed personnel have been accepted in establishing the quantity-distance values provided by the DOD Ammunition and Explosive Safety Standards.

In evaluating a variety of types of buildings and their response to blast, it became apparent that virtually no data existed relative to the spectrum of fragment sizes produced by marginal breakage of plate glass windows in a blast environment. The reported tests of the breakage of a 4-foot by 6-foot plate glass window provides an initial data base to meet this requirement.

The aforementioned analytical investigation into the hazards to specific highway vehicles and their occupants produced evidence to support the position that large highway vehicles, such as a bus or pickup-camper, would be subjected to overturning by lateral blast waves before other potential damage mechanisms would become a serious threat to the vehicle.

A mathematical model of the blast interaction with such vehicles was formulated and programmed for computer use. The model was believed to represent a reasonable interaction between a wide range of blast waves and the vehicles described, but was not supported by experimental evidence, since little was available.

1. "Evaluation of Explosive Storage Safety Criteria," Falcon Research and Development Company, for ASESAB, March 1970, Contract DAHC04-69-C-0095.

Tests described in this report represent a first attempt to secure experimental verification of the model elements. It should be noted that the vehicles exposed in these tests were substantially different from the vehicles described for the analytical study in a number of respects. Further, the location of three of these vehicles relative to the charge was substantially closer than the criteria of the model would have indicated, since only 80 percent of the overturning energy was allowed in the model. In general, these tests were intended as a test of mathematical model parametric relationships rather than a direct test of vehicle damage or survival at a specific location; the small bus exposed at 3000 feet is the only exception.

Two of these tests were included as an addition to another experiment involving bomb fragment distributions. Vehicles available to the project at the Naval Weapons Center, China Lake, California, were used as an expedient method of securing an initial data base with a minimum test effort.

The other two exposures were a part of the Dial Pack tests conducted in Alberta, Canada and exposed school buses which were obtained locally by the Dial Pack support contractor.

## II. BACKGROUND DISCUSSION

### A. PLATE GLASS WINDOW HAZARDS

Modern architectural and construction practice employs large quantities of plate glass in houses, office buildings, schools, hotels, and other public buildings. Since the quantity-distance standards for stored explosives do not generally protect against glass breakage, the plate glass in these structures presents a potential hazard to building occupants or to persons near such buildings at the time of an accidental detonation. While there are many instances of plate glass exposure in areas near explosive storage or handling facilities, no data which quantitatively defines plate glass behavior under low levels of blast loading has been found which is adequate for estimating the nature of the associated hazards.

During the Operation Plumbbob tests of 1957, there were eight tests involving plate glass. All glass was mounted in a frame which was essentially in the open; thus, the effect of the building, which normally shields the window from pressure on the back side of the glass, was not present in any of these tests. Further, the exposures were in the 4-9 psi incident pressure level range and thus were substantially above the thresholds for this type of glass breakage. Less than 150 fragments were captured from all eight of these tests. Consequently, the statistical sample is not large, even for these relatively high pressure exposures.

Extensive glass fragment lethality and wounding data have been developed through the work of the Lovelace Foundation; however, that data applies only to the small, high velocity fragments produced by the breakage of single and double strength window glass. There are indications that large glass fragments may be produced from the interaction of low incident pressures with large plate glass windows. Such large pieces of glass may constitute a substantial hazard when falling on occupants or persons below such a window, even when the blast induced forward velocity of the glass pieces is near zero. Data from many explosive accidents show that the forward velocity may actually be negative and the glass pieces often fall toward the blast source. Under these conditions large glass pieces

can fall several stories to the ground and might be expected to be quite hazardous to persons exposed below.

Work accomplished at the Stanford Research Institute<sup>2</sup> provides analytical predictions for the blast loadings associated with the 50 percent probability of failure for many weights, thicknesses, and sizes of windows. Their prediction of incipient failure blast pressure for front-face loading as a function of pane area is summarized in Figure 1. These data were derived through the application of a computer mathematical model of window glass behavior based on a load-deflection relationship. Tables I and II provide physical data for a wide range of glazing materials.

Glass is a brittle material and conforms to elastic theory to the point of failure but the usual methods of structural analysis have been found to be inappropriate because glass failure depends so strongly on the flaws and defects in the piece.

The SRI work suggests that windows exposed to blast loading behave as simple oscillators and thus the differential equation of motion for a single-degree-of-freedom system with no damping was used in their model. A static resistance function describing the response of the window was established and a factor of 1.8 selected as the ratio of dynamic to static failure loads.

Work with this computer model is continuing and the analytical results produced to date are believed to be the most reliable estimates of window behavior available. The analytical evidence needs supporting experimental data which have been largely unavailable for blast exposures near threshold damage levels.

The analytical data available provides estimates of window breakage thresholds but does not attempt to estimate the

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2. Iverson, J. H., "Existing Structures Evaluation - Part II: Window Glass and Applications," Final Report, Contract No. OCD-DAHC20-67-C-0136 for Office of Civil Defense by Stanford Research Institute, December, 1968.

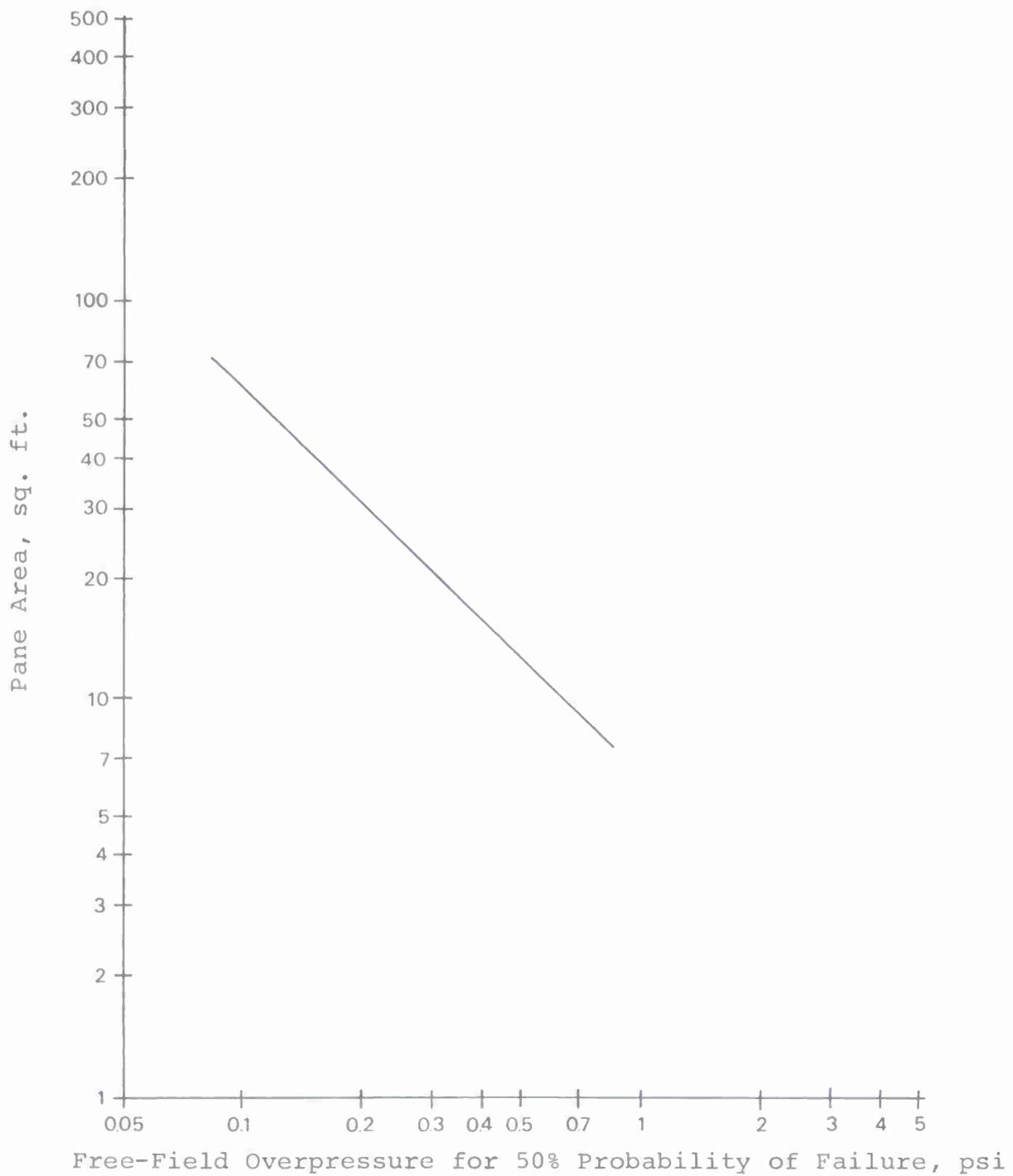


Figure 1. Incipient Failure Pressures for Front-Face Loading as a Function of Pane Area and Thickness for 1/4 inch Plate Glass.

TABLE I. Plate Glass Specifications

Type	Thickness (in)		Approximate Weight per Square Foot (pounds)	Maximum Size (in)
	Nominal	Tolerance		
Float	1/4	+1/32	3.24	122x200
Regular plate	1/8	+1/32	1.64	76x128
Regular plate	1/4	+1/32	3.28	127x226
Regular plate	5/16	+1/32	4.10	127x226
Regular plate	3/8	+1/32	4.92	125x281
Regular plate	1/2	+1/32	6.56	125x281
Regular plate	3/4	+1/32 -3/64	9.85	120x280
Regular plate	1	+3/64 -1/16	13.13	74x148

TABLE II. Sheet Glass Specifications

Type	Thickness (in)		Approximate Weight per Square Foot		Maximum Size (in)
	Nominal	Range	Ounces	Pounds	
Single strength	3/32	(.085-.097)	19	1.20	40x50
Double strength	1/8	(.117-.131)	26	1.60	60x80
3/16" heavy sheet	3/16	(.182-.200)	40	2.51	120x84
7/32" heavy sheet	7/32	(.212-.230)	45	2.82	120x84
1/4" heavy sheet	1/4	(.240-.260)	52	3.23	120x84
3/8" heavy sheet	3/8	(.356-.384)	77	4.78	60x84
7/16" heavy sheet	7/16	(.400-.430)	86	5.36	60x84

sizes of glass fragments produced from theoretical considerations. Experimental evidence from windows exposed in the various nuclear tests was used to estimate fragment sizes and velocities in the SRI model; however, this was largely an empirical input which cannot realistically be extrapolated to threshold breakage conditions.

## B. VEHICLE BLAST INTERACTIONS

The recent analytical work at Falcon Research, which has been referred to earlier, indicated that the prevention of overturning is a reasonable basis upon which acceptable damage criteria can be established for vehicular targets--such as a passenger bus, camper-pickup unit, or mobile home. The pressure-impulse requirements to overturn these vehicles were estimated through analysis. An acceptable damage level was arbitrarily established as being that damage associated with 80 percent of the reflected impulse necessary to overturn each vehicle. With such forces imparted to the vehicle, some deformation of the exposed sidewalls, window breakage, and the dislocation of some internal fixtures was anticipated. These effects, however, were not necessarily considered to present an unacceptable hazard to the vehicle occupants.

Preliminary investigation with available experimental data indicated that vehicular targets will overturn prior to experiencing any substantial degree of sideways displacement, at least on dry asphalt or concrete surfaces. These estimates assumed a coefficient of friction of approximately 0.7.

While the analytical approach taken in the work previously accomplished is believed to be sound, directly applicable experimental tests of blast interactions with vehicles was needed to confirm the analytical inputs and model assumptions.

An extensive search of the literature provided very little data which was applicable to vehicle overturning due to blast. The best available data prior to these tests was taken from the nuclear tests in which house trailers were exposed to blast. In this instance two trailers were overturned without other major damage. The blast exposure conditions for these units are known within reasonable limits, but the positive

duration of the blast wave was very long for conventional explosive comparisons. Further, the trailers were relatively light units in comparison with large highway vehicles and the physical data on each unit was quite sketchy.

An example of the model which was applied to a specific highway bus in the recent Falcon study is as follows.

The bus analyzed was a rather standard intercity highway bus made by Mack. The external skin sections of the bus were attached to a rather light but extensive space frame composed of many small members, primarily square or rectangular steel tubing. There was no main frame such as is commonly found in trucks and older cars. The outer skin, either steel or aluminum, and the plywood passenger and baggage floors were rigidly attached to the framework and provided part of the structural strength.

The side of the bus below the passenger floor was extremely resistant to sideways deformation. However, the upper half was considerably lighter and would undergo deformation at reasonably low overpressures. The principal dangers to passengers were considered to come from window breakage or overturning of the bus.

The empty bus weighed approximately 22,000 pounds, and when fully loaded with 40 people and baggage, an estimated weight of 30,000 pounds was attained. The center of gravity was estimated at 40 inches above the ground plane.

The reflected impulse needed to overturn a stationary target requires a determination of the mass distribution of the target and the location of the center of gravity. The height of the center of gravity above the point of rotation, on the ground plane, was designated as  $h_g$  and the distance, on the ground plane, from the center of gravity to the point of rotation as  $d$ . The distance,  $d_o = \sqrt{d^2 + h_g^2} - h_g$ , represents the distance the center of gravity must rise so that it is directly above point of rotation, A. At this position gravitational forces will assist in overturning the target. For most targets, point A may be assumed to be in the ground plane and directly below the outside vertical surface of the vehicle.

The work, W, done in overturning the target is

$$W = d_o \cdot (\text{weight of the vehicle, } w). \quad (1)$$

When a sufficient impulse is applied to the target rapidly, it will give the target an angular velocity,  $\omega$ , great enough to permit inertial forces to complete the overturning action. The angular velocity will be sufficient when the kinetic energy is greater than the work required from equation (1), where

$$KE = 1/2 I_A \omega^2. \quad (2)$$

The value  $I_A$  is the moment of inertia about point A and is given as

$$I_A = m \left( \frac{b^2 + h^2}{12} + c^2 \right) \quad (3)$$

where:

m = mass of the target

b = width of the target

h = height of the target

c = the transfer axis distance;  $c = d_o + h_g$ .

By equating the required work, W, with the kinetic energy and substituting equation (3) into (2), an expression for the required angular velocity,  $\omega$ , to overturn the target is obtained:

$$\omega = [2W/I_A]^{1/2} = \left[ \frac{2 d_o w}{I_A} \right]^{1/2}. \quad (4)$$

The required unit impulse, H, (psi-ms) required to produce this angular velocity is

$$H = \frac{1000 \cdot I_A \cdot \omega}{h_c \cdot (\text{presented area of the target})} \quad (5)$$

where  $h_c$  represents the height above the ground where the center of the blast pressure is applied.

The net loading concept was used in the analysis of the vehicular targets. The blast loading on the rear side of the target was subtracted from the reflected loading on the front surface to determine a net loading. Integration of the net loading function then determined the net reflected impulse imparted to the target.

### III. TEST PLAN

#### A. PLATE GLASS WINDOWS

The evaluation of plate glass fragment hazards requires quantitative data relative to the range of glass fragment sizes which may be produced from the breakage of plate glass windows under low pressure or marginal blast loading conditions.

