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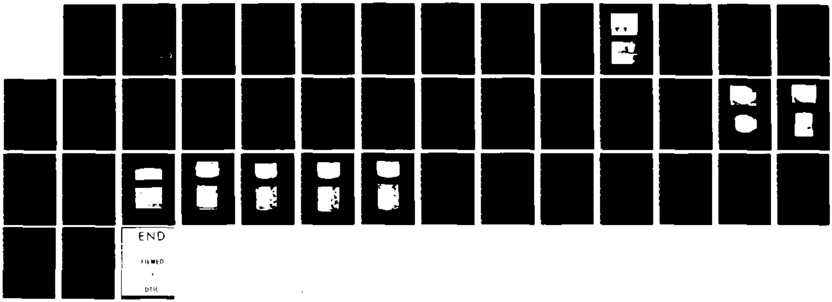

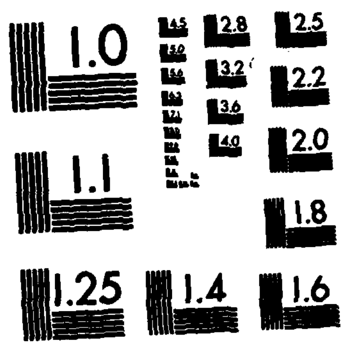

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SIMULATED BLAST TESTING OF ADVANCE INTERCEPTOR MATERIALS

May 1982

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FINAL REPORT

Contract No. DAAG46-79-C-0056

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Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
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An experimental program was conducted to develop a simulation blast loading technique for testing advance interceptor materials. Kevlar/epoxy, carbon/epoxy, and hybrid frusta were tested with 50 and 80 psig reflected blast loads. The carbon frusta sustained the least amount of visible damage, while the hybrid frusta revealed the most damage from the simulated blast loads.

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PREFACE

This final report was prepared by Southwest Research Institute for the Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts under contract DAAG46-79-C-0056. This work was performed under the guidance and monitoring of Mr. John F. Dignam, the AMMRC technical supervisor.

The author acknowledges the contributions to this program of the following personnel from Southwest Research Institute:

W. E. Baker	J. C. Hokanson
M. R. Castle	L. R. Ramon
J. L. Decker	N. R. Sandoval
A. G. Garcia	D. J. Stowitts
V. J. Hernandez	A. B. Wenzel

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I. INTRODUCTION

This document is the final report for Contract No. DAAG46-79-C-0056 performed by Southwest Research Institute (SwRI) for the Army Materials and Mechanics Research Center (AMMRC). The report describes an experimental research program whose objective was to determine qualitatively the structural damage to advance interceptor materials loaded by simulated blast loads. The peak reflected pressures of the blast waves were 50 and 80 spig, both with approximate decay times of 30 milliseconds.

The work on this program was divided into four tasks. The approach was to take an existing blast chamber, which had been designed, built and tested previously for flat targets, and modify it to develop similar blasting loads on curved targets such as a frustum. A total of 88 experiments were conducted in this program.

The first task consisted of calibrating the existing blast chamber to obtain the two desired peak reflected pressures on a flat target and decreasing the vent area to increase the duration. Nineteen tests were performed to accomplish this. In the second task, 15 additional experiments were used to develop the right combination of variables to obtain the desired pressure-time histories on a fixed half-frustum bolted to the flat plate.

In the third task, 29 experiments were performed in further developing the blast loading techniques for use on frusta which were only constrained by nylon straps around the top and bottom (minor and major perimeters). No rigid coupling was used between the mock-up frustum and the blast chamber. Finally, in the fourth and last task of this experimental effort, a series of 25 tests was accomplished to load frusta made from three candidate composite materials. Twenty-four frusta, furnished by AMMRC, were tested using blast simulations of 50 and 80 psig reflected pressures. Eight of the test items were made from Kevlar 49/epoxy, 8 were made from Carbon AS-4/epoxy, and 8 were hybrids made from these two materials. The frusta were 8.5 inches tall, with a major inside diameter of 16 inches and a cone half-angle of 6°.

The next section of this report details the experimental apparatus used to simulate the blast loads. The subsequent section describes in detail the complete test program and presents the result of each task. Finally, the last section of the report summarizes the conclusions derived.

II. DESCRIPTION OF EXPERIMENTAL APPARATUS

A modified blast simulator designed, fabricated and tested by Southwest Research Institute as described by Esparza and Wenzel[1] was used to generate the reflected blast waves required in this program. This partially vented chamber, cubic in geometry and shown in Figure 1, measures internally 3 ft on the side and has one open side. This open side was placed originally adjacent to a simulated fuel tank. Sheet explosive was detonated to provide the blast loading. The loading caused by an explosion in a partially vented structure consists of two, almost distinct phases. The first phase consists of the initial blast wave and subsequent reflections. This initial shock impinging on the walls of the vented structure applies an intense loading of short duration. This loading can be estimated with reasonable accuracy from test data of blast waves normally reflected from rigid, plane surfaces.[2,3,4] However, reflections and reinforcements can occur in the corners and edges of a cubic structure so that the implosion process after shock reflections is complex and irregular.

---

1. E. D. Esparza and A. B. Wenzel, "Development of a Blast Simulator for Testing Simulated Aircraft Fuel Tanks," Report JTCG/AS-76-T-004, Southwest Research Institute, San Antonio, Texas, July 1978.

2. W. H. Jack, Jr., "Measurements of Normally Reflected Shock Waves From Explosive Charges," BRL Report No. MR 1499, Aberdeen Proving Ground, MD, 1968.

3. W. E. Baker, Explosions in Air, University of Texas Press, Austin, Texas, 1973.

4. A. B. Wenzel and E. D. Esparza, "Measurements of Pressures and Impulses at Close Distances from Explosive Charges Buried and in Air," Final Report on Contract No. DAAK02-71-C-0393, Southwest Research Institute, San Antonio, Texas, August 1972.

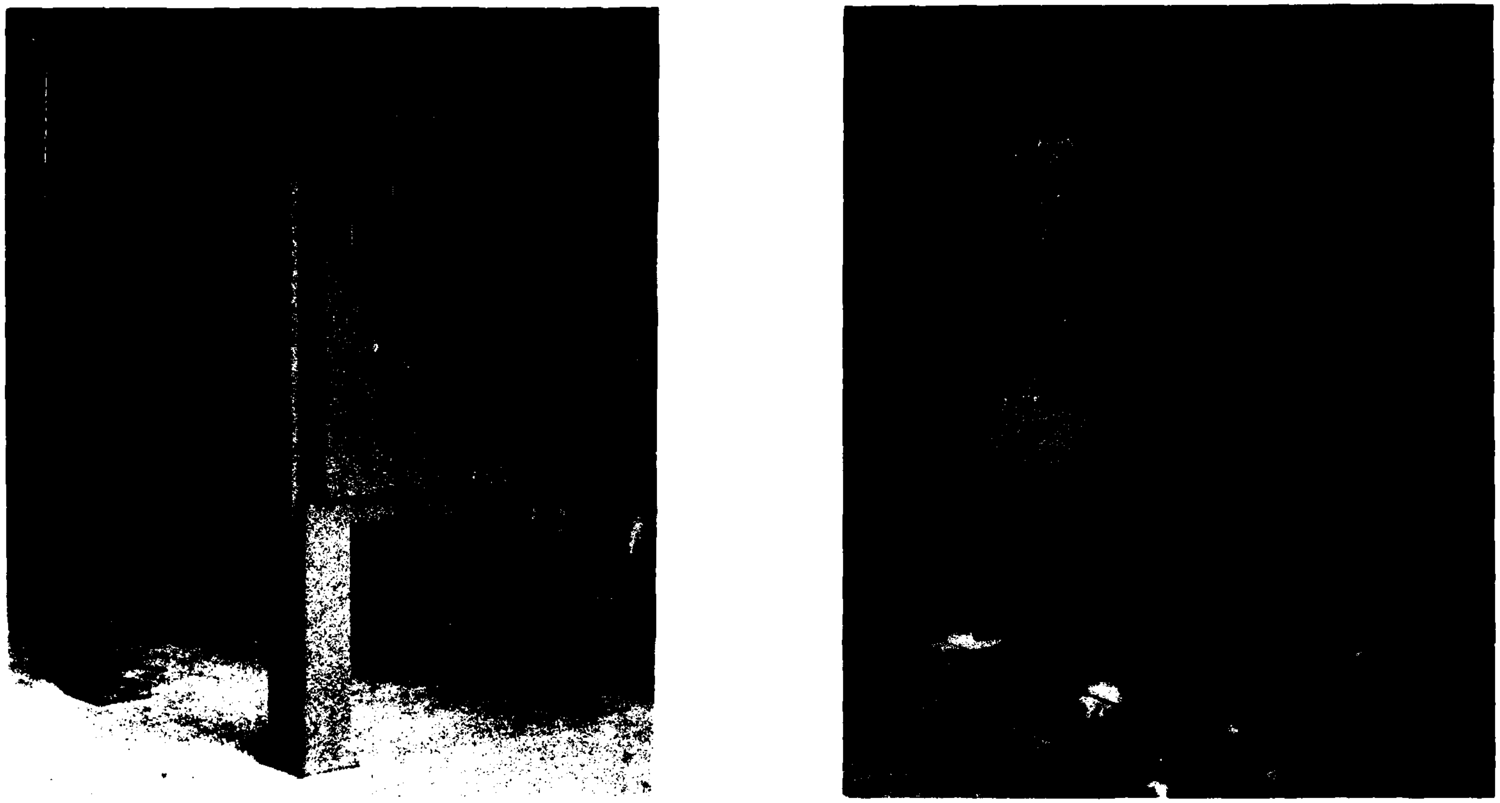

Figure 1. Blast Simulation Chamber

As the blast wave reflects and re-reflects within the structure and as the energy available from the explosive source is added to the air within the structure, a gas pressure rise occurs in the structure. This is the second phase of the loading. The gas or quasi-static pressure is of a much lower amplitude and longer duration than the initial reflected pressure. In order to obtain reasonable pressure profiles on the flat, test surfaces the initial blast peak pressure and reflections were attenuated using a light, open cell foam over the test plates. This technique lowered the amplitude and stretched the duration of the blast wave so that it would coalesce with the decay of the quasi-static pressure whose duration was controlled by the amount of venting in the cubic blast chamber.

The blast simulator used is similar in design to uniformly vented structures tested in model scale by the Ballistic Research Laboratory.[5,6] The five sides of the blast simulator consisted of an inner layer of structural angles uniformly spaced and perforated plate as the outer layer. This double layer design was chosen over a single vented plate primarily because test data from the similar suppressive structures showed that a closed, evenly spaced layer of angles seemed to break the initial shock wave better than flat surfaces and reduced the number and intensity of the subsequent reflections.[5,6] Thus, the double-layer design made it slightly easier to tailor the pressure profile on the test plate. The duration of the simulated blast pressure pulse was controlled by varying the amount of venting (openings) allowed around the blast tank.