The Dial Pack tests conducted during July and August 1970 provided an opportunity to secure such breakage data. The tests which were planned for Dial Pack recognized that it was important to determine the size of the plate glass fragments immediately after the primary window breakage and before secondary breakage takes place as the pieces strike each other or the surfaces below the window. It was anticipated that some glass pieces might be large and thus, secondary breakup might be a significant factor if the collection of the fragments was employed as the basic measurement technique. For this reason it was proposed that a unique photographic approach be used to determine fragment size. Particular emphasis was placed on determining the size of the largest fragments, since these present the greatest potential hazard when they fall on persons near windows.

The technique employed is indicated in Figure 2. Briefly stated, the technique employs a reflected grid system on the face of the window to make deflections of the glass and fracture patterns readily visible. Framing cameras operating at 400 and 1,000 frames per second adequately showed the action of greatest interest.

The test employed a 1/4-inch plate glass window which was 4 by 6 feet in size. The window was mounted in the front wall of a small structure 10 feet wide by 8 feet deep and 8 feet high which simulated any building in which a plate glass window might be located. This structure prevented any direct loading of the back surface of the glass by blast energy other than that which flowed through the broken window opening.

Two identical test exposures were set up for the main Dial Pack test, one at the 0.5 psi incident peak pressure level

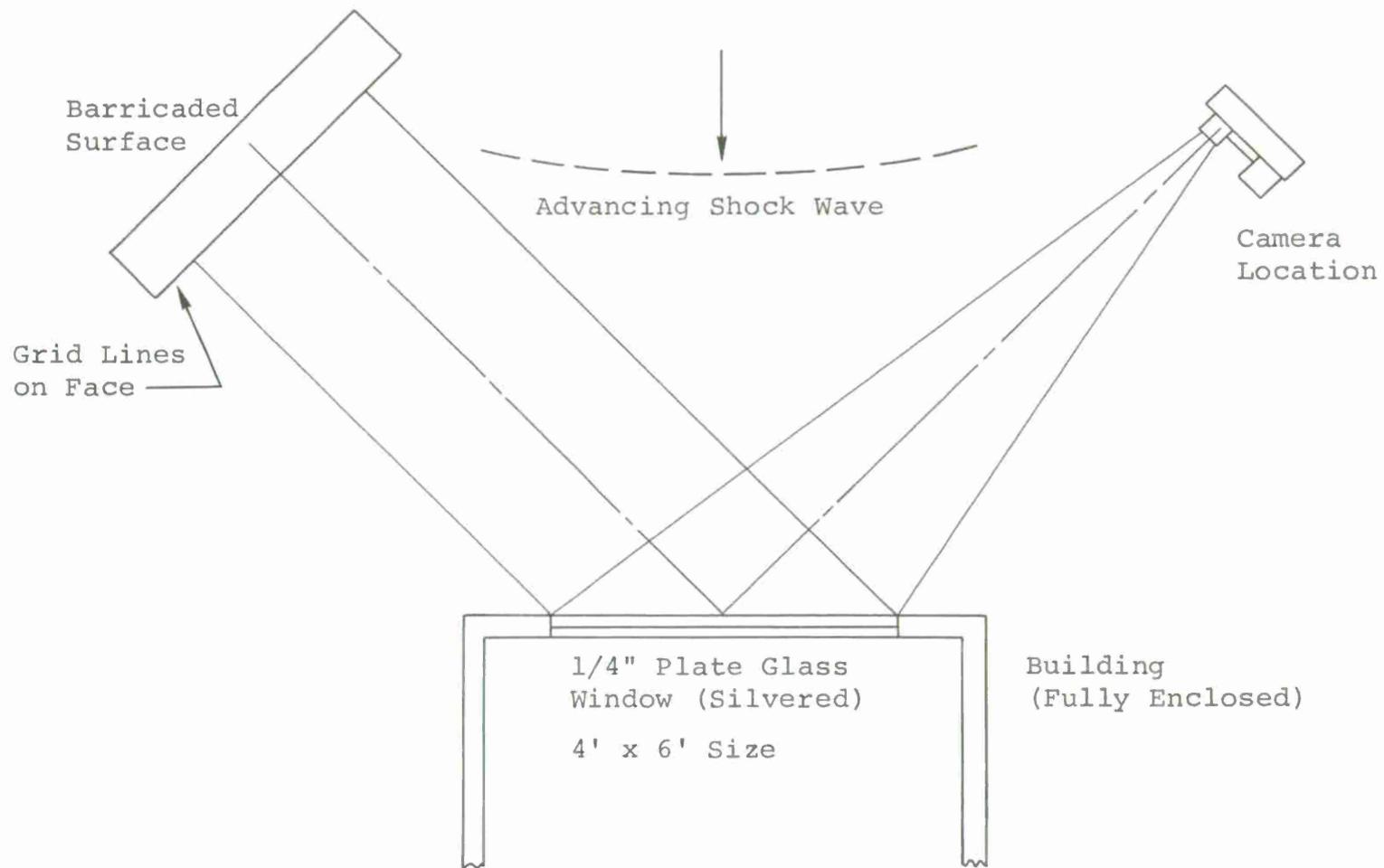


Figure 2. Test Arrangement for Observing Window Breakage and Resultant Glass Fragments

(about 6,800 feet from the one million-pound charge) and the other at the 0.8 psi incident peak pressure level (about 5,000 feet from this charge). These exposures were the ones indicated by the available data where threshold glass breakage was probable. The incident impulse values were anticipated as approximately 120 and 170 psi-ms respectively.

Photographic documentation was provided at each test position. To record the glass breakage, 16-mm motion picture cameras were used. One camera running at approximately 400 frames per second, and an additional camera running at about 1,000 frames per second, was used at each test position. Both cameras recorded similar data but the use of two cameras provided assurance that the needed information would be secured even if an equipment malfunction occurred during the test. Camera coverage was used as the primary means of securing data. No attempts were made to measure glass velocities, since these were expected to be quite low; however, the photographic record gives an indication of the initial direction and rate of motion of the glass pieces of greatest importance.

Glass fragments which fell near the test structure were collected and examined following the test. Many of these fragments may have been broken further by impacts with the ground, but some indication of the degree of secondary breakup was secured by an examination of these glass pieces. The available fragments were counted, measured, and weighed and observations recorded relative to the location from which the fragments were recovered.

Repeat window exposures were planned for the large scale blast directing experiment because of data loss in the main Dial Pack event. This exposure of the plate glass windows was made on August 6, 1970, in connection with experiment LN105. For this test, the small buildings were moved to new locations which were normal to the charge array. The closer building was located at 530 feet and the farther one at 850 feet. Both windows were face-on to the blast. All other aspects of the test setup were essentially the same as for the test on July 23. All cameras were started at -2.0 seconds. The arrangement of the cameras relative to the buildings is shown in Figures 3 and 4.

Cameras:

Fastax, 1000 fps, 50mm lens

Locam, 400 fps, 50mm lens

Time: -2.0 sec

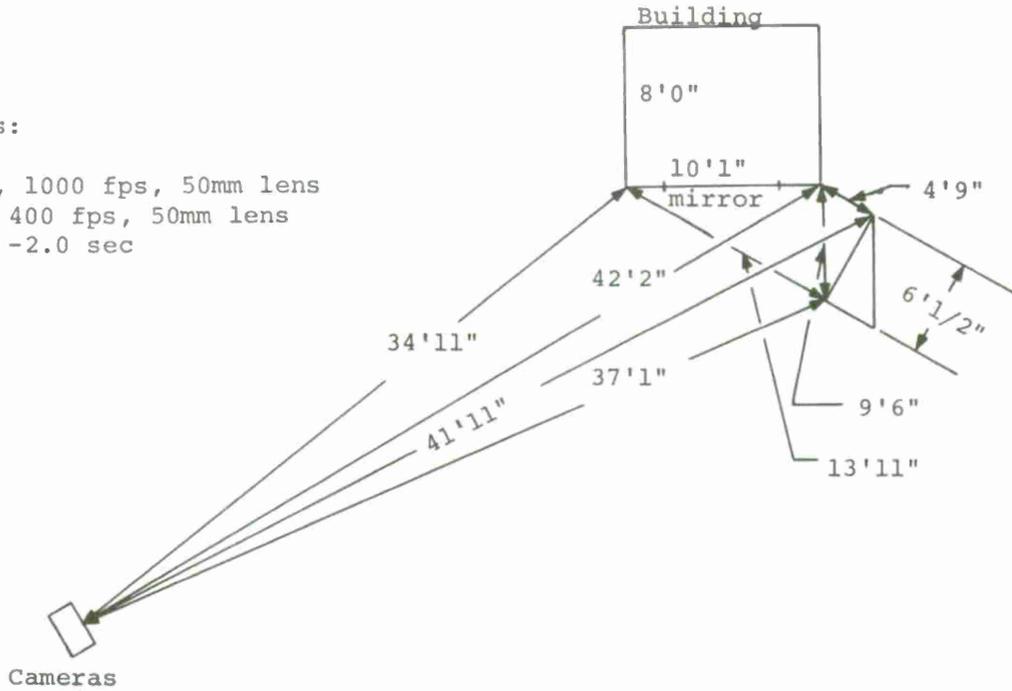


Figure 3. Plate Window Exposure Arrangement for 1.2 psi at 530 Feet.

Cameras:

Fastax, 1000 fps, 50mm lens

Locam, 500 fps, 25mm lens

Time: -2.0 sec

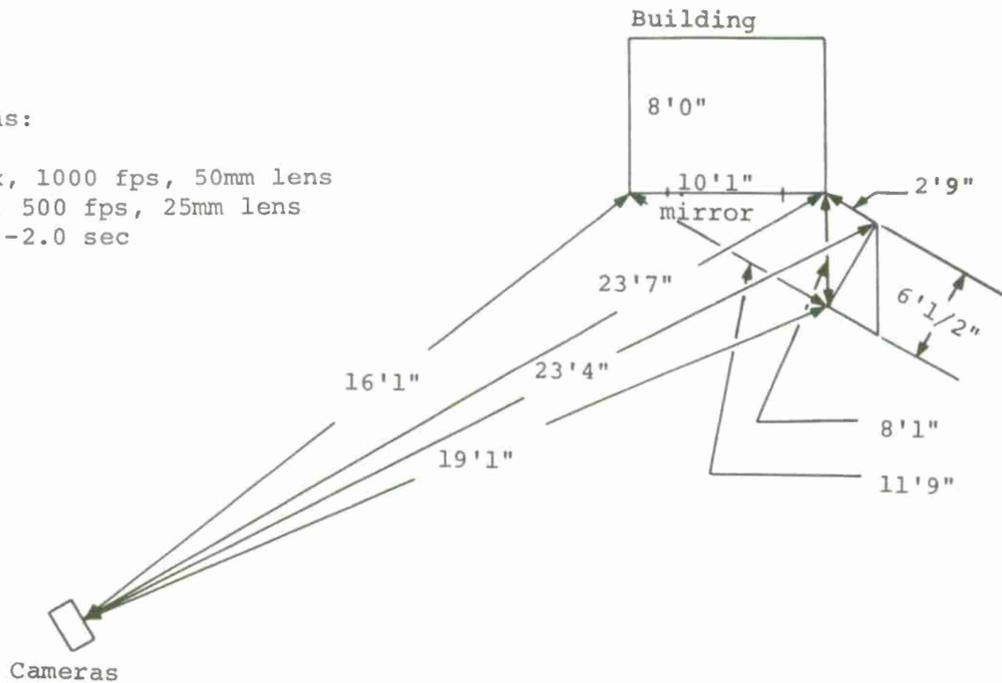


Figure 4. Plate Window Exposure Arrangement for 0.75 psi at 850 Feet.

Precise predictions of the blast pressure and impulse levels to be experienced by these locations were not possible because of the nature of the test. For this reason, somewhat higher pressure exposures were planned to insure that useful data would be obtained. The 530-foot location was selected to provide 1.2 psi with the actual weight of the total charge used as a basis for estimation. Similarly, the 850-foot location was selected to provide 0.75 psi. These pressure levels are approximately 50 percent higher than the exposures of the initial Dial Pack event. Positive duration and impulse were, of course, much less for this smaller charge.

Selfrecording BRL pressure gages were located at each position to determine the actual blast exposures. Figure 5 shows a photograph of the test site arrangement at the 1.2 psi exposure.

## B. VEHICLE EXPOSURES

### 1. U. S. Naval Weapons Center Tests

This test exposed two vehicles to the blast forces from a stack of fifteen 750-pound bombs. The vehicles were oriented in such a way as to present maximum surface to the blast wave and thus maximize the opportunity for the vehicles to be overturned. These tests were conducted at the Naval Weapons Center, China Lake, California. All test setup, photographic coverage, and other support work was provided by the staff of that facility. The two vehicles were a bus and a pickup with a camper body. The bus is shown in Figure 6 and the pickup-camper in Figure 7.

The bus was a school bus, body model T-334, Serial No. 36,868, manufactured in 1959 by the Blue Bird Body Company of Fort Valley, Georgia. It had a shipping weight of 15,490 pounds, a gross vehicle weight of 24,000 pounds, and held 44 passengers. The total length of the bus was 404 inches, width 96 inches, height 120 inches, and wheelbase 208 inches.

This bus had a flat floor which was 34 inches above the ground and passenger seats which were 16 inches above the floor. The front tires were size 10.00 x 20 and were spaced 90 inches from rim outer edge to rim outer edge. Rear tires

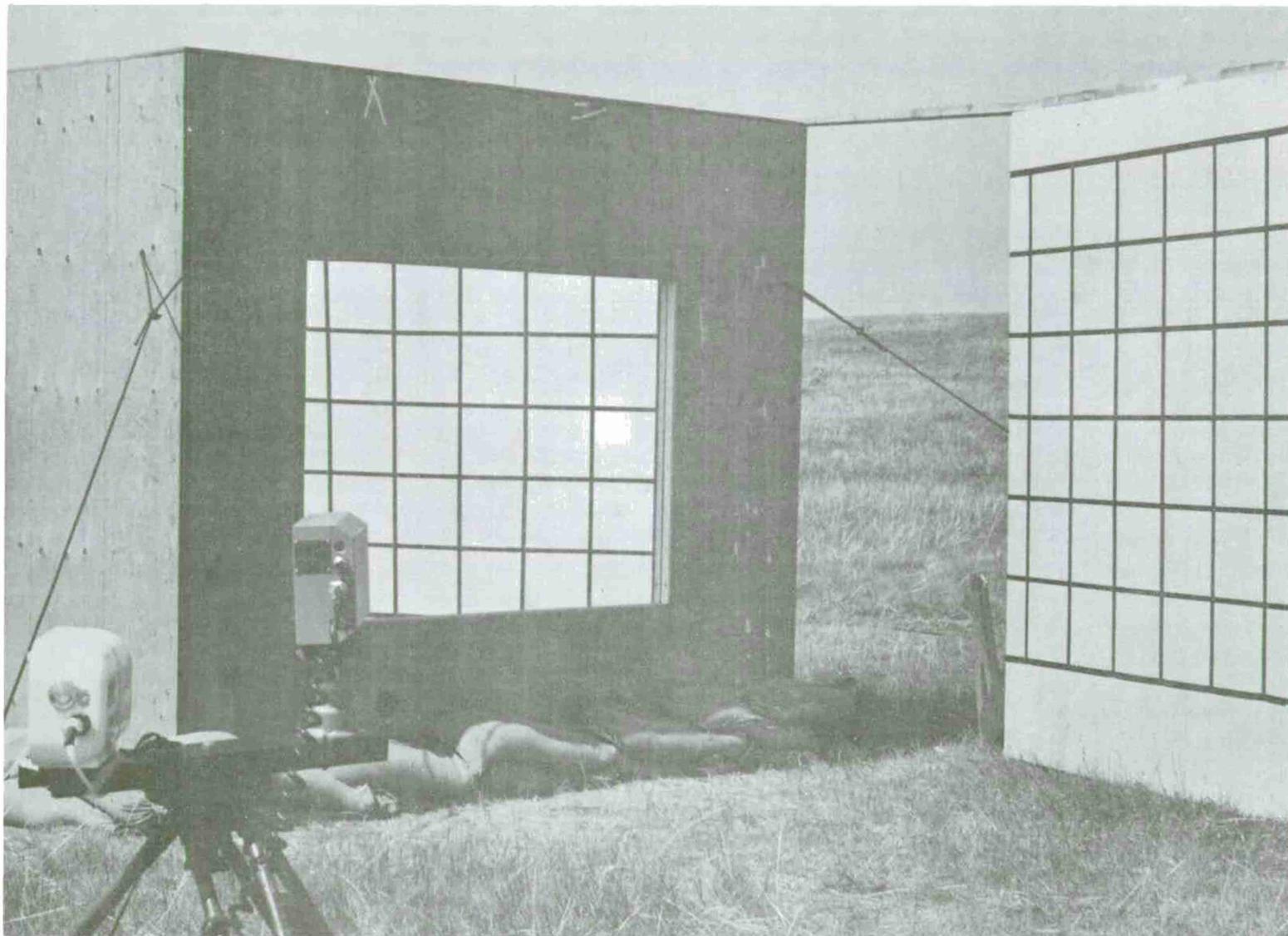


Figure 5. Plate Glass Window Test Site at 530 Feet. August 6, 1970.



Figure 6. The Bus Vehicle Set in Place Ready for the Test at China Lake.



Figure 7. The Pickup-Camper Vehicle Set in Place Ready for the Test at China Lake.

were dual and size 10.3 x 20. The outside rear tires were spaced three inches farther apart than the front tires.

The center of gravity of the empty bus was estimated to be 40 inches above the ground. The center of gravity of the bus filled with passengers was estimated to be 60 inches above the ground. The side area, with all windows closed, was estimated to be 40,000 square inches and the height of the center of pressure 64 inches.

The truck was a 1953 Dodge Cargo Truck, M-37, Model T-245, rated at 3/4-ton capacity with 4 x 4 drive. The truck was without engine but included all other essential components and weighed 5,000 pounds in its test condition.

The camper was made of plywood and sheet aluminum and was securely attached to the truck bed. Following the test it was determined that the truck bed had not been securely attached to the frame. The attachment bolts appear to have been in place, but the nuts that normally secure these bolts had been removed. The tires of this vehicle were size 9:00 x 16 and were spaced 68 inches from outside of the rim to the outside of the rim.

The center of gravity of this truck-camper combination was estimated to be 36 inches above the ground. The side area, with windows closed, was estimated to be 11,860 square inches and the height of the center of pressure 51 inches.

The fifteen M-117 bombs were positioned on the surface of the ground. They were stacked three high and five wide and were individually fuzed. The orientation of the bomb stack and the vehicles was such as to place the bus approximately 20 degrees off the nose of the bombs and the pickup-camper about 20 degrees off the tail of the stack.

These bombs contained a total of approximately 5,500 pounds of explosive. The explosive was Tritonal, aluminized TNT. The normal mixture for this explosive is 80 percent TNT and 20 percent aluminum. The air blast of Tritonal is approximately 110 percent of an equivalent quantity of TNT.

The bus was located at a distance of 205 feet from the charge and was exposed to an incident peak overpressure of about 8.5 psi and an incident impulse of 140 psi-ms. The pickup-camper was at a distance of 180 feet and was exposed to an incident peak pressure of about 9.2 psi and an incident impulse of 155 psi-ms. These distances were computed for the test vehicles previously described using the model of blast interaction. The model does not include a treatment of the effect of vehicle suspension systems upon the overturning action and thus implies that such effects are zero. Insight into the influence of the suspension system was an objective of these tests.

Primary instrumentation for these tests consisted of high-speed motion picture coverage of the blast interaction with the vehicles. The vehicles were viewed end-on so that the extent and rate of rotation might be viewed and measured. A stationary horizontal reference line was provided within the field of view for each vehicle and a linear scale placed on the end of the vehicle so that accurate dimensions and measurements of the motion would be easy to make on any frame of the motion picture film. Timing marks were placed on the film so that an accurate time scale would be available.

In addition to the high-speed motion picture coverage, other observations were made. These included still photographs of the vehicle, both before and after the exposure; marking and measurement of precise tire locations before and after the tests; observations relative to window breakage and distances that glass fragments were thrown; measurement of sheet metal and stiffener bending for both vehicles; damage to internal components such as seats; and estimates of vehicle behavior during the blast exposure. Attention was focused upon the damage caused by blast action even though many fragments perforated the vehicles. Fragment lethality or vulnerability evaluations were not objectives of these vehicle tests.

## 2. Dial Pack Test at Suffield, Alberta

This test exposed two vehicles to the blast forces from a 500 ton spherical TNT, surface burst, charge. The vehicles were oriented side-on to the blast to maximize the opportunity for the vehicles to be overturned. The tests were conducted in connection with the Dial Pack tests of July 1970 at the

Suffield Experiment Station, Ralston, Alberta, Canada. Two school buses were locally secured for this test. Figure 8 shows the larger bus exposed at the closer location and Figure 9 shows the small bus exposed at the present highway separation distance as specified by the DOD Ammunition and Explosives Safety Standards.

The larger bus was a 1951 Reo, Model F-122, 55-passenger school bus, Serial No. 502382. This bus weighed 12,400 pounds without occupants. Total length of this bus was 370 inches, width 96 inches, height 105 inches and wheelbase 220 inches.

The floor of this bus was 32 inches above the ground. Front tires were size 9:00 x 20 spaced 78 inches from rim outer edge to rim outer edge. The rear tires were dual size 9:00 x 20 and were 10 inches farther apart than the front ones.

The center of gravity of the empty bus was estimated to be 38 inches above the ground. The side area of the bus, with all windows in place and closed was estimated to be 28,000 square inches. With the windows removed and an adjustment made for the curved top of the bus, the effective side area was reduced to 21,800 square inches. The height of the center of pressure was estimated to be 53 inches with window area included or 49 inches with windows removed.

The smaller bus was a 1957 GMC, 20-passenger school bus. Maximum gross weight of this bus was shown as 8800 pounds with no net weight available. Net weight was estimated at 6500 pounds. The total length of this bus was 214 inches, width 81 inches, height 94 inches and wheelbase 141 inches.

The floor of this bus was 28 inches above the ground. Both front and rear tires were 7:00 x 17, single tires spaced 70 inches from rim outside edge to rim outside edge.

The explosive source for Event Dial Pack was a 500-ton TNT sphere, tangent to and above the ground surface. The sphere was built up of individual 32.6-pound, cast TNT blocks. Support for this charge consisted of special high-strength styrofoam blocks resting on four sheets of 3/4-inch Douglas fir plywood. This type of support ensured a mechanically clean air blast, protected the instruments, and reduced the blast



Figure 8. The Large Bus Set in Place at 1200 Feet From the 500 Ton Charge.



Figure 9. The Small Bus Set in Place at 3000 Feet From the 500 Ton Charge.

anomalies. This is the same configuration employed for the 500-ton Prairie Flat Event. This configuration produces an energy deposition ratio between the ground and air very nearly that of a nuclear detonation on the surface, and because crater ejecta are less extensive than for surface-hemispherical or partially-buried spherical charges of equivalent yield, the configuration is well suited for target response tests. The charge was detonated electrically at the center to provide a symmetrically expanding shock front.

The larger bus was located at a distance of 1200 feet from ground zero where the peak incident overpressure was predicted to be 7 psi and the predicted impulse 650 psi-ms. A dynamic pressure of about 1.2 psi was anticipated at this location.

The smaller bus was located at a distance of 3000 feet from ground zero which is the present highway separation distance. At 3000 feet a peak pressure of 1.7 psi was anticipated with the impulse 270 psi-ms and the dynamic pressure down to 0.06 psi.

Standard and high speed motion picture framing cameras were located at each site to provide a record of the shock interaction with the vehicles. These cameras were started by a separate Slave Console relay closure from the master control and held on for several seconds by auxiliary circuitry.

Reference marks were placed at the vehicles to provide a scale. Heavy black and yellow stripes one foot in length were used. These were heavy enough to show clearly in high-speed photographs. A reference line for the purpose of determining the angle of rotation of the vehicles was provided by a heavy vertical column that was unaffected by the blast. The reference line was also clearly visible in the high-speed photographs. A time base was provided and color film employed.

The appearance of the large bus from the camera's point of view is shown in Figure 10. The charge was to the right of the bus from this position so that the overturning action would be to the left and away from the reference pole. Note the headlights which were rigidly mounted at the front bumper. These were useful in defining bus motion when dust and fine grass pieces obscured other components of the vehicle.



Figure 10. Large Bus Viewed From the Camera Location.

#### IV. RESULTS

##### A. PLATE GLASS FRAGMENTATION

The plate glass window at the 530-foot site was broken but the window at 850 feet was not damaged by the blast. These results show that the exposures were very close to the threshold loading condition for this size of plate glass window.

All cameras operated properly on this test and good quality 16-mm photographs of the loading and breakage process were secured. Figures 11 and 12 show series of frames taken from the two film records of the 530-foot window test. These photographs were taken at 1000 and 400 frames per second for Figures 11 and 12 respectively. An analysis of the film records shows that the first cracking of the window took place 35 milliseconds after shock arrival and that the breaking process continued for an additional 10 milliseconds.

The deflection of this window was somewhat more complex than a simple oscillation prior to breakage. The center portion of the window appears to complete a full cycle at about 12 milliseconds after shock arrival; however, the surrounding glass has, at times, moved in different directions than the center of the window. At about +23 milliseconds the left side of the window appears to be well forward of its original position and starting to move in a rearward direction while the right side of the window is beginning to move back from the original position. The total deflection at this point in time is sufficient to allow the right side of the window to escape from the supporting moulding. This would have required a radial deflection of about 3 inches if simple window curvature were assumed. The window continues to be held at the top, bottom and left edges even after the right side escapes from its support. It is interesting that breakage did not occur until twelve more milliseconds elapsed and substantially more window motion had taken place. At breakage, or at least soon thereafter the left side of the window can be seen to be moving forward while the right side is moving backward or into the building.

An analysis of these film records has permitted a reasonable estimate of the initial size of most of the fragments produced

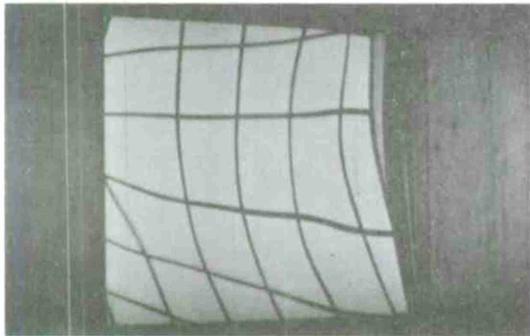
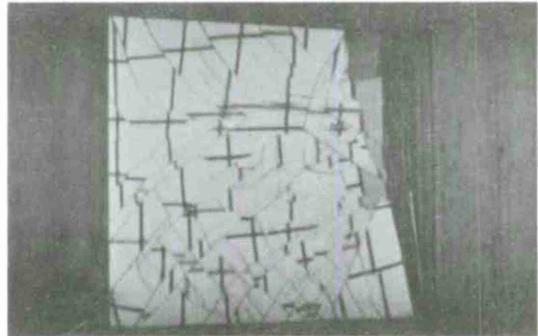
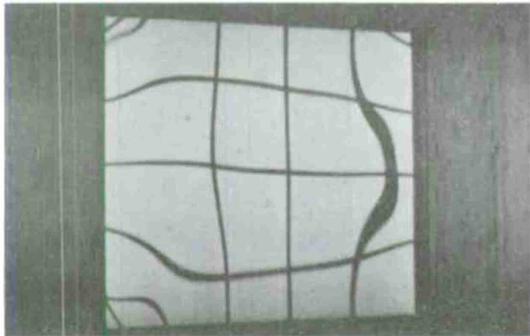
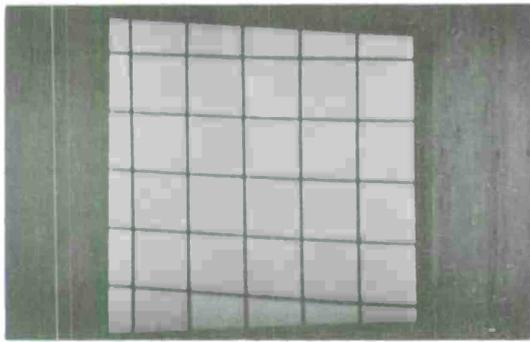


Figure 11. Selected Frames from the Film Record of Window Breakage Taken at 1,000 Frames/Second.

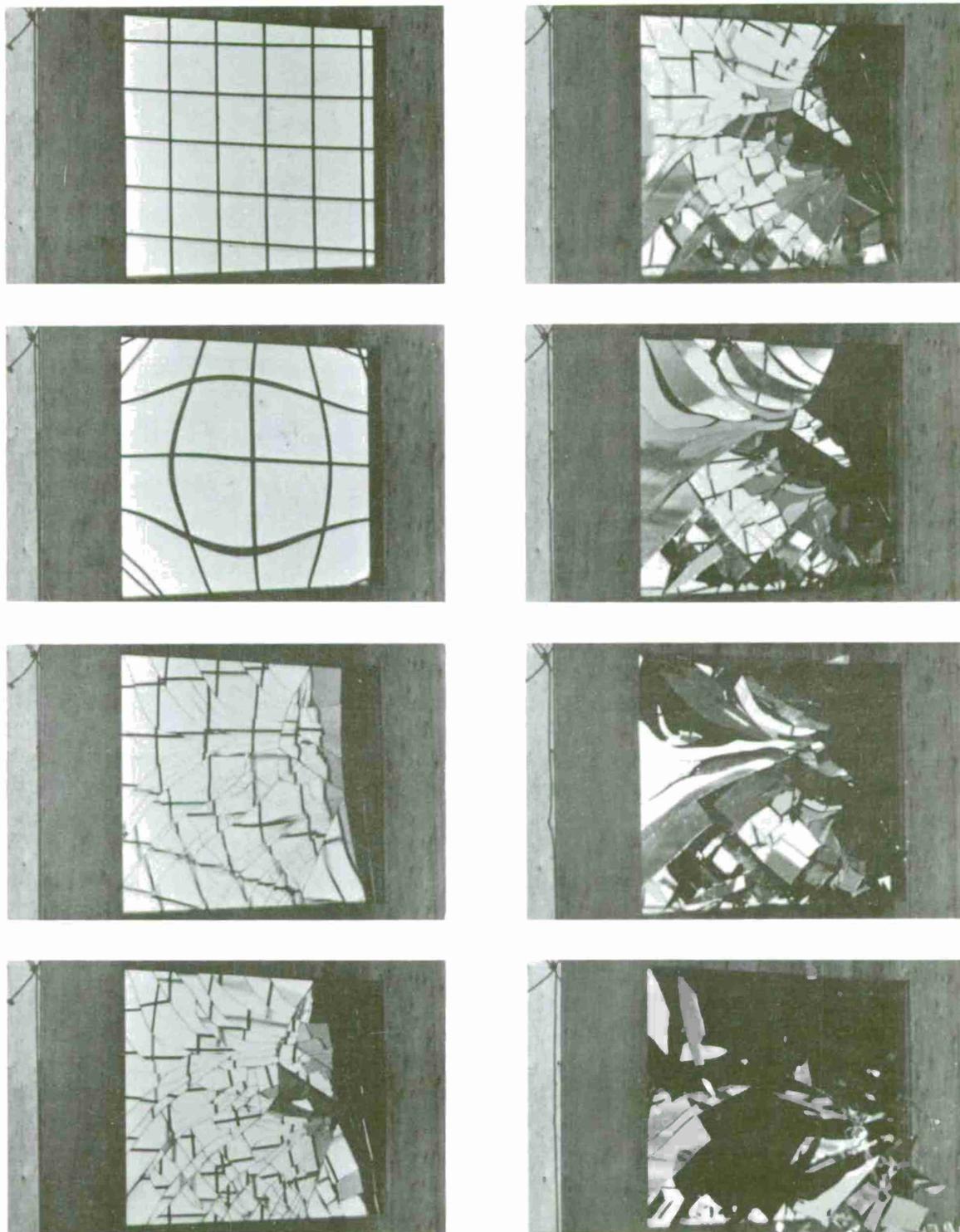


Figure 12. Selected Frames from the Film Record of Window Breakage Taken at 400 Frames/Second.

in this test of blast interaction with the window. Figure 13 provides a diagram of these fragments. At least for the larger fragments the shape and size of the fragments is clear and can be accurately drawn. The smaller fragments cannot be defined with as much accuracy since they cannot be seen as clearly and since each crack did not always produce a separate fragment. A number of fragments were found on the ground which had cracks within them but which had not been sufficiently fractured to separate. Figure 13 thus represents a best estimate of the discrete fragments into which the window was broken.