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5. R. M. Schumacher and W. O. Ewing, "Blast Attenuation Outside Cubical Enclosures made Up of Selected Suppressive Structure Panel Configurations," BRL-MR-2537, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1975.

6. C. Kingery, R. N. Schumacher, and W. O. Ewing, "Internal Pressure from Explosions in Suppressive Structures," BRL-IMR-403, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1975.

III. TEST PROGRAM AND RESULTS

Calibration of Blast Simulator

In the work reported in Reference 1, the blast simulator was developed for simulating reflected blast overpressures ranging from 10 to 50 psig against a flat target. The amount of venting was adjusted to provide pressure pulses with 12 millisecond durations. For this project, the reflected pressures desired were 50 and 80 psig, both with 30 millisecond durations. Therefore the first task was to determine the quantities of sheet explosive, reticulated foam thickness, and the amount of venting necessary to obtain the desired reflected pressure-time profiles on a flat target area.

A series of 19 experiments was performed to identify the proper combination of the three variables (explosive, foam, venting) to obtain the desired reflected pressure pulses. To conduct these tests, the blast chamber was fitted with a solid cover plate over the one open side. On this plate, provisions were made for mounting four piezoelectric pressure transducers for measuring the reflected pressures. Figure 2 is a sketch showing the layout for this series of experiments.

Cover plates were required over the large circular opening, as well as over the rest of the uniformly vented sides of the chamber in order to reduce the amount of venting sufficiently to increase the duration of the reflected pressure pulses to 30 milliseconds. Figure 3 shows two pressure-time traces from a test in which the 50 psig peak reflected pressure was obtained. Similarly, Figure 4 shows two pressure traces from a test in which the 80 psig peak reflected pressure was the goal. These figures indicate that the proper combination of the variable parameters was found for generating the desired pressure-time loads on a flat target.

Development of Fixed Frustum Loading Technique

With the blast simulator calibrated to impart the desired reflected pulses on a flat target, the next task in the program was to establish

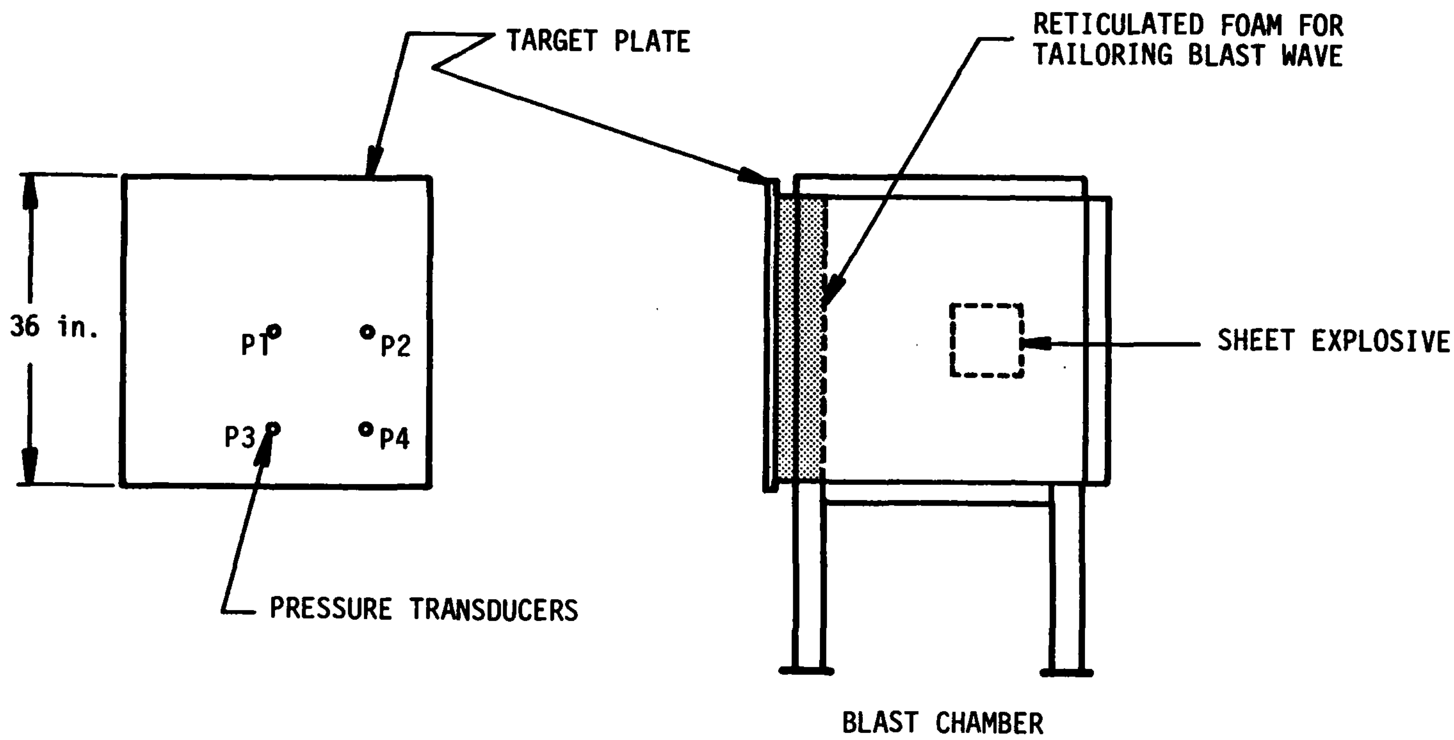
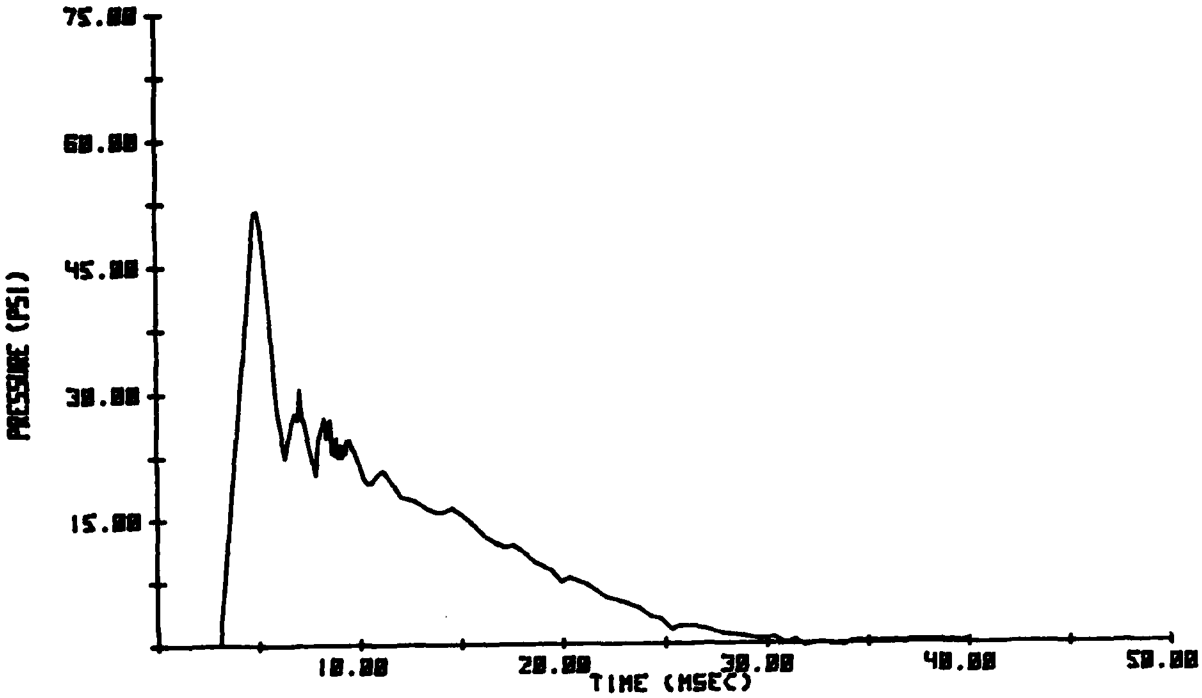


Figure 2. Experimental Layout For Calibration Of Chamber With Flat Target



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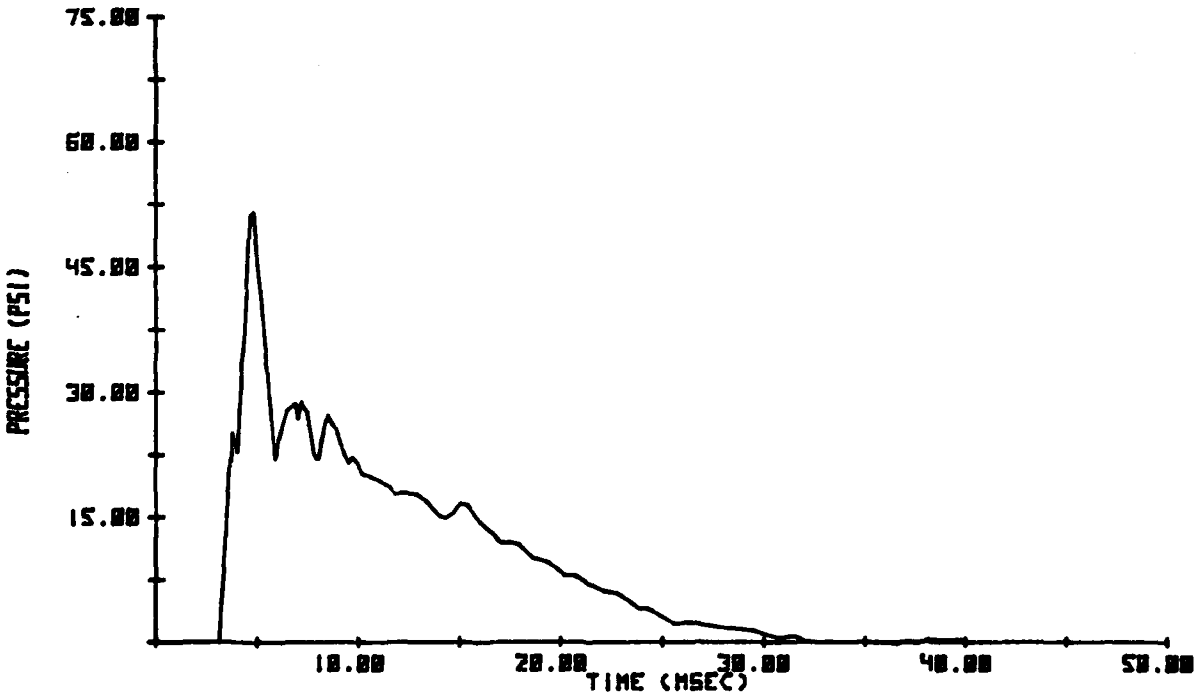