The total surface area of the window was 24 square feet thus measurements of these fragment areas were readily converted to fragment weights by the application of suitable conversion factors. Table III presents a listing of these fragment weights. No attempt was made to estimate to an accuracy of greater than  $\pm 10$  grams.

The larger fragments which were found on the ground following the test were also examined. Figure 14 shows the pile of fragments which landed outside the building and Figure 15 shows the fragments which went into the building. Very few fragments moved more than six feet forward of the building as they fell outside. Inside the building most fragments were within three feet of the front wall and none reached the back wall, only eight feet away. Approximately 60 percent of the fragment weight fell outside the building and 35 percent inside with 5 percent remaining in or on the window frame.

Table IV presents a listing of the fragment weights as recovered on the ground. These have been rounded to a precision of one gram.

Figure 16 provides a plot of the data in Tables III and IV. The separation between the two curves must be attributed to secondary breakup of fragments caused by striking the ground or striking other fragments.

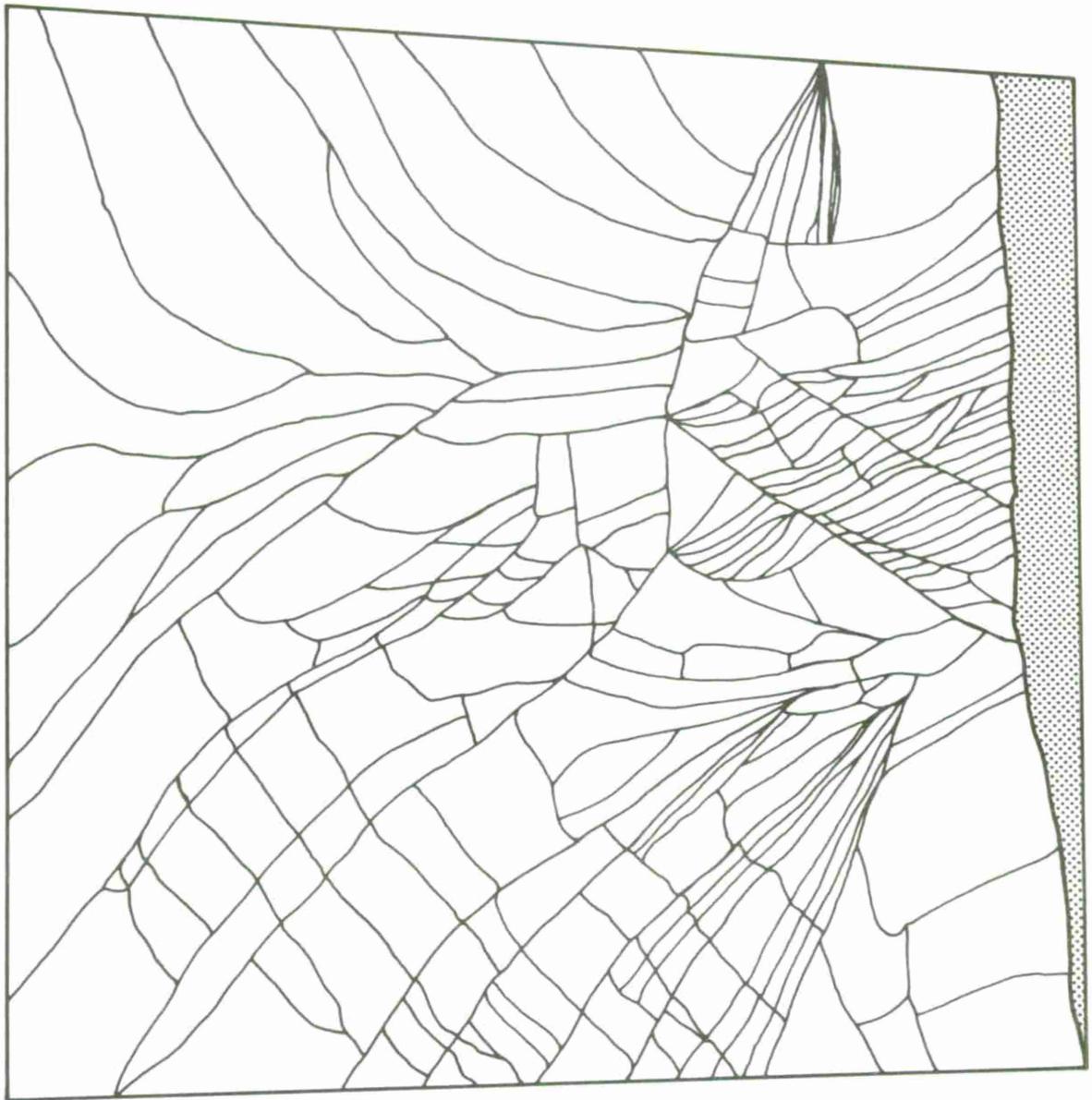


Figure 13. Fragments Produced by the Blast Loading of 4 Ft. by 6 Ft. Plate Glass Window.

Table III. Plate Glass Fragment Weight Array as Estimated From High Speed Photographs. Weight in Grams.

---

1,700	300	140	80	50	40	30
1,310	290	140	80	50	40	30
1,050	290	140	70	50	40	30
1,030	270	140	70	50	40	30
1,010	270	130	70	50	40	20
890	260	130	70	50	30	20
820	260	130	70	50	30	20
780	260	130	70	50	30	20
750	250	120	70	50	30	20
730	240	120	70	50	30	20
620	240	120	70	50	30	20
610	230	110	70	50	30	20
540	230	110	60	40	30	20
530	230	110	60	40	30	20
530	220	110	60	40	30	20
510	210	110	60	40	30	20
460	210	100	60	40	30	20
450	190	100	60	40	30	20
450	190	100	60	40	30	20
430	180	100	60	40	30	20
430	170	100	60	40	30	20
410	170	90	60	40	30	10
410	170	90	60	40	30	10
410	160	90	60	40	30	10
400	160	90	60	40	30	10
400	160	90	60	40	30	10
400	160	90	60	40	30	10
380	160	90	60	40	30	10
360	160	80	60	40	30	10
330	150	80	60	40	30	10
300	150	80	60	40	30	10
300	140	80	50	40	30	10

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Figure 14. Glass Fragment Distribution Outside the Structure.



Figure 15. Glass Fragment Distribution Inside the Structure.

Table IV. Plate Glass Fragment Weight Array as Measured Following the Test. Weight in Grams.

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1,504	295	193	129	107	10 @ 74 Av.
1,110	291	183	123	102	10 @ 73 Av.
951	281	182	122	102	10 @ 70 Av.
865	281	163	121	102	10 @ 59 Av.
693	276	162	119	101	10 @ 57 Av.
645	259	161	119	100	10 @ 50 Av.
637	258	159	118	95	10 @ 43 Av.
582	256	157	117	94	10 @ 43 Av.
517	255	148	116	94	10 @ 42 Av.
513	246	144	115	94	10 @ 40 Av.
484	242	144	115	91	10 @ 39 Av.
462	236	142	114	90	10 @ 35 Av.
416	211	141	114	88	10 @ 33 Av.
391	200	141	114	86	10 @ 31 Av.
390	195	140	111	85	10 @ 28 Av.
349	194	140	110	84	10 @ 24 Av.
331	194	140	109	80	
311	193	134	109	78	

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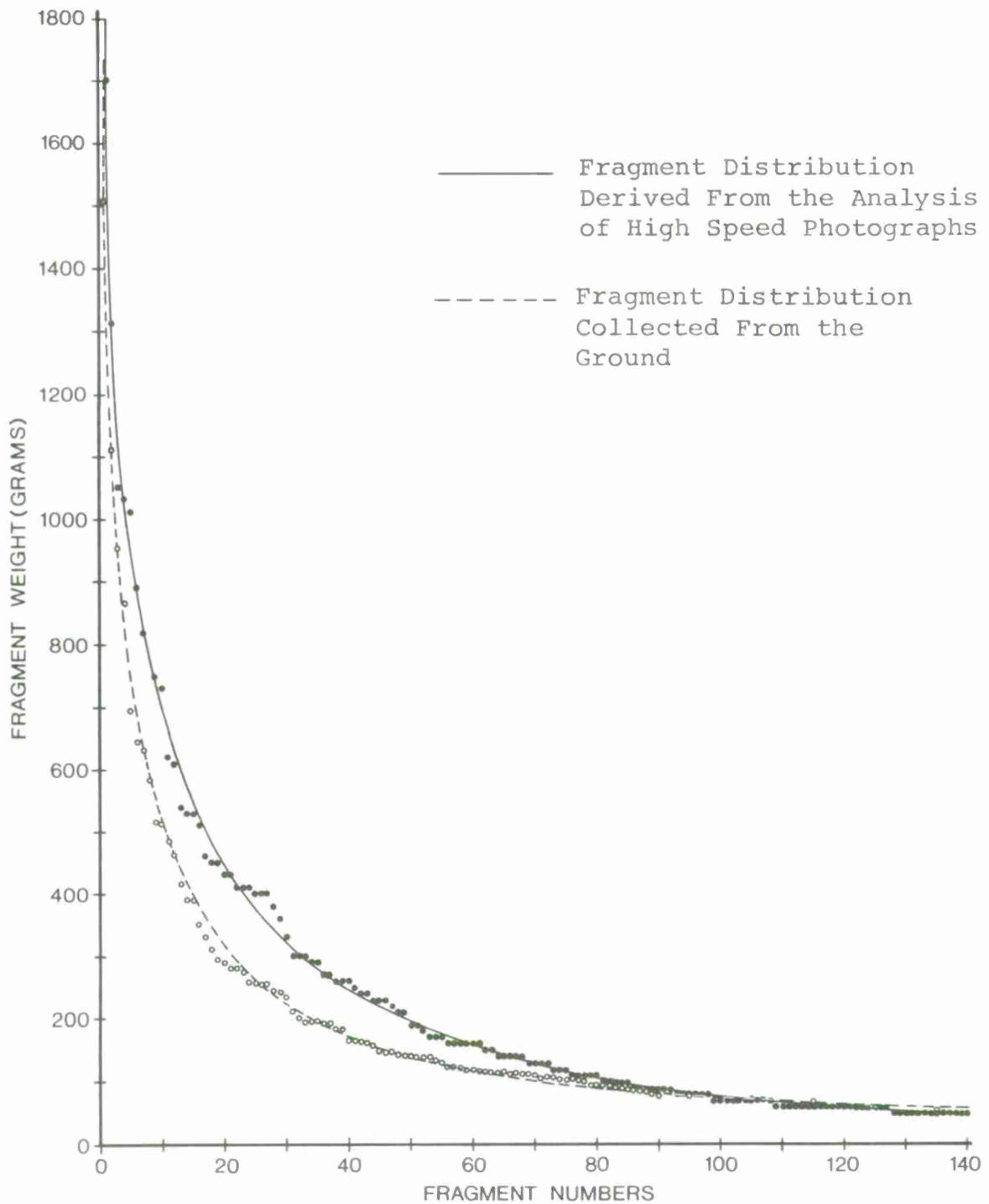


Figure 16. Cumulative Fragment Weight Distributions Produced by Threshold Blast Loading of a 4 Ft. by 6 Ft. Plate Glass Window 1/4 inch Thick.

## B. VEHICLE OVERTURNING

### 1. China Lake Tests

Only the camper body-truck bed unit was actually overturned in these tests. There is substantial evidence to indicate that both vehicles were severely rocked by the blast energy and that the near-side wheels may have actually been lifted off the ground, but both the bus and the truck came to rest in an upright position as shown by Figures 17 and 18.

Post test examination indicated that the truck bed had not been securely bolted to the truck frame. An analysis of the potential for overturning the camper body as a separate unit indicates that the observed action would have been predicted. The weight of this unit has been estimated at 700 pounds with a center of gravity 17.3 inches above the frame members and 30 inches laterally from the overturning axis. The computed net impulse required to overturn such a unit is 50 psi-ms, while the actual impulse, from this test at 180 feet, on the camper body was approximately 150 psi-ms. The observed overturning action for this unit would have been much more severe had it not been for the binding, bending, and general restraint provided by the attachment bolts even though they were without nuts. A number of these bolts were seriously bent following the test. Other factors tending to reduce the overturning action for the camper included a 5- to 10-knot wind and poor blast coupling due to deformation and destruction of the near side of the camper by the blast wave.

Both the bus and the pickup were moved laterally by the blast wave. The bus was moved 3 to 4 inches at the front and 7 to 8 inches at the rear. The pickup was moved 5 inches at the front and 4 inches at the rear.

An examination of the earth surface in the vicinity of the tires showed that the tires which were on the far side of the blast had slid along the surface and had dug into the soil at the far edge to a significant extent. Tires on the near side of the vehicle left no marks at all and may have actually been above the surface as the lateral motion took place. This would indicate that the vehicles may have approached an overturning condition but then fell back to their original posi-



Figure 17. Damaged Bus Following the Test at China Lake.

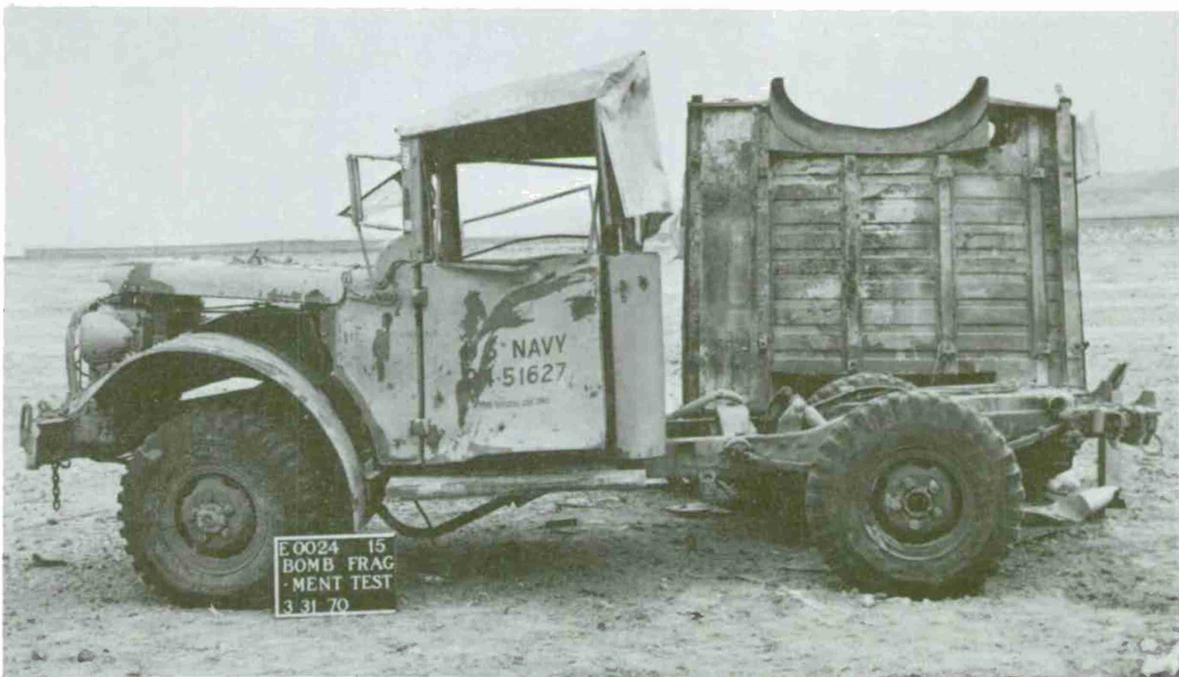


Figure 18. Damaged Pickup-Camper Following the Test at China Lake.

tion after having slid sideways the distances which have been indicated.

No further data relative to the extent of the overturning action is available, since the high-speed camera installed by the NWC staff to secure this information did not run during the test.

Other damage to the vehicles which is directly attributable to the blast includes glass breakage, sheet metal deformation, wall rib or stiffener bending, and seat movement.

All windows in both vehicles were broken, although it is not clear that all were broken by the blast, since many steel fragments went through the windows. It is probable that all of the larger windows would have been broken without fragment impacts; however, many of the smaller windows remained in their frames and might have been undamaged without the bomb fragment shower. Most glass fragments came to rest within 50 feet of the vehicles and some large pieces of glass remained in the frame or very close to it. All glass was of the laminated safety type and thus large pieces were held together by the center layer of plastic. One piece of glass, having an area of about 40 square inches, was found at a distance of 110 feet. No glass was found beyond this distance. Much of the glass from the near side of the vehicle remained within the vehicle with pieces between 3 square inches and 1 square foot most common.

The sheet metal of the bus was steel, about 0.030 inch thick. Surface bending of this steel is evident in Figure 17. The sheet metal of the truck was heavier, except for the homemade cab, and was damaged less extensively. Maximum deformation of the bus sidewall was 7 to 8 inches on the near side. The far side of the bus was bulged outward only slightly between the vertical stiffeners. The sheet metal below the floor line was bent outward as much as 3 to 4 inches in some locations on the far side of the bus. The bus door was torn loose at the hinge attachment.

Wall rib or stiffener bending was significant for both the bus and the camper unit. The bus sidewall was stiffened with steel hat sections of 0.062-inch thick material. These were

about 75 inches long and had a total width of 3 inches, with the box of the hat section 1.6 inches wide by 1.1 inches deep. These were fixed at the top and semifixed at the bottom and were on 28-inch centers. These ribs on the near side of the bus were bent inward a maximum of 7 to 8 inches along the center portion of the bus. The stiffeners on the far side of the bus were not damaged.

The stiffeners of the camper unit were of 1-inch square steel tubing having a wall thickness of about 0.050 inch. These were located on approximately 14-inch centers. Most of these members were bent 6 to 10 inches at the center of their span and the tack welds that held them to other frame members were, frequently broken. Some of this damage may be attributable to the impact of the overturning action; however, it appears that a substantial portion of the bending took place before the impact with the ground. Most of the light aluminum skin and plywood on the side toward the blast was blown loose from the frame and into the unit.

The seats on the near side of the bus were torn loose from the floor and generally overturned. These seats had been located only 2 inches from the sidewall and thus the inward motion of the sidewall moved the seats about 5 to 6 inches in a lateral direction. The seats had no passenger-simulating mass on them, and half of the seats had been removed prior to the test. It is possible that seat movement would have been substantially less if all seats had been present and at least part of them "occupied" by a reasonable mass.

Figure 17 shows a seat cushion outside the bus. This cushion was not thrown out by the blast but had been removed immediately after the test because of a smoldering fire in the padding. Apparently friction between a fragment and the seat springs had been sufficient to ignite this seat. There is no significance to its location in Figure 17.

## 2. Dial Pack Tests

### a. 1200-foot Site

The bus at this location received substantial damage and was severely rocked by the blast but did not overturn. The tire

marks on the downstream side of the bus, in damp soil, indicate that the bus was rotated in that direction to a considerable degree. Tires on the near side of the bus (toward the blast) made no visible sliding marks and these wheels may have been off the ground for some time.

A careful examination of the cameras and controls at this site indicated that the camera mounting performed well; the sandbag protection for the cameras performed well; all plugs and connections were undisturbed by the blast and in place; the cameras apparently started on signal as planned and ran for a brief period of time. A discontinuity in line power caused the control relay at this position to open, since the line voltage had been used to lock in the control relay. This opening of the control relay by the brief power drop caused the cameras to be turned off prematurely.

The film from this location was processed and the results analyzed to produce the evidence of overturning shown in Figure 19.

An examination of this vehicle following the test provided specific details relative to the direct blast damage caused to this bus.

The front wheels were moved sideways a distance of 8 inches and forward about 2 inches. The hood was blown 35 feet downstream and forward at about a 60 degree angle.

Glass fragments were found forward of the front of the bus; one window was found 90 feet back toward ground zero from the bus; and five or six other windows were on the side toward the blast. There were many windows scattered out behind the bus, and some were found as far as 90 feet downstream from the bus. Some glass fragments were found as far as 115 feet downstream from the bus; however, the main glass and frame debris was within 25 feet of the bus.

The rear wheels of the bus were displaced sideways 11 inches; all windows were broken out of the vehicle except for one small one on the right front by the door which was not even cracked. The three small windows in the door itself were only cracked and not removed. The fourth window in the door was blown out.

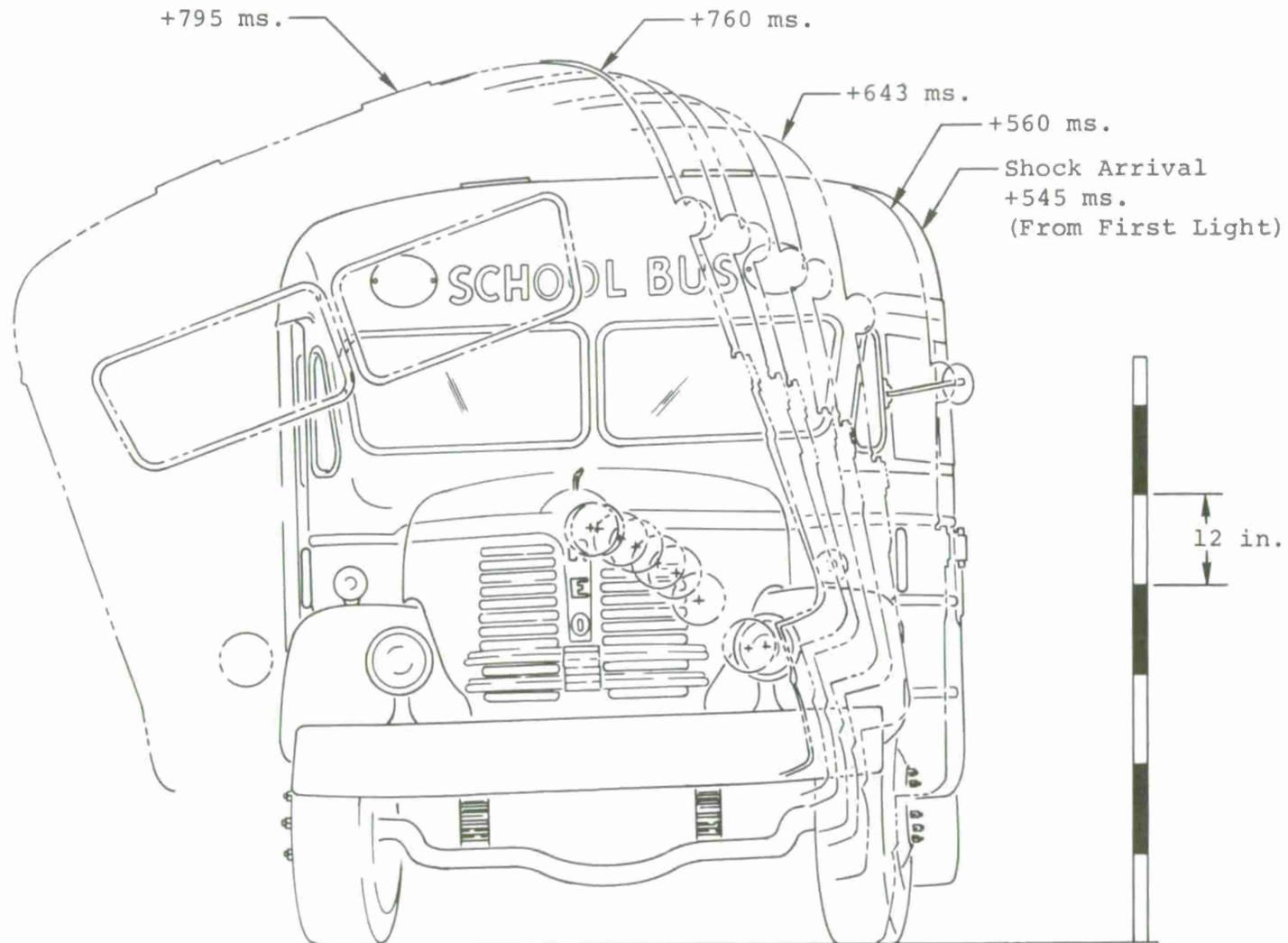


Figure 19. Bus Overturning Motion as Derived From the Analysis of High Speed Photographs.

One of the seats inside the bus was torn loose from the floor; however, this one appeared to have been seriously rusted prior to the test, the other seat frames remained attached and in place. About half of the seat cushions were still in their original location, the others had been tossed about. The luggage rack on the far side of the bus was torn loose, but on the near side (the side toward the blast) the rack was in place with the exception of one brace or hanger.

Glass and other fragments seemed to have done rather minimal damage to seat cushions and upholstery; there were a couple of seats, however, where fragments of some sort had chopped into the upholstery. The glass from the near side windows appears to have generally moved straight across the bus and hit the far side without much rotation or tipping. In some cases the metal panels on the far side of the bus appear to be bulged, which may be due to these impacts. It also appeared that the seat cushions themselves shifted against the side wall rather heavily and this caused some of the deformation of the sheet metal on the far side of the bus, near the seats.

The entry doors stayed on the bus but were slightly jammed and deformed, making them difficult to open.

The carburetor air cleaner was blown off as were a few other relatively loose components, otherwise the engine appeared to be undamaged. The radiator hoses and wiring were still intact. The front headlights were undamaged, as were the front red flashing school bus lights; their plastic lenses were in good condition.

The near side of the bus dented in 3 to 6 inches and was generally racked away from the blast, the top half of the bus having been pushed sideways as much as a foot. All the tires survived in good condition.

The lower part of the sheet metal on the downstream side of the bus was bent outward, anywhere from 1 to 5 inches. This appeared to have been done as the bus was tipped up and the blast came underneath and pushed on this metal. The rear tire skirt, a sheet metal piece approximately 6 inches wide was intact on the downstream side and pushed out slightly;

a similar skirt on the upstream side of the bus was blown in against the tire and detached.

Figure 20 shows the imprint of the rear tire sidewall which was made by the partial rotation and depression of the bus. The slight rib on the side of the tire made the rectangular groove in the compacted soil. The soil was compressed and smoothed by the upper portion of the tire sidewall to a considerable extent but no rim marks were visible on the ground. It must, therefore, be concluded that the rim did not reach the ground. Figure 21 shows the appearance of the opposite or upstream tire and ground surface following the blast. Figures 22 and 23 show the general extent of sheet metal damage to this bus.

b. 3000-foot Site

The bus at this location received very light damage and was not significantly moved from its initial pre-test position in any way. Only about half of the windows on the near side of the bus were cracked. Only one window on the near side was broken out completely and the frame moved out with this one. The windshield and rear window were the two largest pieces of glass in this bus and both were severely cracked and blown into the bus. These windows remained as very large pieces of glass inside the bus. The windshield was in two main pieces (each piece about 17 by 35 inches) and was three-layered safety glass. These windshield pieces were mounted in a rubber strip. The rubber strip overlapped the sheet metal of the front of the body by approximately 1/2 inch and overlapped the glass surface by approximately 1/4 inch. The rubber stripping was entirely pulled loose, but was completely intact except for one break in the center of the strip, where the two pieces came together. A joining strip which was approximately 1 inch wide was torn loose at the top. This mounting strip could be reinserted to install new glass by just gluing the one broken spot.

The rear window was damaged similarly; this piece of glass was approximately 19 by 27 inches and the rubber strip overlapped the sheet metal by something less than 1/2 inch and overlapped the glass approximately 1/4 inch.