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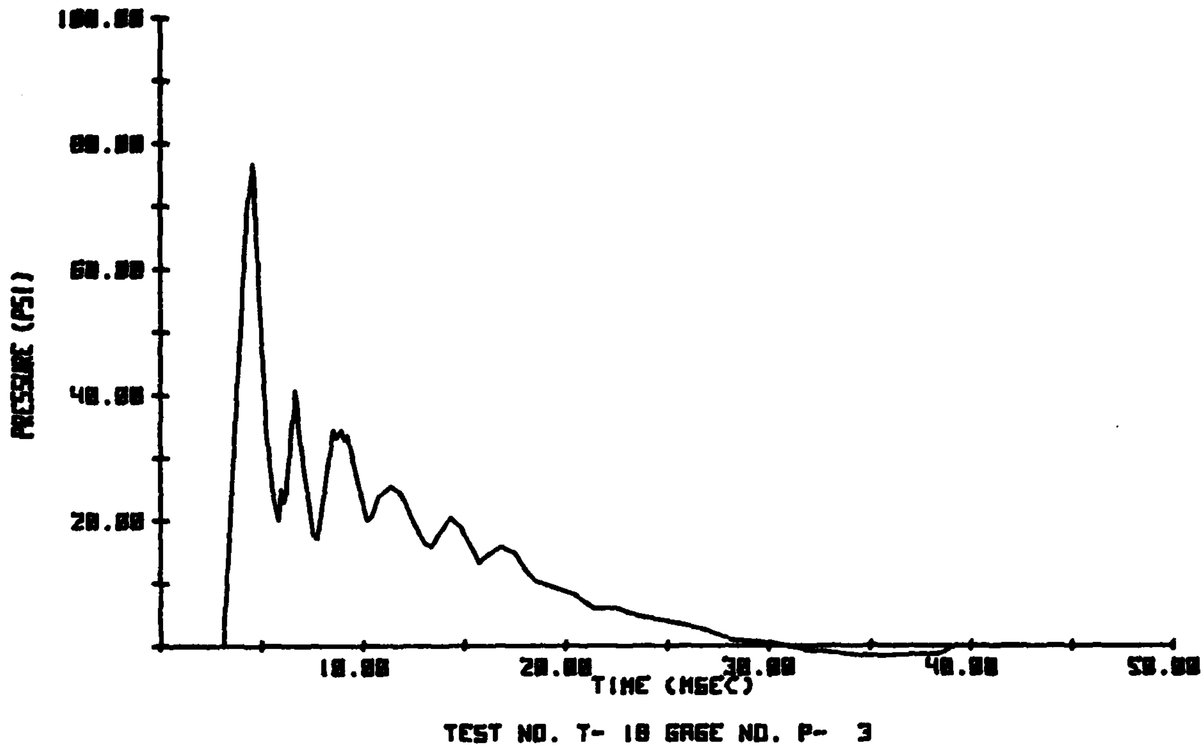
Figure 3. Typical Reflected Pressure Records On Flat Target, Peak Pressure ~ 50 Psig



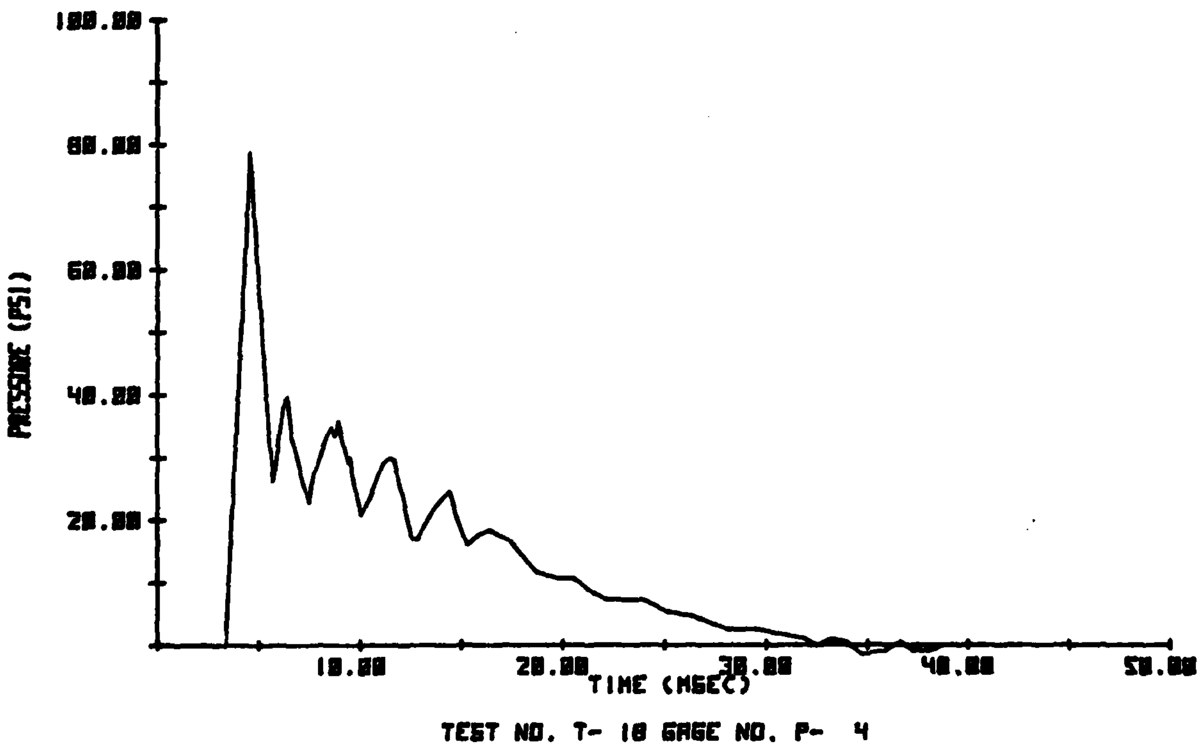


Figure 4. Typical Reflected Pressure Records On Flat Target, Peak Pressure ≈ 80 Psig

that similar pressures would load a frustum. A solid half-frustum made of wood was fabricated with provision for mounting five pressure transducers. This wooden test item was mounted on a fixed plate as shown in Figure 5.

The dimensions of the wooden frustum were the same as the composite frusta originally specified in the contract (a cone half-angle of 10°, major diameter of eight inches and a height of nine inches). The geometries of the government furnished test items were later modified. However, tests in the task that followed indicated that it was not necessary to run fixed frusta tests with the larger geometry.

A total of 15 experiments were conducted in this phase of the program to establish the charge weight and venting area required to produce the desired loading pressures. Also, because of the curved surfaces, some of the tests were run to determine the best way of configuring the eight-inch foam thickness in front and around the test frustum. Figure 6 shows two traces from a 50 psig reflected pressure test. The top trace is from a transducer mounted at the front of the frustum (0°), while the bottom trace is from one located at 60° from the front.

Similarly, Figure 7 shows two traces from transducers mounted at 0° and 60° locations for a test in which the peak reflected pressure was expected to be 80 psig. These results indicate that the peak reflected pressure at the front of the frustum was of the desired amplitude, and that it decreased somewhat as the measurement location was moved around from the front. However, the loading does not quite approach a cosine distribution around the half-frustum and is in fact close to a uniform distribution. This load distribution appears to be inherent in this blast simulation technique.

In the process of conducting all of the experiments in this program, some weld cracks developed around the blast chamber, particularly when conducting the higher pressure tests. These welds were ground out and repaired at various times during the test program.