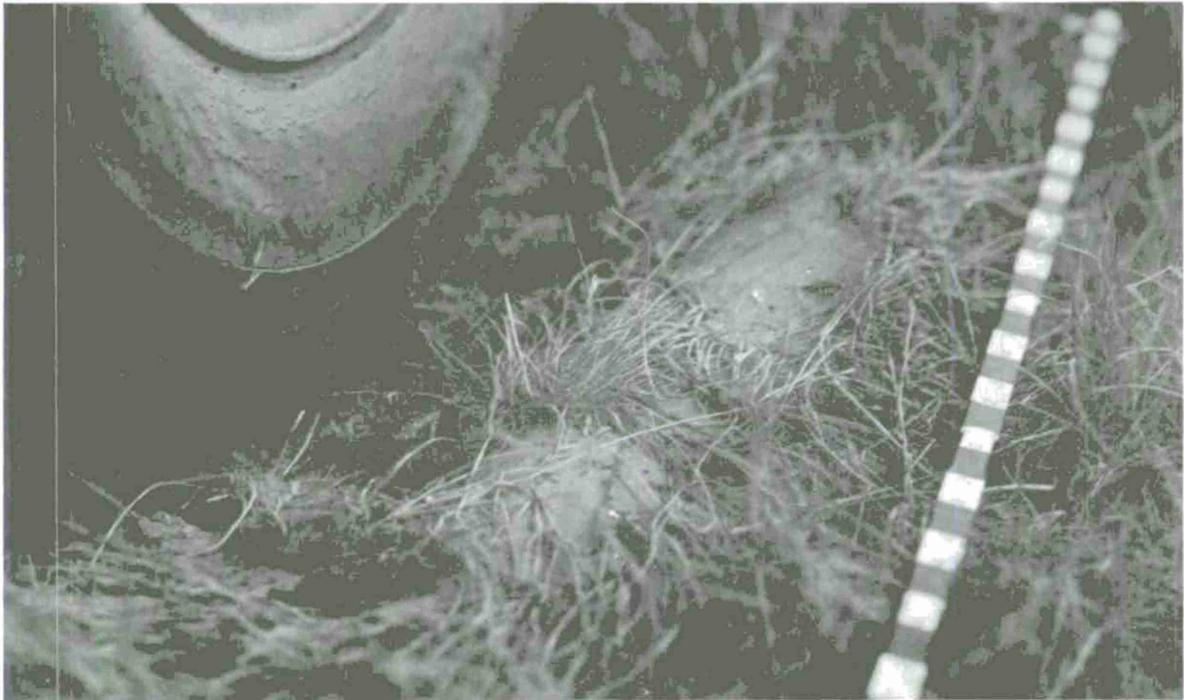


Figure 20. Tire Print in the Soil Following Bus Rotation.



Figure 21. Up-Stream Tire and Soil Following Bus Rotation.



Figure 22. Damage to the Large Bus Following the Dial Pack Test - Side View.

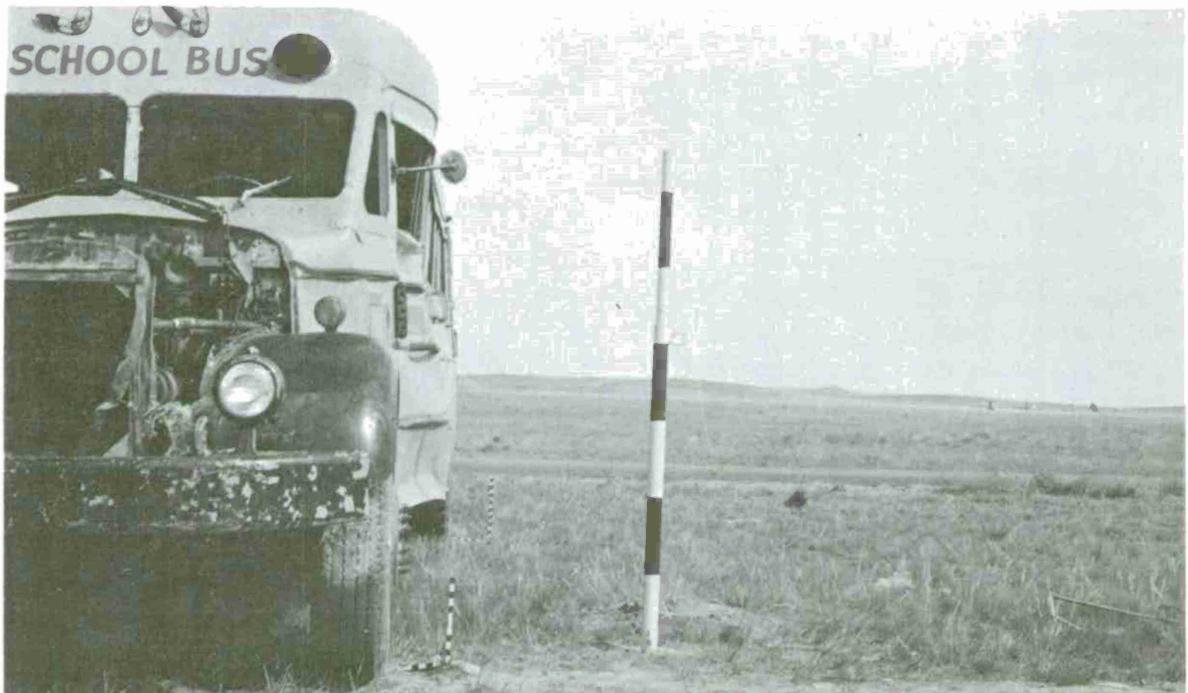


Figure 23. Damage to the Large Bus Following the Dial Pack Test - Front View.

One of the windows on the near side was blown out, frame and all; however, the glass was retained in the frame and only cracked. Four of the other windows in the near side were cracked, but the glass was intact and a fifth one of the regular side windows was undamaged by the blast. The small window on the blast side at the back of the bus was also undamaged by the blast. One of the two windows in the door was undamaged by the blast, the other one was cracked but not knocked loose.

There was no other blast damage to the bus. The far side windows were undamaged, even one that was previously cracked was not further cracked by the blast. There was no sheet metal bending except for some slight bending of the front door and this could be bent back rather easily. The bus was started and driven away in a completely normal fashion.

## V. DISCUSSION OF RESULTS

### A. PLATE GLASS FRAGMENTATION

These data represent the only known instance of plate glass exposure to low levels of blast energy in which the fragment size distribution has been fully documented. While the precision of these data is not as high as might be wished, it is believed to be well within plus or minus ten percent for all of the fragments larger than about 25 grams. It is believed to be substantially better for the larger fragments which are of greatest interest to safety considerations involving falling glass pieces.

The ground surface to which these glass fragments fell was, in general, very soft. A significant layer of grass was present and the soil was generally fine textured and sandy. This undoubtedly did much to minimize the secondary breaking of glass pieces as they struck the ground. It will be noted from Figure 14, however, that many fragments landed on top of other fragments and much of the secondary breakup must surely have been derived from these impacts. If the fragments had fallen onto hard clay or concrete the secondary breakup would have been much greater.

The incident peak pressure to which this window was subjected was determined to be 1.09 psi and the incident impulse 26.94 psi-ms. These data were secured from a BRL self recording gage located at the ground surface and to the side of the building. At the 850-foot location where the window was undamaged, the peak pressure was measured as 0.65 psi and the impulse was 18.46 psi-ms. The reflected pressure levels to which these windows were subjected were 2.26 psi and 1.33 psi respectively. Positive duration at the 530-foot site was 52 ms and at the 850-foot site, 65 ms. These window exposure are summarized in Figure 24.

These blast data indicate that the exposures at these distances, from the directed blast array, were less than the exposures anticipated from a 4000-pound surface burst charge. The net explosive weight of the 62 charges in the actual array was 4,026 pounds. Table V provides a comparison between the experimental values and an idealized 4000 pound surface burst.

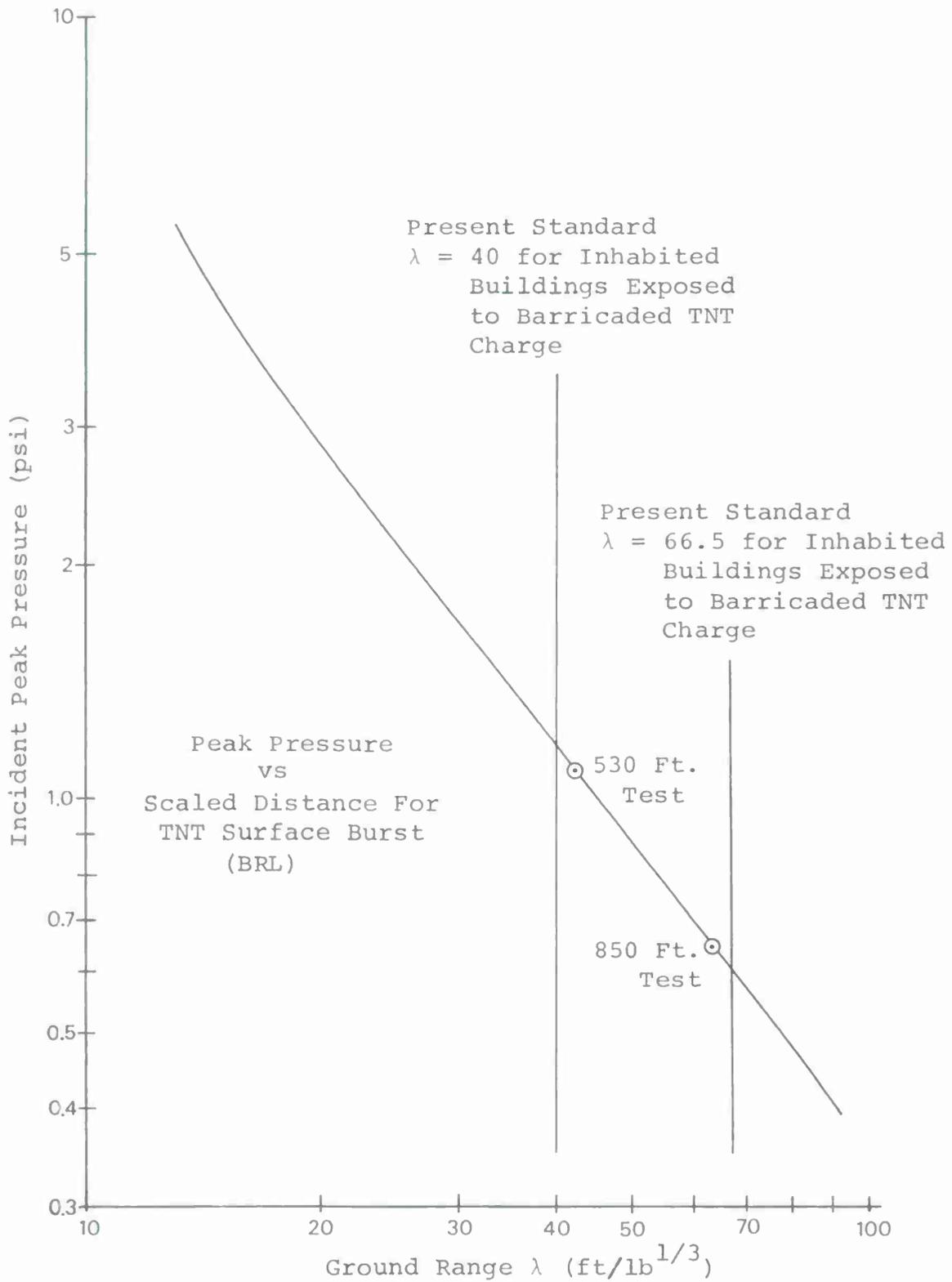


Figure 24. Plate Glass Window Exposures of the Dial Pack Directed Blast Test.

*see window  
sheet for  
steps  
attached to  
window*

Table V. A comparison of Blast Properties for the Test Locations.

Distance and Charge Type	Peak Pressure (psi)	Positive Duration (ms)	Positive Impulse (psi-ms)
530 ft. (blast array)	1.09*	52	27
530 ft. (4000 lb surface)	1.5	64	41
850 ft. (blast array)	.65**	65	18
850 ft. (4000 lb surface)	.86	82	26

\* Equal to  $\lambda$  42 for 2300 lbs. TNT, surface burst at 530 ft.

\*\* Equal to  $\lambda$  63 for 2200 lbs. TNT, surface burst at 850 ft.

The forward velocity of all fragments was essentially zero as was expected for these blast loading conditions. Had the positive duration been longer, a more significant forward velocity vector would have been anticipated.

The velocities which these glass fragments might attain due to the acceleration of gravity is not known with precision. The presented area of the larger fragments can vary by at least an order of magnitude depending upon the orientation of the fragment. Thus the effect of air drag variations can be very significant in determining actual acceleration rates.

The edges of the broken fragments were observed to be very sharp in many instances and it would appear that such fragments could cause serious cuts even at low velocities when the fragment struck edge on.

An examination of the films of the shock interaction with the window located at 850 feet, which was unbroken, indicated that more than simple vibratory motion was involved in its response to the blast wave. While the glass plate can be seen vibrating to alternately concave and convex configurations it never is really restored to a flat surface between these extremes. The major vibration periods are not all of the same duration which further indicates a complex or compound vibrational phenomena.

The time from shock arrival to the end of the first quarter period (maximum concave curvature) is observed to be about 26 ms. The next half period (to the position of maximum convex curvature) takes an additional 42 ms. To complete the first full period required an additional 37 ms for a total of 105 ms from shock arrival through the first full cycle. The plate is under a positive loading for most of this cycle but does receive a slight negative loading during the last quarter period. This may account for the longer duration of this quarter. Subsequent full cycles were measured from the 3/4 cycle point since the maximum convex image was most easily defined. The second cycle was thus completed in only 62 ms; the third took 95 ms; the fourth 82; the fifth 86; the sixth 77 and the seventh 76. By the seventh cycle the amplitude had diminished substantially; however, a pattern of long and short cycles seems quite clear. No ready explanation for this type of behavior is available; however, it may relate to the long and short dimensions of the rectangular window. An investigation into the various parameters controlling this sort of vibratory motion is beyond the scope of the present effort although these data may be useful to those who are developing models of such systems.

#### B. VEHICLE RESPONSE TO BLAST

The results obtained in these tests of vehicle response to blast indicate that overturning is less of a hazard to large vehicles such as buses than had been predicted by early estimates. Overturning is still more of a threat, however, than a significant lateral motion. The exposure conditions for the buses in the Dial Pack 500 ton TNT test are summarized in Figure 25.