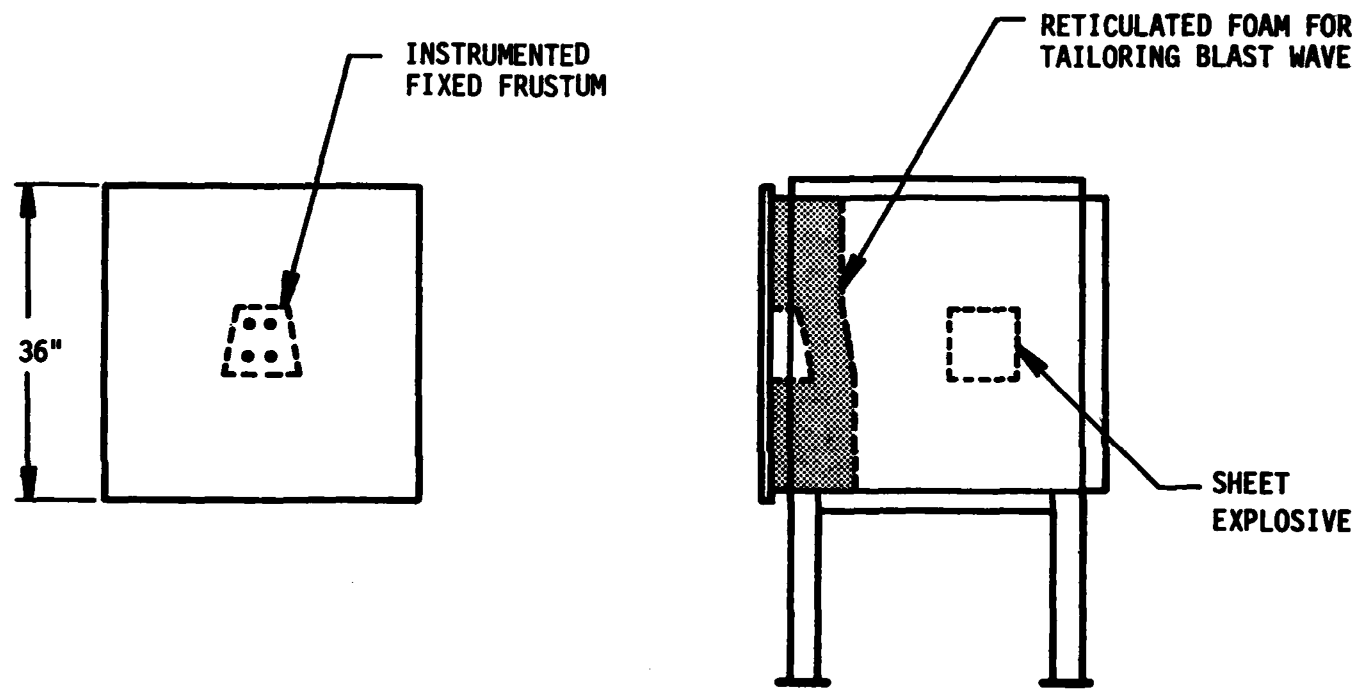


Figure 5. Experimental Setup For Fixed Frustum Tests

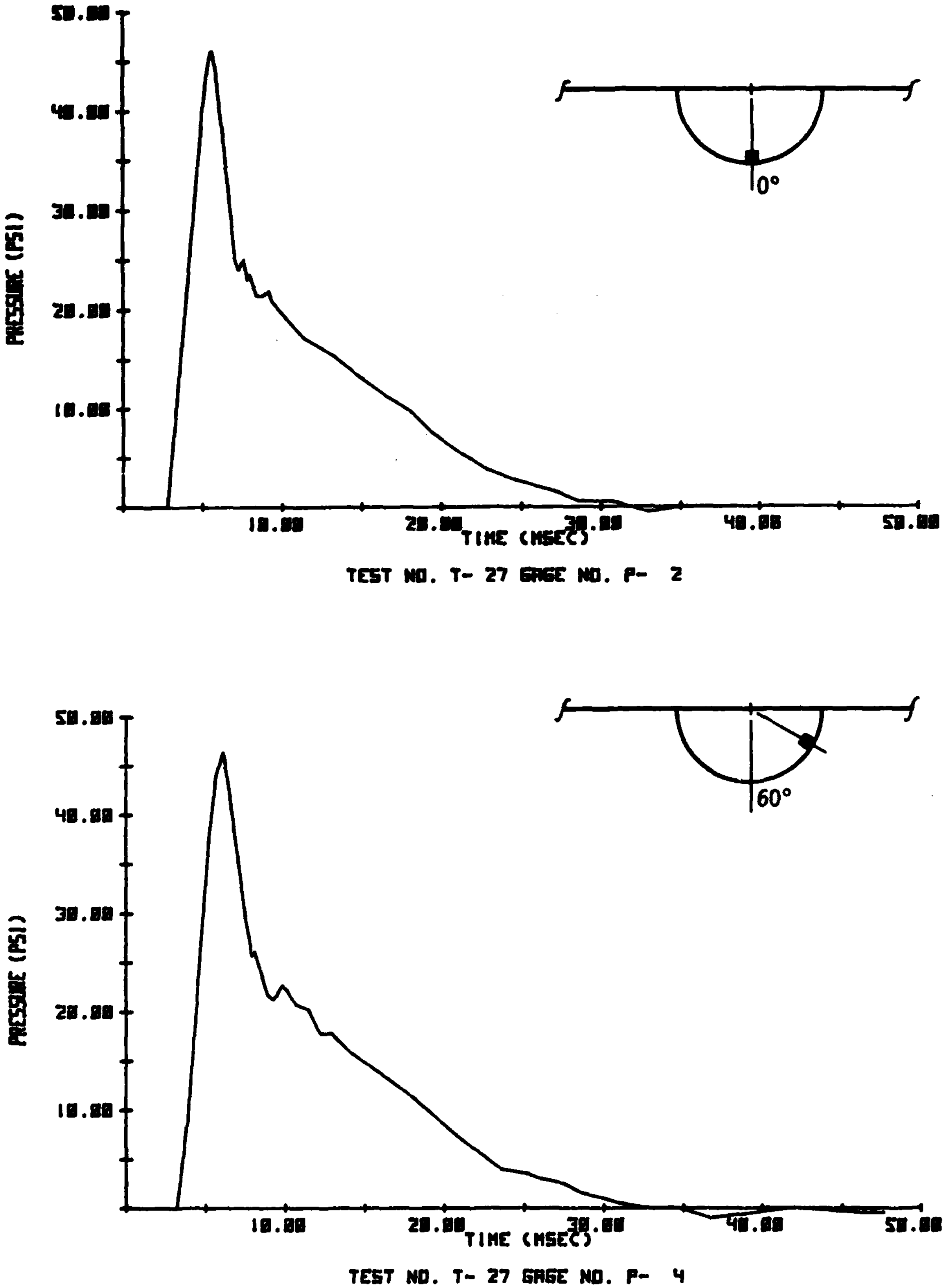
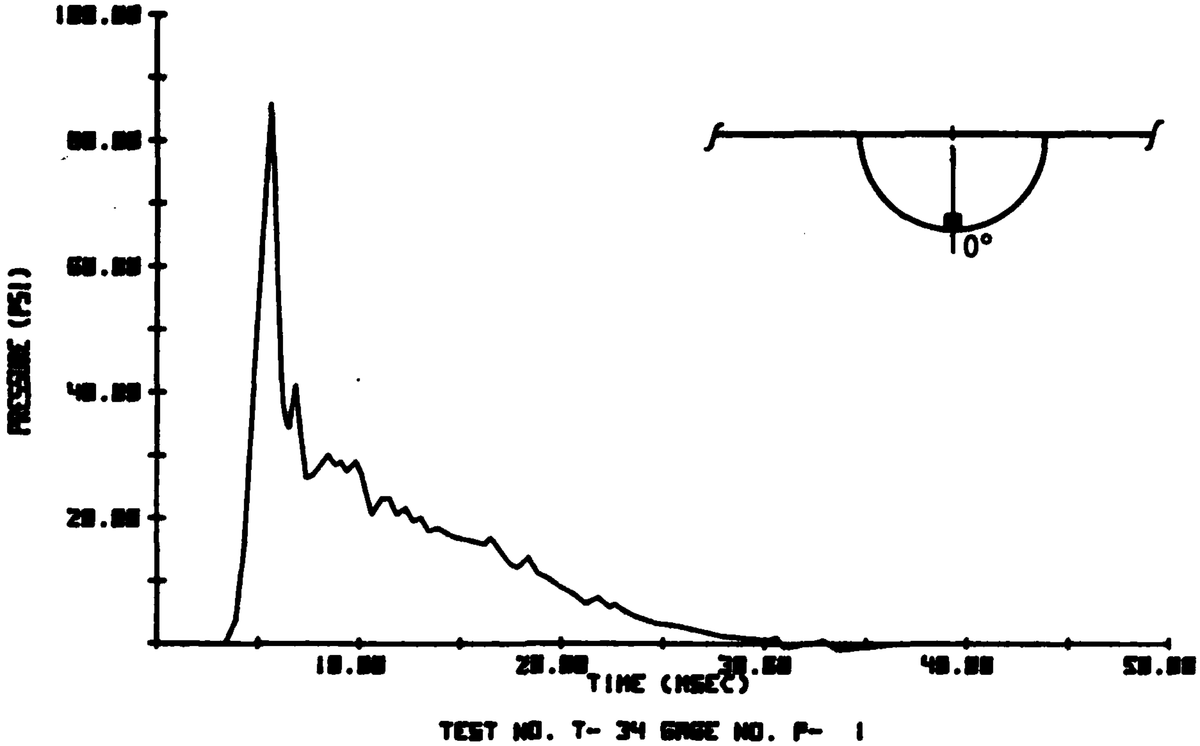