Two modifications to the model of blast interaction with a bus are needed to accurately reflect the behavior of the bus in response to blast loading. First the window area should be subtracted from the effective side area of the bus since the windows fail soon after shock arrival and do not transmit the energy they receive to the body of the bus effectively. The windows of the large bus were broken and moving out of their frames by 20 ms after shock arrival. The large windows of the small bus failed similarly. Second, some factor repre-

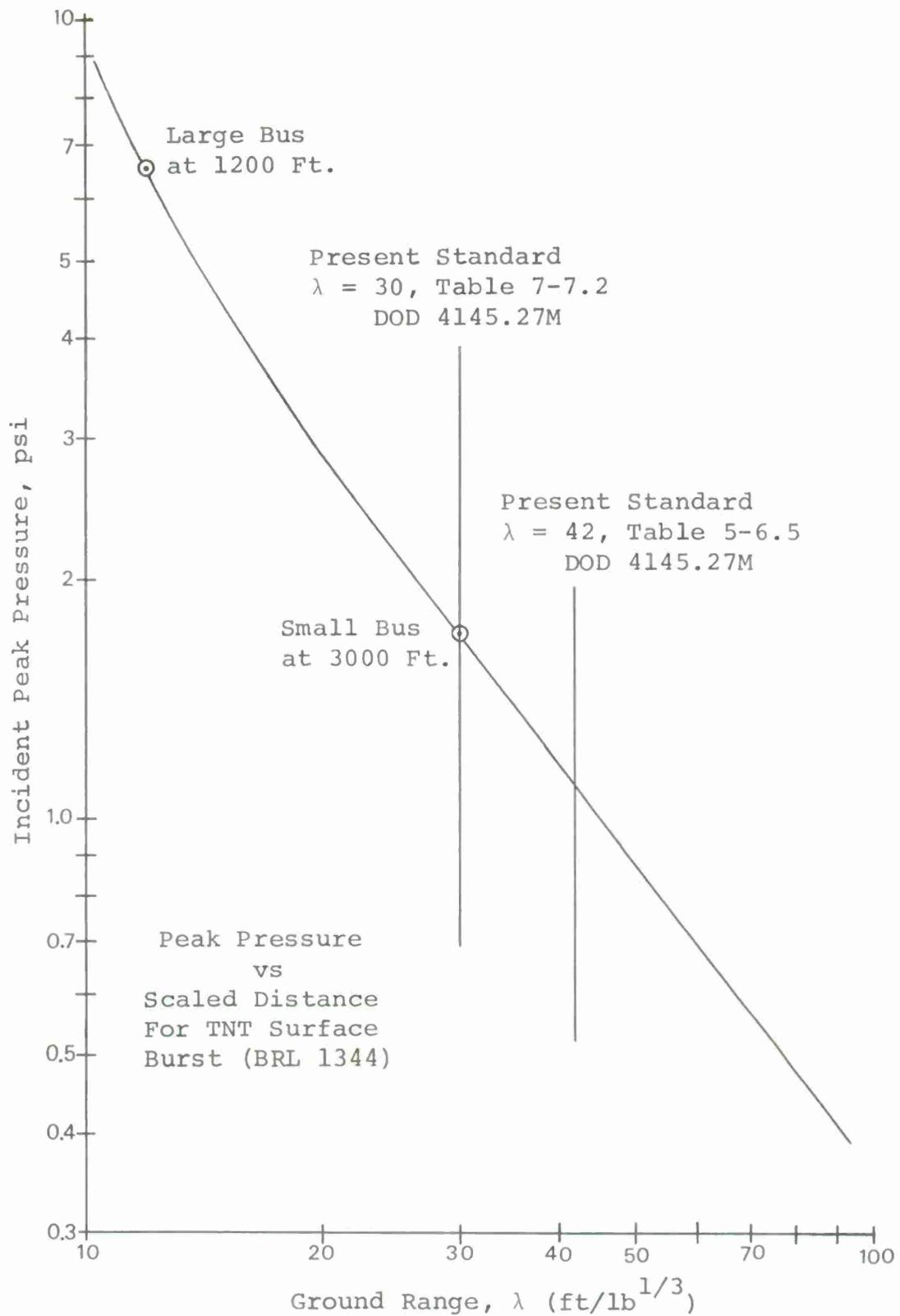


Figure 25. Bus Vehicle Exposures in the Dial Pack 500 Ton TNT test.

senting the bus suspension system needs to be incorporated into the model. The net effect of the suspension system appears to have retarded overturning in these tests.

The springs can affect the overturning in several ways: The springs can store energy through compression of the farside spring and extension of the one on the near side. This energy can, under favorable circumstances, be used to restore the bus to an upright position. Further, the springs tend to isolate the chassis of the bus from the wheels and axles. Thus the chassis can rotate to a considerable degree while the wheels and axles tend to remain stationary. Since the springs are much closer together than the wheels, rotation of the chassis alone will be in a much smaller arc. If the center of gravity of the chassis were defined separately it would appear much easier to get this vehicle component to rotate past the neutral point where gravity can assist in the overturning action. Usually, before a condition is reached where the chassis has passed this point, the undercarriage must be "pulled" along or the restoring process will begin due to the energy stored in the springs.

The components below the springs, considered alone, have a low center of gravity and must rotate in the larger arc defined by tire spacing. Thus something of a discontinuity in the overturning process must be anticipated at the point where the springs are fully loaded. This point in the overturning cycle is dependent upon the spacing, length, and stiffness of the springs on the vehicle.

A revised estimate of the impulse which was needed to overturn the large bus of the Dial Pack test, based upon the elimination of window areas from effective side surface, indicates that 250 psi-ms would be required if the bus overturned as a single unit. Figure 26 shows the assumed loading diagram for this vehicle. Only front and rear loading have been considered. This diagram does not include an influence for top and bottom pressure effects or for loading of internal surfaces through broken windows. The total net impulse derived from this loading diagram is 315 psi-ms. About half of this is available during the first 21 ms and the other half must be delivered during the remaining 250 ms where the pressure differential is quite low.

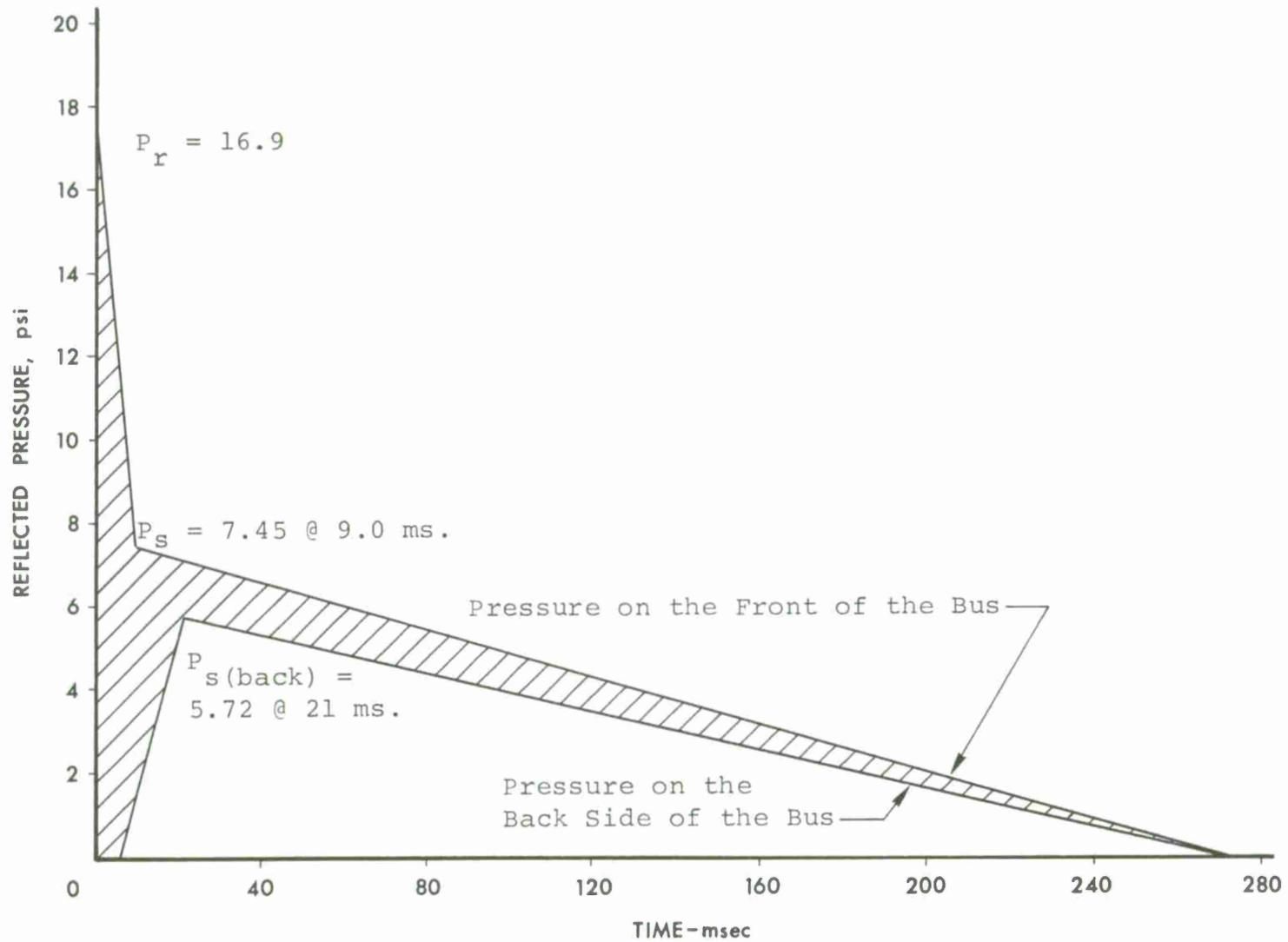


Figure 26. Loading Diagram for the Large Bus Exposed at 1200 Feet From the 500 Ton Charge.

An examination of the rotation of the bus as shown in the high speed films (summarized in Figure 19) indicates that 60 to 30 percent of the work needed to overturn the bus was completed. The center of gravity was lifted approximately two thirds of the total rise needed for overturning. Thus one conclusion which might be drawn from these data would be that the suspension system of this bus absorbed about one third of the impulse delivered to it and consequently the estimate of impulse needed for overturning should have been proportionately higher. While these data may not be sufficient to accurately determine such a factor, they do clearly indicate that more impulse was needed to complete the overturning. The needed additional impulse must have been at least an additional 80 psi-ms since no more than 80 percent of the required work has been done at a time near the end of the loading curve when the maximum delivered impulse was 315 psi-ms. Similarly the additional impulse needed must be no more than 200 psi-ms since at least 60 percent of the required work was accomplished. The total required impulse for this vehicle is thus bracketed between approximately 400 and 500 psi-ms.

A more precise evaluation of these factors may not be required for the determination of separation distances from stored explosives since the available data place the bus overturning distance at a position in the blast field where direct injury to occupants of the bus must be considered. Limiting the impulse to 80 percent of that required for overturning, as was proposed in the earlier study, would still place the vehicle at a pressure level which is above the threshold for eardrum damage for persons exposed directly to blast. Unless a substantial case can be made for the shielding of bus occupants by the structure, the passengers would be subjected to an unacceptable hazard without regard for the interaction between the blast and the bus at the distance defined by 80 percent of the overturning impulse. It may be that the separation distances which have been suggested to protect personnel in the open are also appropriate for the protection of personnel in vehicles.

No attempt has been made to evaluate the hazards to bus occupants which the broken windows create. The glass pieces were held together by the plastic center layer to a considerable degree and thus passengers would have been struck by large

pieces in many cases. The velocity of glass fragments in the bus at 1200 feet was sufficient to make impressions in the aluminum sheet metal on the far side of the bus in some instances. This glass did not generally cut through the seat upholstery, however.

While no quantitative data are available, it seems improbable that all passengers could have escaped serious injury from broken glass under the 1200-foot exposure conditions. At 3000 feet all passengers should have escaped serious injury but the driver would have been struck by half of the windshield. The extent to which this would cause injury or inability to control the bus is unknown.

## VI. CONCLUSIONS

The tests which have been accomplished within the scope of this work provide the basis for several conclusions; the most important of these are summarized in the following statements.

### A. PLATE GLASS HAZARDS

1. Large glass fragments are produced by the breakage of quarter-inch plate glass windows exposed to blast energy levels near the threshold for window survival. These tests have shown that the breakage of a 4-foot by 6-foot pane of glass can produce 15 to 20 fragments which weigh more than one pound each. This represents approximately 40 percent of the original window.
2. Plate glass windows may be somewhat more resistant to blast energy than present theoretical considerations have suggested.
3. The oscillation of a rectangular window under conditions of blast loading has been found to be more involved than the idealized plate model assumption would indicate.
4. The horizontal velocity of glass fragments produced in the test exposure was essentially zero. Thus the force of gravity may be assumed to govern the significant fragment velocity vector under threshold glass breakage conditions unless dynamic pressure levels are sustained for long time periods following breakage. Such dynamic pressure pulses are usually only associated with nuclear explosions.
5. Falling pieces of glass, which weigh one to three pounds and have sharp edges and jagged points, must be considered to represent a serious hazard to exposed persons when the height of fall is greater than from a single story building. While precise lethality or wound probability data are unavailable, an examination of such glass fragments and a consideration of their cutting ability leaves little doubt that serious wounds would result from encounters

with them. The probability of serious wounds from the smaller fragments or from large fragments falling very short distances is less certain. While some serious wounds may be caused by such encounters, it is believed that many wounds would be superficial or minor in nature when the net energy delivered by the fragment is below some threshold in the 50 to 100 foot-pound region.

6. The experimental techniques used in these tests for observing the glass motion and breakage were quite successful and could be employed to provide even more precise data on the window breaking process.

#### B. VEHICLE BLAST HAZARDS

The evaluation of the initial vehicle-blast interaction model and its underlying assumptions was a primary objective of the tests involving vehicles in a blast field. The actual damage caused to the vehicles and their components as well as estimates of passenger-vehicle interactions were of secondary importance in the test plans. Three of the four vehicles were exposed to blast conditions where the model indicated some likelihood of overturning, but none of these represent conditions where any set of accepted criteria would allow passenger exposure. The conclusions drawn from these test data reflect this emphasis upon the evaluation of the vehicle overturning model.

1. The blast energy which is applied to the window area of buses and similar vehicles is not effectively transmitted to the other vehicle components and thus does not contribute significantly to overturning. The windows are broken out early in the blast loading cycle and their presented area should thus not be included in models of overturning by blast energy.
2. Vehicle suspension systems can, at least under some circumstances, act to inhibit or prevent overturning.
3. Vehicles such as the buses tested will be tipped substantially or overturned before relative position on the highway will be lost through lateral motion. The buses exposed were tipped to a considerable degree but

the lateral motion was only a few inches in the most severe exposure.

4. Vehicle overturning criteria may not be appropriate for establishing explosive quantity-distance standards because of the hazards to passengers which are associated with the blast pressure levels required for overturning vehicles.
5. Window breakage involves a hazard to personnel sitting beside windows which cannot be evaluated precisely with present data. Similarly, persons within a bus are subjected to lateral motions which appear serious at conditions approaching vehicle overturning.
6. The test exposure of the bus at 3000 feet from the one million pound charge confirms the adequacy of the present standard in that passengers would have been uninjured by direct action of the blast on the vehicle. The driver of the vehicle would have been subjected to a very low velocity impact by the windshield of the bus. This does not appear to offer a serious threat to the driver from a wounding standpoint but might seriously interfere with his ability to control the moving vehicle.
7. Present public highway separation distances are adequate to prevent vehicle overturning for all charge sizes up to, and including, the nine million pound limit.
8. The protection criterion for exposed personnel, which was proposed in the earlier study, may also be quite appropriate to public highway separation distances. Thus it may be possible and useful to establish these separation distances without an actual consideration of the blast damage to the vehicular targets as such.