Figure 6. Reflected Pressure On Fixed Half-Frustum,
50 Psig Test



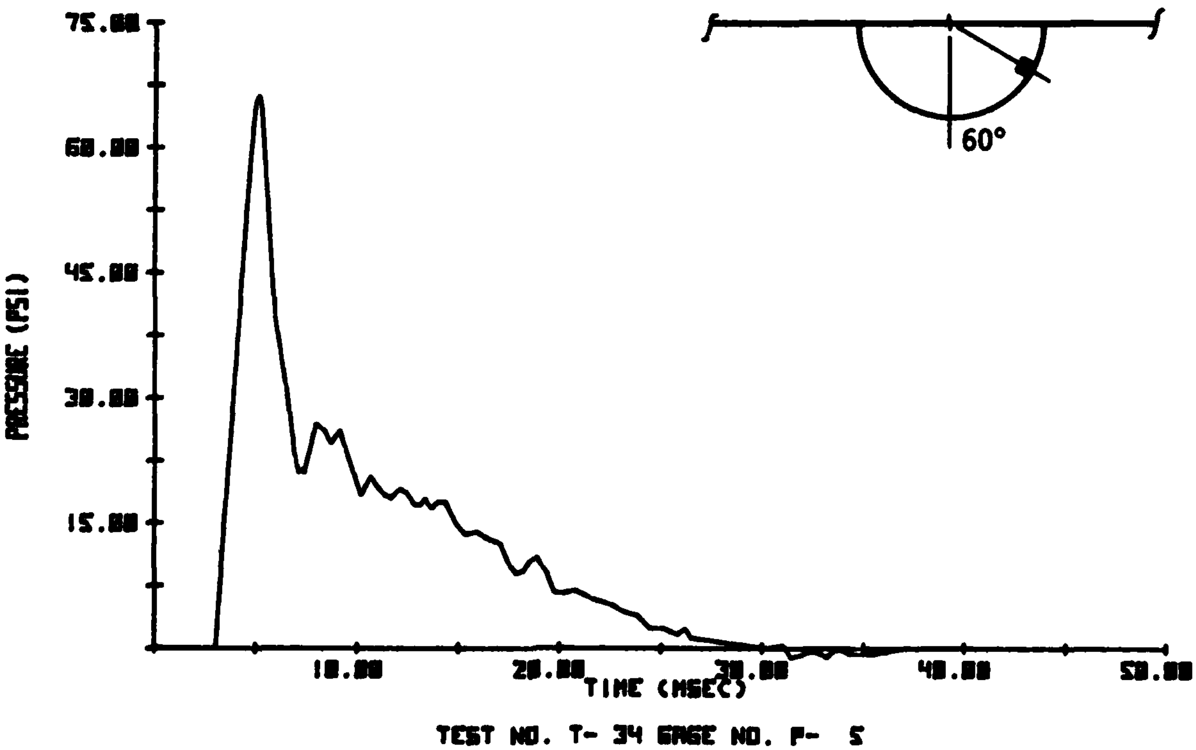


Figure 7. Reflected Pressures On Fixed Half-Frustum, 80 Psig Test

Development of Loading Technique for Unconstrained Frusta

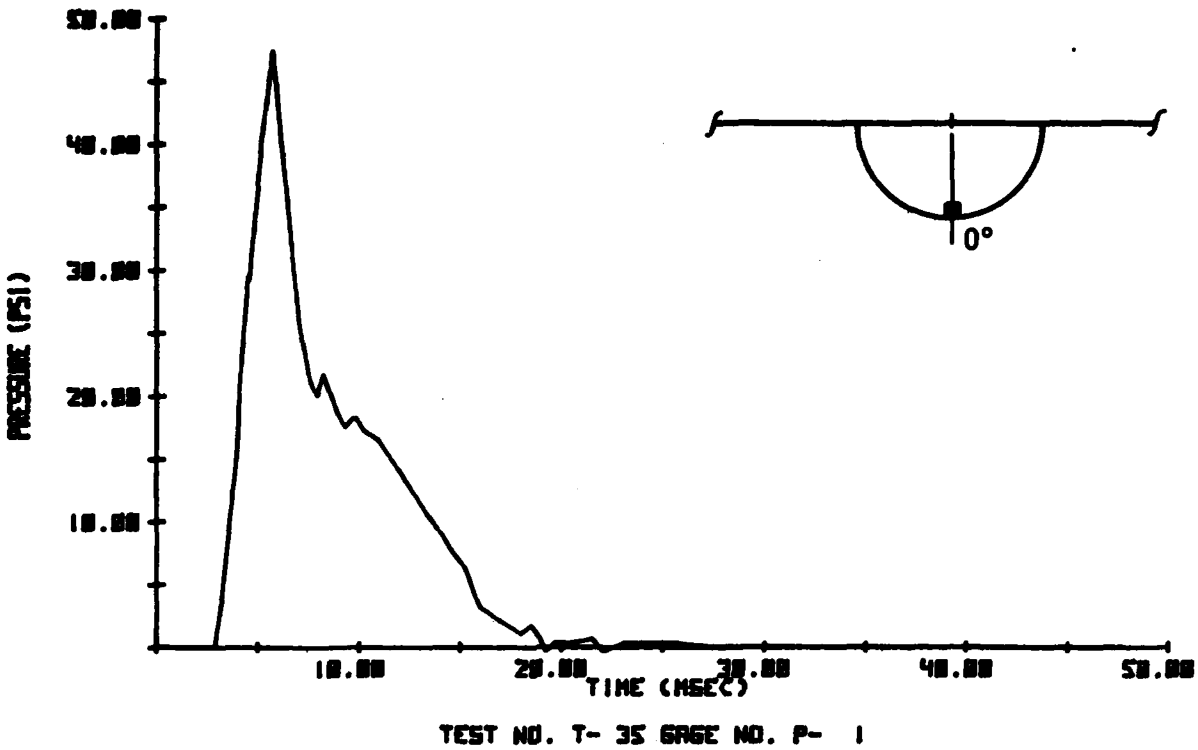
After the development of the fixed frustum loading technique, the next task was to conduct a series of tests to develop further the simulated blast loading technique for use on unconstrained frusta. For these tests another wooden frustum of similar dimensions as used in the previous task was fabricated. Provisions were made for mounting two pressure transducers, at the front and at a location rotated 60° from the front.

A steel plate, similar to the one used on the fixed frustum tests was fabricated with an opening and brackets which allowed placement of the wooden frustum into the blast chamber. A catcher box lined with soft foam material was also fabricated and used to catch any frusta which existed from the blast chamber. A total of 29 experiments were conducted in this phase of the project.

The first six experiments were conducted to develop a way of holding the frustum in place long enough for the blast loading to occur before it exited the blast chamber, without decreasing the pulse duration. In the first test, the frustum was simply placed halfway into the blast chamber without any constraint to determine the pulse duration when it was allowed to simply free fly out as a result of the blast loading. Figure 8 shows the two pressure traces recorded. The trace from the transducer at 0° shows an abbreviated duration of about 17 ms as compared to about 30 ms experienced by the fixed half-frustum tested in Task 2. The second pressure trace measured at 60° shows an even shorter duration of about 13 ms. This short duration at this location is a result of this part of the frustum exiting the blast chamber ahead of the 0° location.

In the subsequent five tests, various schemes to lengthen the blast pressure loading time on the frustum without using rigid restraints were attempted. Slightly longer durations were obtained but they were still much closer to those shown in Figure 8 than values obtained on the fixed frustum tests.

In the subsequent seven tests, it was determined that the best way of holding the wooden frustum was the use of tubular nylon straps



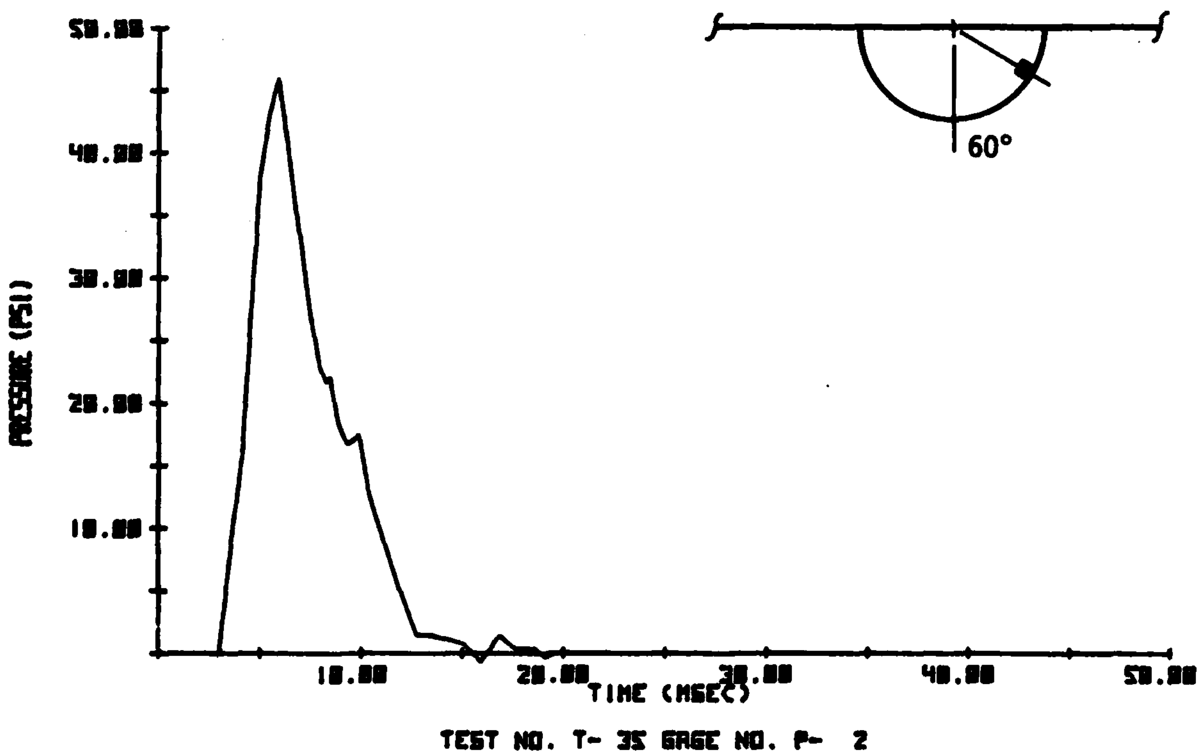


Figure 8. Pressure Data For Free-Flying Frustum

around the top and bottom of the frustum. This technique is illustrated in Figure 9. Typical pressure-time data records for the nylon strap tests are shown in Figure 10 for a 50 psig test.

During this phase of the project, the government requirements concerning the size of the composite frusta to be tested were changed. The initial new estimated size was a half-angle of 6°, major diameter of 20 in. and a height of 13 in. Therefore, a larger wooden frustum was fabricated to match this size and tested to find out if the same loading technique and method of holding the test item in the chamber used on the smaller test item was applicable to the larger one.

After modifications to the blast chamber cover plate to accept the larger frustum were made, six tests were fired. The first of these experiments was conducted using a charge weight selected to produce a 50 psig peak reflected pressure. The large frustum was strapped in place as was done previously with the smaller one to hold it in place long enough for the 30 millisecond loading duration to occur. The straps held and the desired pressure and duration were achieved. However, because of the larger test geometry, the charge detonated closer to the foam surrounding the frustum causing the foam to ignite. While using the smaller frustum, only once did the foam catch on fire. Of the next five large frusta experiments, only in one other case did the foam catch on fire. In general, the nylon straps used held the large wooden frustum in place during the explosive loading of both 50 and 80 psig reflected pressures long enough to obtain approximately 30 millisecond durations.

Subsequent to the large wooden frustum tests, the size of the composite test items was finalized by the government to be 16 inch major inside diameter (I.D.), 14.2 inch minor I.D., 8.48 in. high, and 6° cone half-angle. To insure that the loading technique developed for the nylon strapped frusta was also applicable to the new geometry, the blast chamber and large wooden frustum were modified to match the new geometry.

Five more calibration experiments were performed to verify that the 50 and 80 psig reflected pressures were being generated in the blast chamber