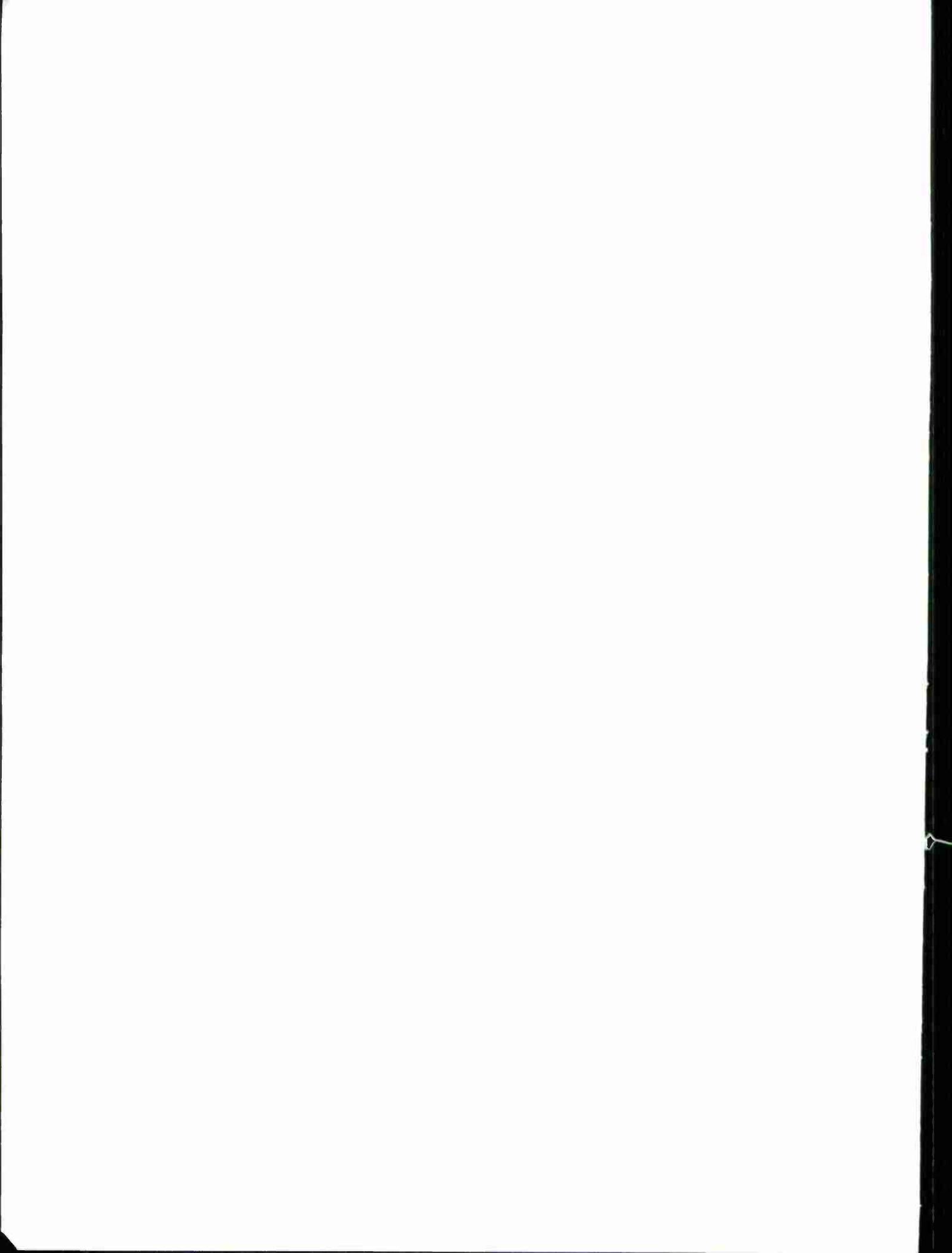
## VII. RECOMMENDATIONS

The objectives of these tests were to meet the needs of the Armed Services Explosive Safety Board for more specific experimental data relative to two types of hazards. These needs have been met by the information secured even though a complete understanding of the glass breakage process and vehicle overturning interactions cannot be derived from such limited experimental evidence. These data can be used, where applicable, to establish greater confidence in the levels of protection afforded by present quantity-distance standards or to form a basis upon which to consider the need for modifications to existing separation requirements.

1. It is recommended that serious consideration be given to the hazards associated with plate glass windows on inhabited buildings and a determination made as to the level of glass injuries near such buildings that will be considered acceptable.
2. It is recommended that a study be made of alternative ways of providing greater levels of protection to the exposed personnel near such plate glass windows if it is determined that present separation distances do not afford acceptable levels of anticipated injuries. It is recognized that this may imply modifications to the inhabited structure rather than modifications to the explosive storage facility but the importance of adequate protection and the high cost of additional separation distance requires that a full consideration of alternatives be undertaken.
3. It is recommended that consideration be given to establishing new criteria for the determination of required separation distances applicable to public highways and railroads. These data have shown that occupants of highway vehicles may be subjected to hazards which produce some serious injuries before the vehicle-related damage criteria are reached. There may be value in considering railway distances separately since occupied rail vehicles are quite different from highway vehicles and may actually

afford some level of personnel protection not available in most highway vehicles.

4. It is recommended that additional testing of the type herein reported be undertaken if a clear need is established for more complete or precise data relative to plate glass fragment size distributions or a requirement for a thorough understanding of vehicle overturning parameters exist.



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13. ABSTRACT The work covered by this report extended the knowledge of blast interactions with two types of targets and achieved a fuller understanding of the requirements for protecting personnel exposed to stored explosives. The specific targets were a 1/4 inch plate glass window and a bus. Plate glass windows were exposed to blast pressures of 0.65 and 1.09 psi peak incident pressure from a surface burst charge. Bus vehicles were exposed, side on to the blast wave, to provide maximum opportunity for overturning at blast pressures of 7, 8, and 9 psi peak incident pressure. It was shown that plate glass fragments as large as 1500 grams (3.3 lbs.) are produced under threshold breakage conditions and that approximately 40 percent of the window may break into fragments, each weighing a pound or more. The only velocity vector of importance, under these conditions, is the one provided by the force of gravity. Bus vehicles were shown to be more resistant to overturning by blast than a simple model had indicated. It was concluded that window areas do not effectively transmit blast energy to the bus for overturning and that the suspension system acted to inhibit overturning in these tests.		

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
EXPLOSIVE EFFECTS RESPONSE TO BLAST PLATE GLASS WINDOWS GLASS BREAKAGE VEHICLE OVERTURNING DAMAGE LEVELS SURFACE BURST TNT PRESSURE IMPULSE ANALYTICAL MODELS EXPLOSIVE SAFETY DIAL PACK TESTS						

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5 Feb 1971

Subject: Errata to Report "Target Response to Explosive Blast"

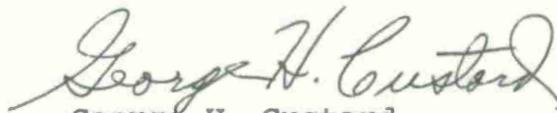
Gentlemen:

An errata sheet to the subject recent report which was distributed to you is enclosed. Figure 24 has been modified to indicate a  $\lambda$  value of 80 for unbarricaded charges. Table V has been modified by removing the distance values from the footnotes and adding asterisks to the measured impulse values in the table. There are no other changes. Please replace pages 45 and 46 with the revised sheet enclosed.

This work was performed for the Armed Services Explosive Safety Board and this errata sheet has been prepared in accordance with recommendations from the sponsoring organization.

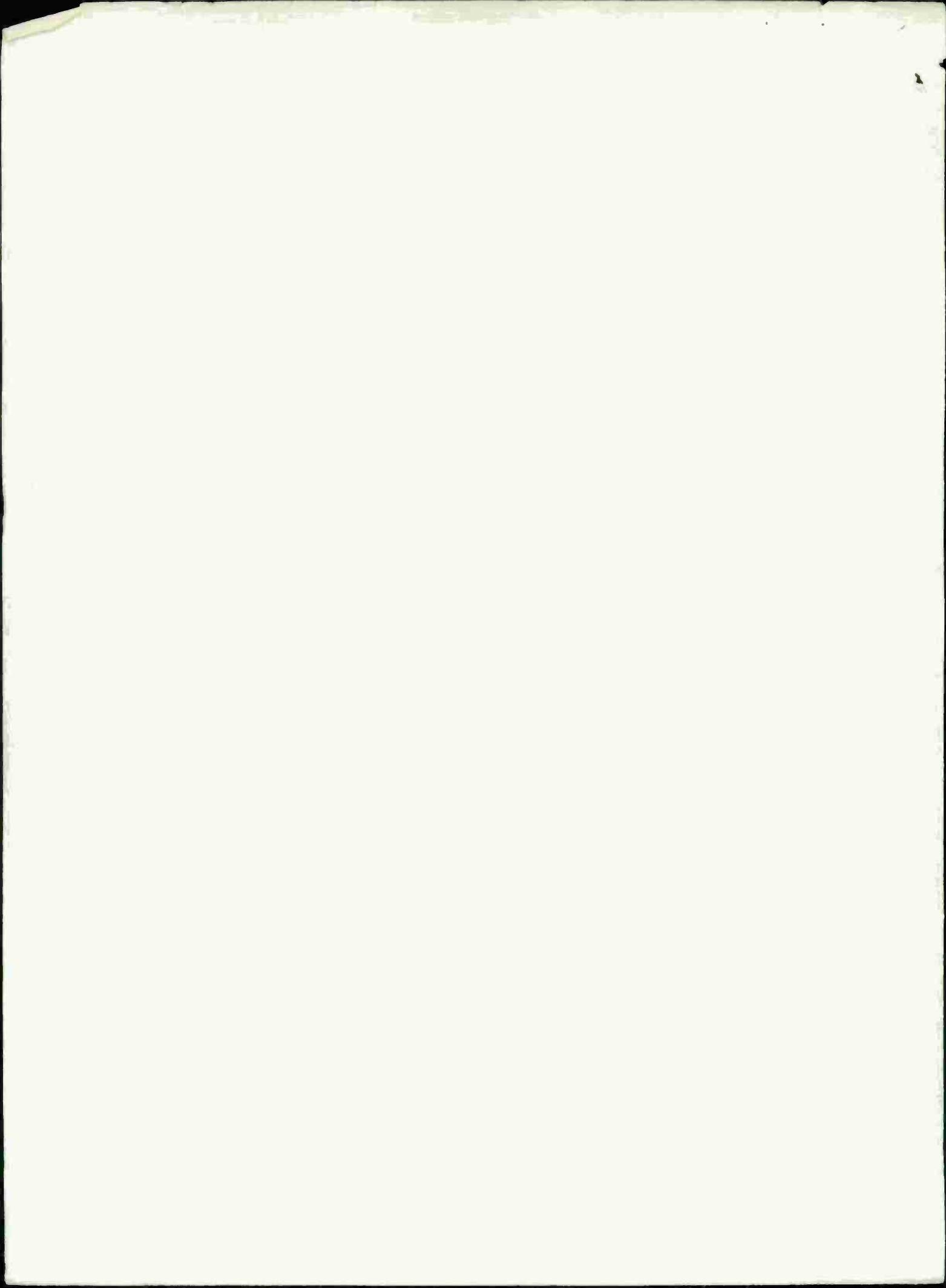
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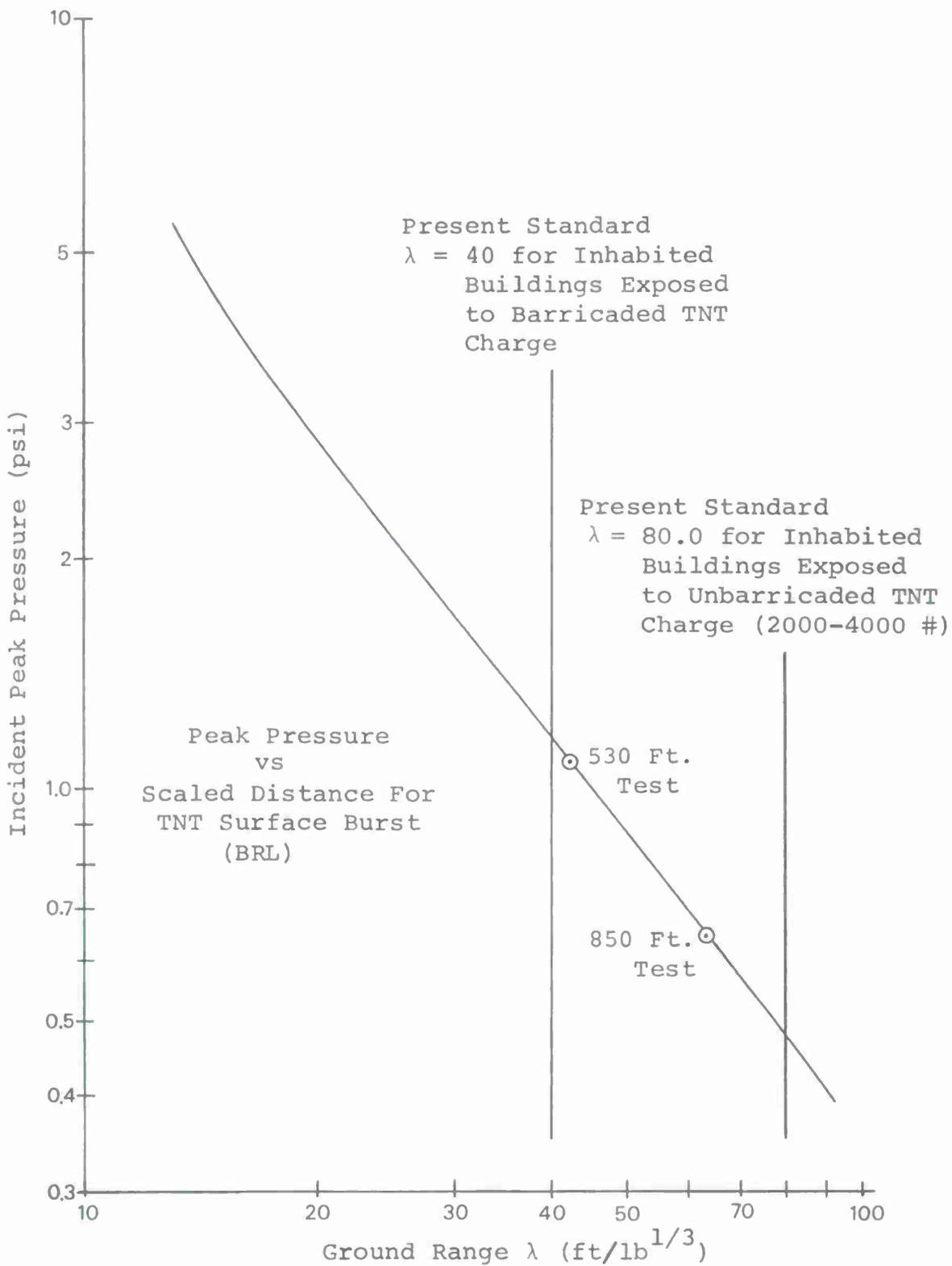


Figure 24. Plate Glass Window Exposures of the Dial Pack Directed Blast Test. (2200 lb. Effective Charge Size)

Table V. A comparison of Blast Properties for the Test Locations.

Distance and Charge Type	Peak Pressure (psi)	Positive Duration (ms)	Positive Impulse (psi-ms)
530 ft. (blast array)	1.09*	52	27 *
530 ft. (4000 lb surface)	1.5	64	41
850 ft. (blast array)	.65**	65	18 **
850 ft. (4000 lb surface)	.86	82	26

\* Equal to  $\lambda=42$  for 2300 lbs. TNT, surface burst.

\*\* Equal to  $\lambda=63$  for 2200 lbs. TNT, surface burst.

The forward velocity of all fragments was essentially zero as was expected for these blast loading conditions. Had the positive duration been longer, a more significant forward velocity vector would have been anticipated.

The velocities which these glass fragments might attain due to the acceleration of gravity is not known with precision. The presented area of the larger fragments can vary by at least an order of magnitude depending upon the orientation of the fragment. Thus the effect of air drag variations can be very significant in determining actual acceleration rates.

The edges of the broken fragments were observed to be very sharp in many instances and it would appear that such fragments could cause serious cuts even at low velocities when the fragment struck edge on.

An examination of the films of the shock interaction with the window located at 850 feet, which was unbroken, indicated that more than simple vibratory motion was involved in its response to the blast wave. While the glass plate can be seen vibrating to alternately concave and convex configurations it never is really restored to a flat surface between these extremes. The major vibration periods are not all of the same duration which further indicates a complex or compound vibrational phenomena.