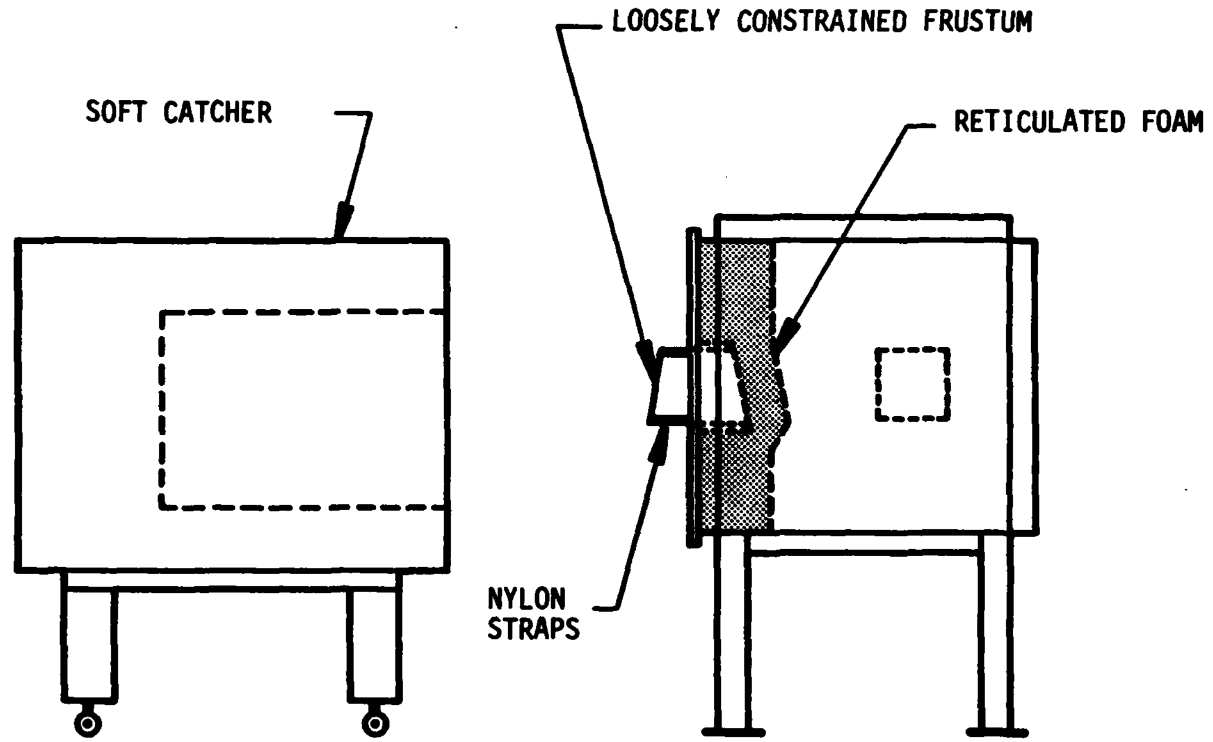
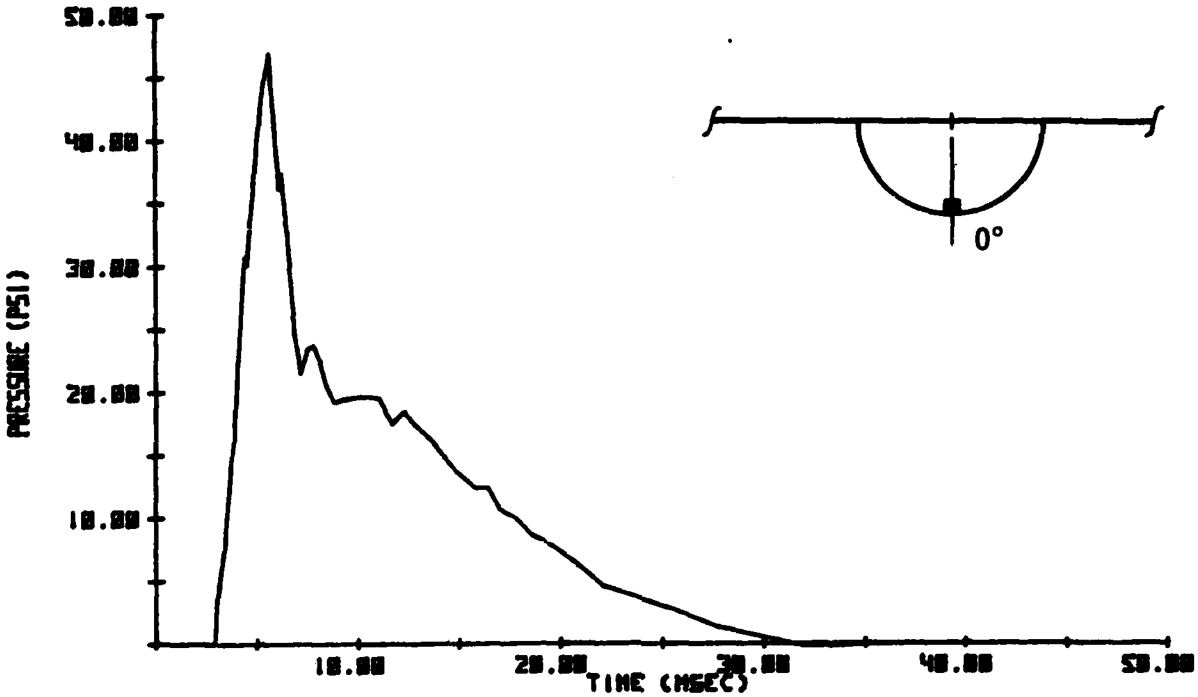


Figure 9. Test Setup To Simulate Loading Of Frusta In Free Flight



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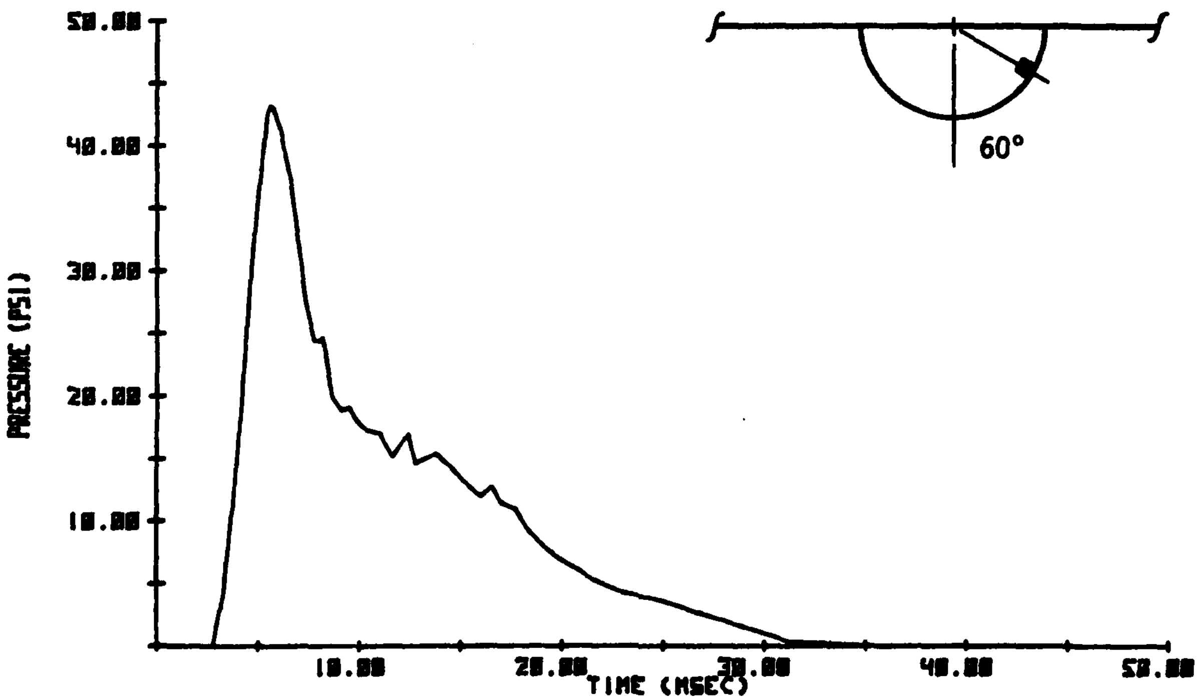

TEST NO. T- 49 GAGE NO. P- 2

Figure 10. Reflected Pressures On Wooden Frustum Constrained With Nylon Straps, 50 Psig Test

with the medium size wooden frustum. Peak pressures and durations were quite close to the desired values. This simulated blast loading technique was now ready for use on the government furnished frusta.

Testing of Composite Material Frusta

Twenty-four frusta were furnished by the government for testing with peak reflected blast overpressures of 50 and 80 psig and durations of 30 milliseconds. The configurations of the furnished frusta were as follows: 16-inch major inside diameter (I.D.), 14.2-inch minor I.D., 8.48-inch high, and 6° cone half-angle. The frusta were of filament wound construction with four layers at ±41°, two layers at ±81°, four layers at ±41°, two layers at ±81°, two layers at ±41°, and two layers at ±81°. Eight of the frusta were made from Kevlar 49/epoxy, eight from carbon AS-4/epoxy, and eight from both combinations. These hybrids had Kevlar 49 in the ±41° layers and AS-4 in the ±81° layers. The epoxy in all cases was Epon 828/RD-21 TONOX 6040 in the 100/25/20 ratio. A photograph of each of the three different composite frusta is shown in Figures 11, 12, and 13.

Testing of these 24 frusta was accomplished using the same techniques for placing the test items in the blast chamber and developing the blast pressure as were used in the previous task. Figure 14 shows one of the frusta ready for testing. In the first few tests of this phase, some problems were encountered with the nylon straps coming loose during the event and frusta being damaged somewhat from impacts against the opening hardware of the blast simulator. However, these difficulties were overcome with minor modifications to the strap and opening hardware.

Visual inspection of each composite frusta after testing revealed that in the majority of the cases some damage was substained, primarily in the form of delamination, as a result of the blast damage. In most cases the delaminations were barely visible except for small pieces of foam being found pinched between layers around the top and bottom edges of the frusta. Table 1 summarizes the damage observed on each composite frusta.

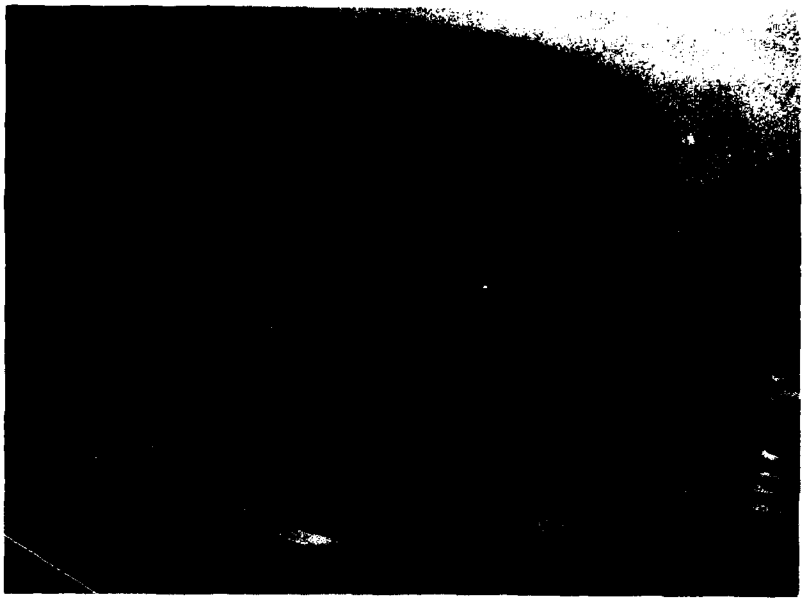

Figure 11. Kevlar/Epoxy Frustum

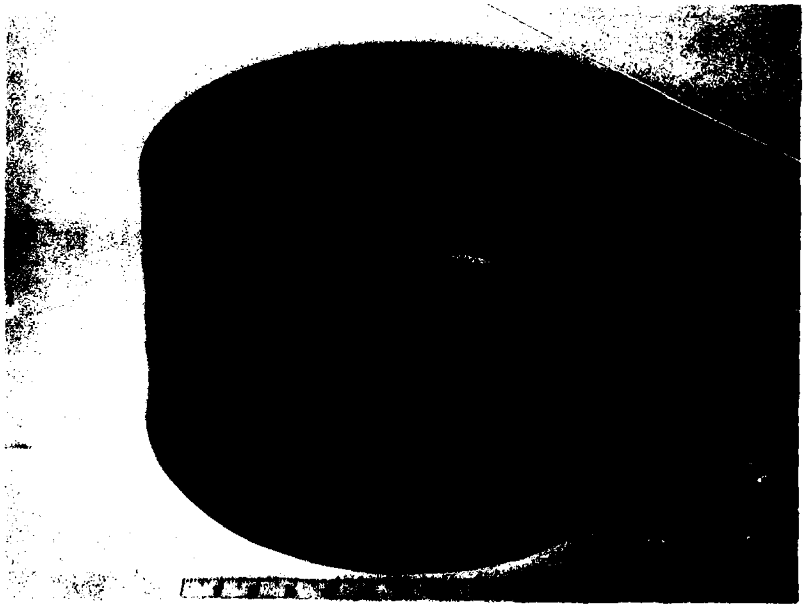

Figure 12. Carbon/Epoxy Frustum

Figure 13. Hybrid Frustum

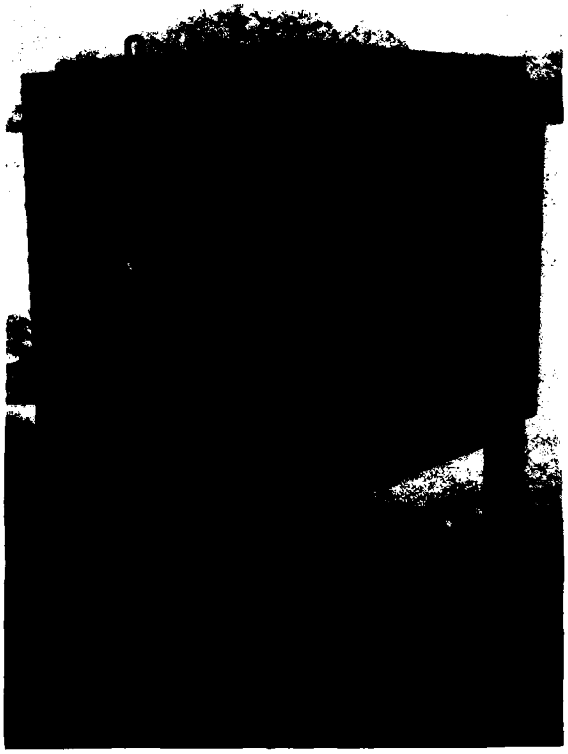

Figure 14. Frustum Ready For Test

Table 1. Summary of Observable Damage To Composite Frusta

Frustum	Reflected Pressure (psig)	Visible Delamination	Other Damage
Kevlar/Epoxy	50	No*	
"	"	No*	
"	"	Yes	
"	"	Yes	
"	"	Yes	
"	80	Yes	
"	"	Yes	
"	"	Yes	
"	"	Yes	Crack on Front Surface
Graphite/Epoxy	50	No	
"	"	No	
"	"	No	
"	80	No	
"	"	Yes	
"	"	No	
"	"	No	
"	"	No	
Hybrid	50	Yes	
"	"	Yes	Crack on Front Surface
"	"	No	
"	"	No	
"	80	Yes	
"	"	Yes	Cracks on Front & Side Surfaces
"	"	Yes	
"	"	Yes	

*For these items, straps holding test items during loading broke. One of these frusta was used in a subsequent test.

Except for the two frusta for which the straps broke during blast loading, all of the Kevlar/epoxy test items suffered some delamination. In Figure 15 are photographs of one of these frusta showing typical visible delaminations. In addition, one of these frusta showed a crack on the front surface as shown in Figure 16. On the other hand, only one of the graphite/epoxy frusta could be identified with certainty as having blast damage. Damage to the hybrid frusta was visible on five of the eight tested items. Again delaminations were observed as well as some front and side surface cracking for two of these frusta. Figure 17 shows the front crack for one hybrid frustum tested at 50 psig. Figures 18 and 19 show the front and side surface cracking for a hybrid specimen tested at a peak reflected pressure of 80 psig.

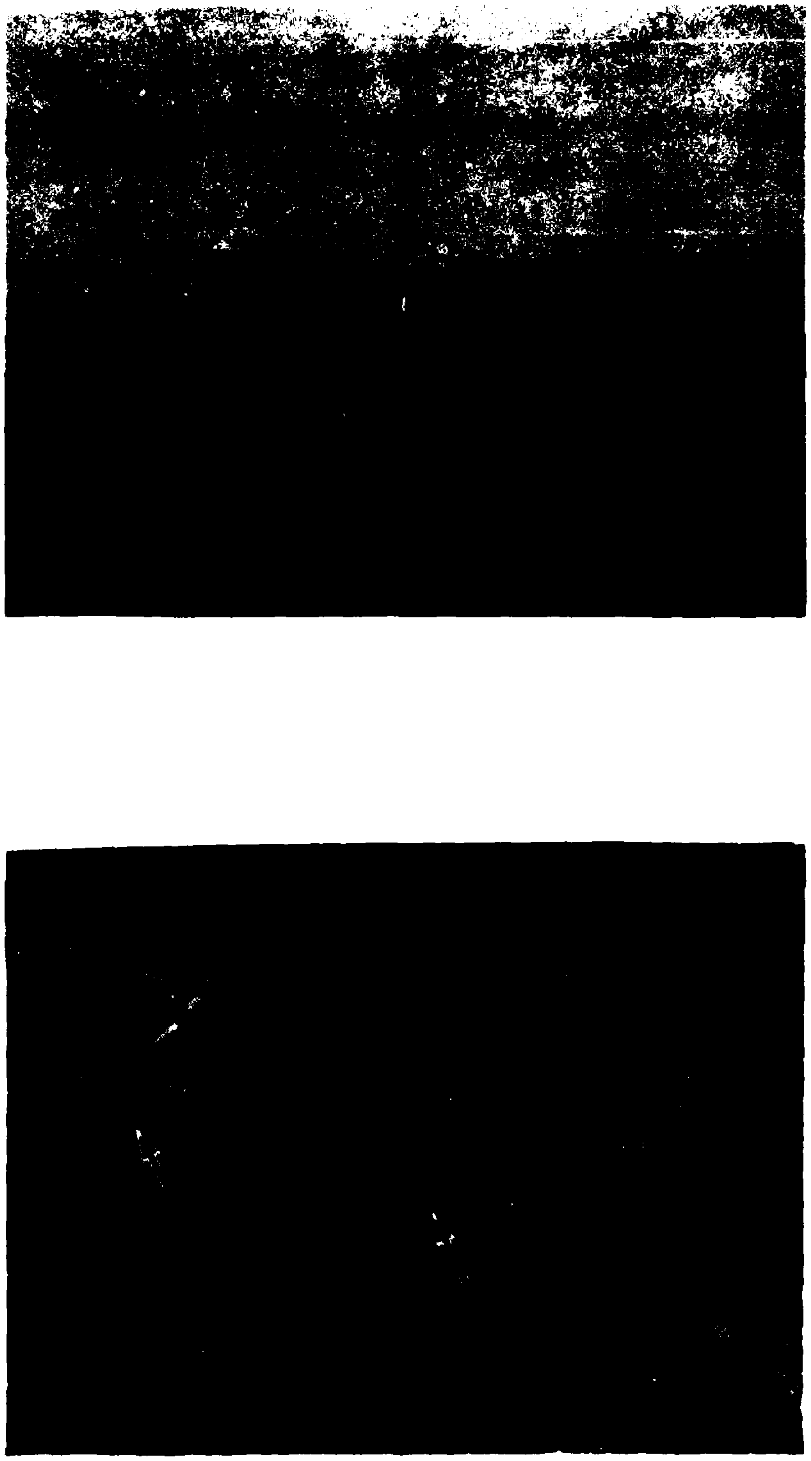

Figure 15. Visible Delaminations On Kevlar Frustum

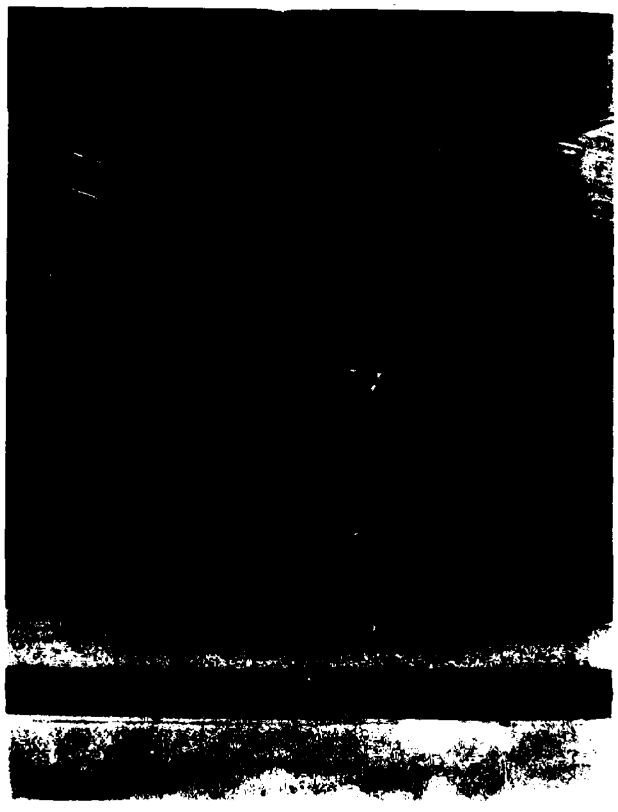

Figure 16. Blast-Induced Cracks On Front Surface Of Kevlar Frustum, 80 Psig Test

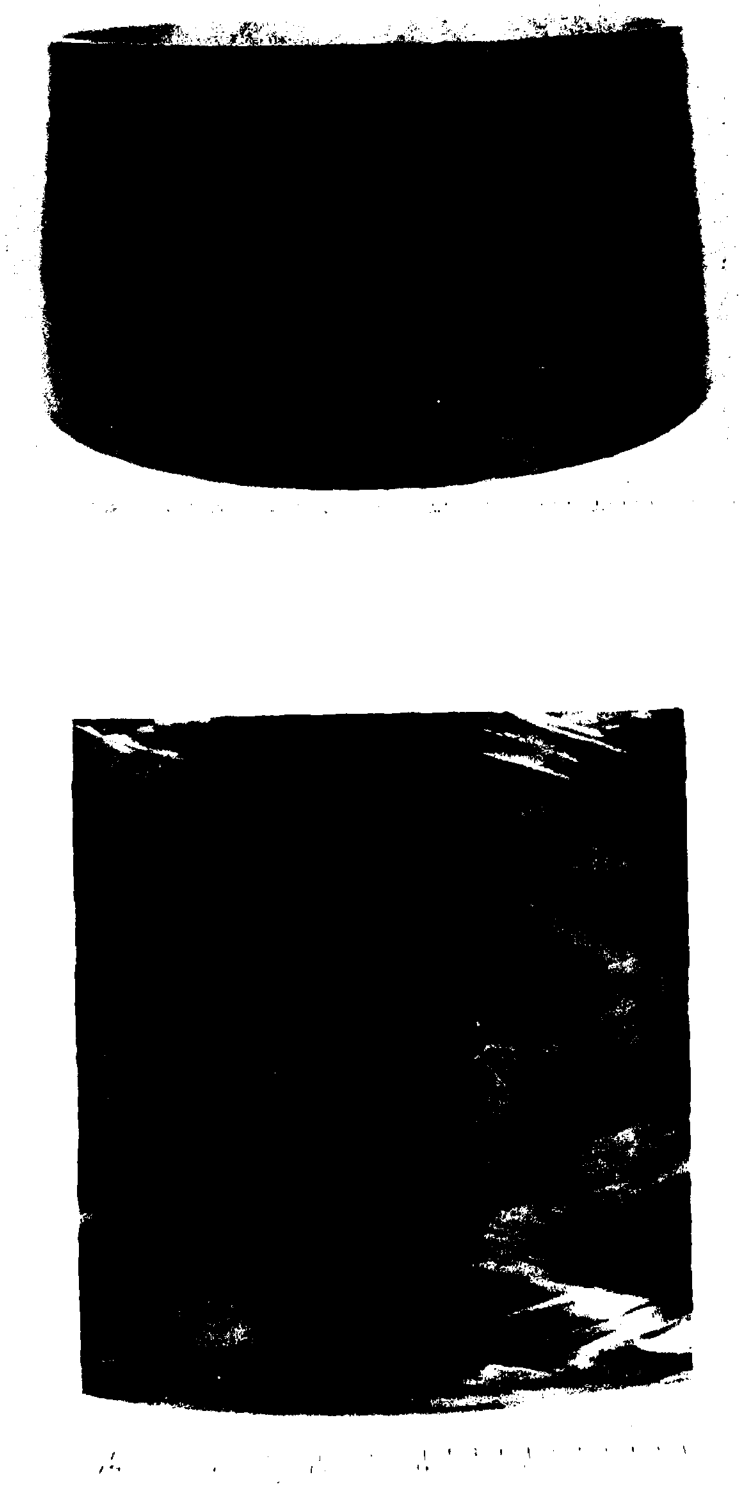

Figure 17. Blast-Induced Cracks On Front Surface Of Hybrid Frustum, 50 Psig Test

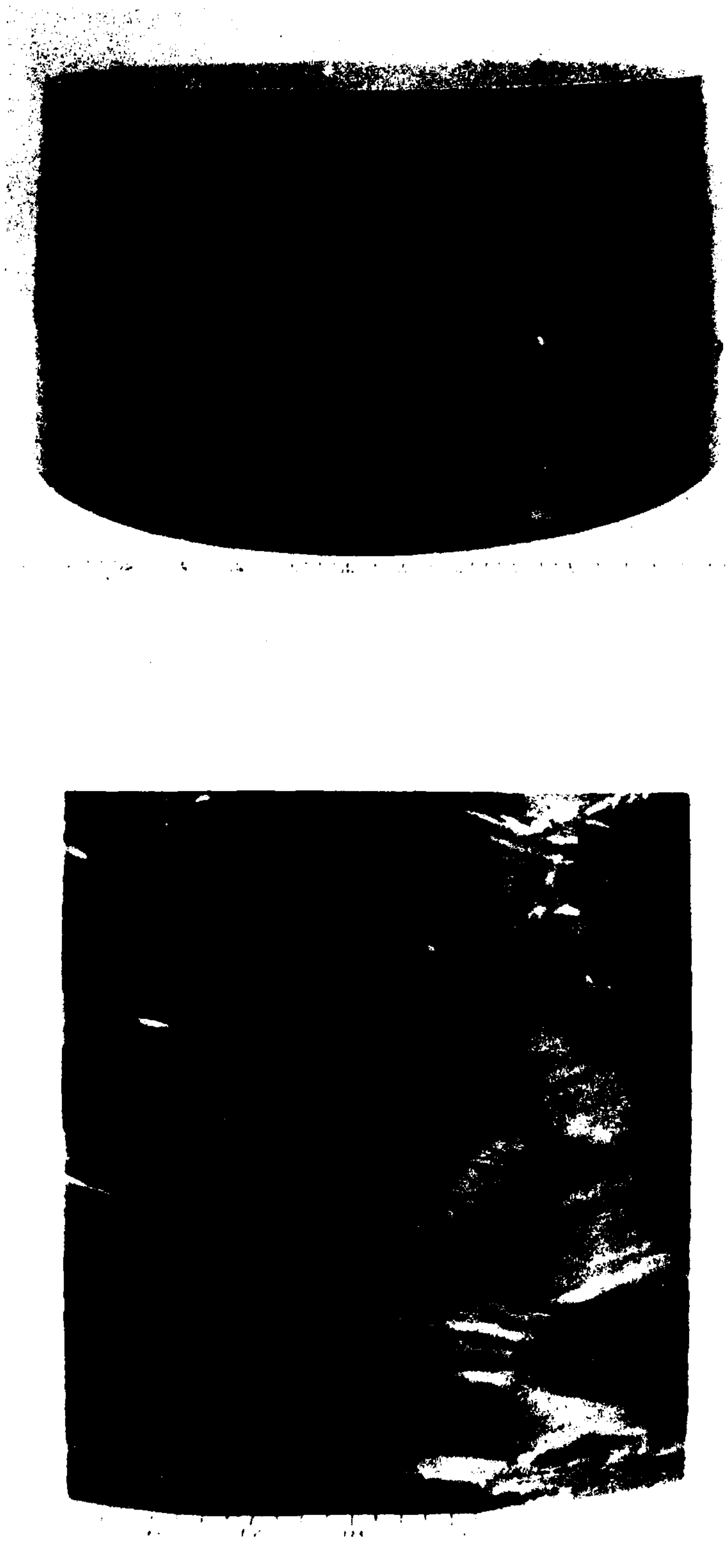

Figure 18. Blast-Induced Cracks On Front Surface Of Hybrid Frustum, 80 Psig Test

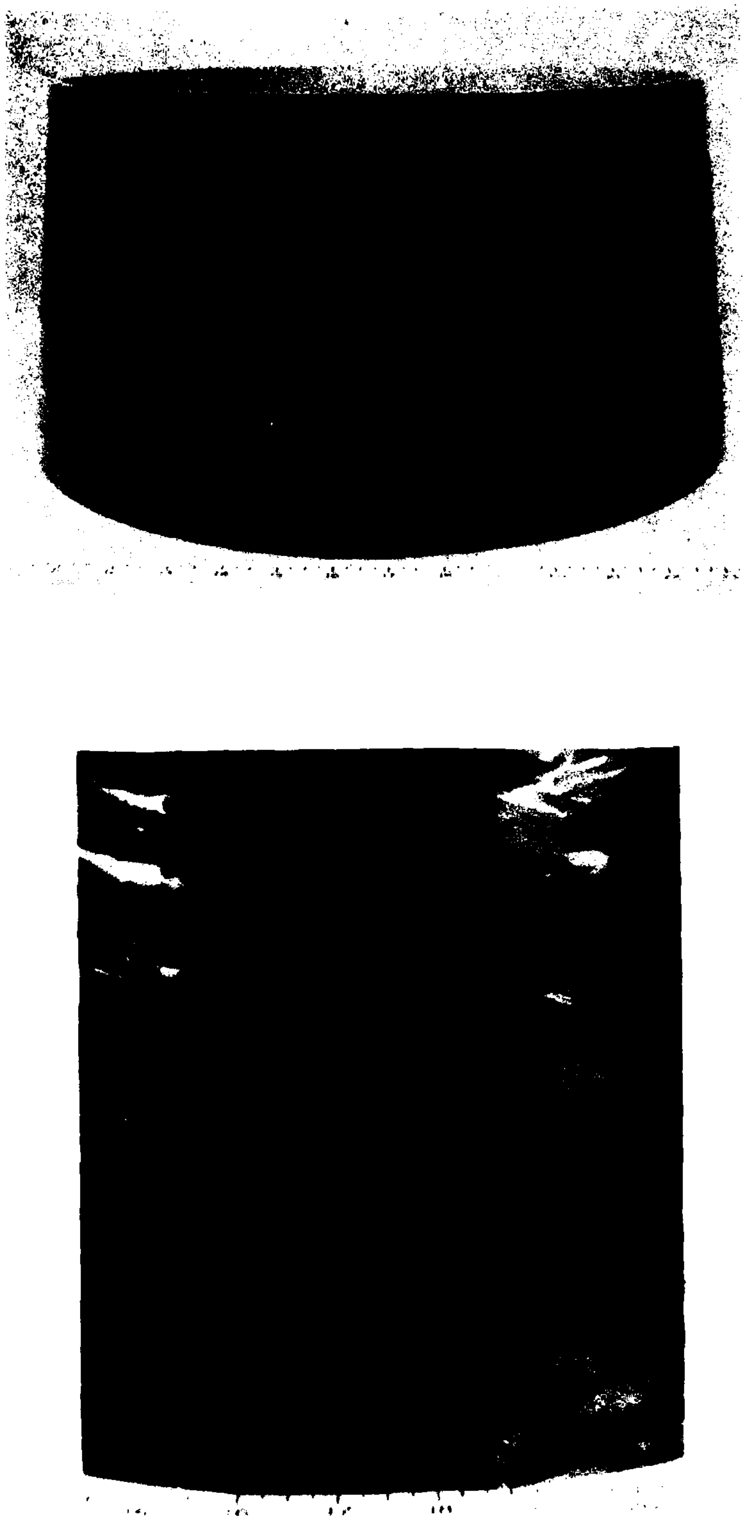

Figure 19. Blast-Induced Cracks On Side Surface Of Hybrid Frustum, 80 Psig Test

IV. FINDINGS AND CONCLUSIONS

In accomplishing this experimental program, a number of findings and conclusions were obtained:

- It was possible to modify the simulation techniques previously developed for blast loading flat targets to loading curved (frusta) targets.
- The blast simulator had been designed and previously used up to a maximum reflected pressure of 50 psig with a 12 millisecond duration. In this program the reflected blast loading was significantly increased to 80 psig with 30 millisecond duration. Because of these much larger repeated loads, cracks in the welds of the blast tank developed quite often, requiring several reweldings.
- Reflected pressures measured on the wooden fixed frustum were essentially the same as on the one held in place with the nylon straps. The same combination of charge weight, vent area, and foam thickness was then used on the composite frusta to provide the two desired reflected blast loads.
- For each type of composite material used, the worst blast damage was consistently found on those frusta loaded with the higher blast pressures.
- Visual evaluation of the blast damage indicated that as a group the carbon/epoxy frusta showed the least amount of damage. The most damage was found on the hybrid frusta group.

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SIMULATED BLAST TESTING OF
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46 pp — illust., Contract DAAG46-79-C-0056
D/A Project: 8X363304D215
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