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INVESTIGATION OF 14.5MM API SELF-SEALING/CRASHWORTHY FUEL TANK MATERIAL

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Goodyear Tire and Rubber Company

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This final report describes the results of a program for a crashworthy, 14.5mm API tolerant fuel cell construction developed and subjected to qualification testing. The preproduction testing was in accordance with the requirements of MIL-T-27422, Rev B and Amendment 1, except the gunfire tests of cube cells (Paragraphs 4.6.6.4 and 4.6.6.5), which were not required by contract. Two fuel tanks were built of a construction designated by The Goodyear Tire & Rubber Company as ARM 066 (DX-680). One tank was tested in accordance with Paragraph 4.6.12 of MIL-T-5578, Rev C, except that 14.5mm API projectiles were used instead of caliber .50 AP M2. The other tank was sent to the Eustis Directorate at Fort Eustis, Virginia, for evaluation.

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EUSTIS DIRECTORATE POSITION STATEMENT

The technology used to design and fabricate the caliber .50 AP M2 self-sealing fuel tanks used on many current Army aircraft was extended to design and fabricate a tank material to seal wounds from the 14.5mm API round. Consequently, the increased sealing capability was achieved primarily by a considerable increase in material thickness and weight. Future developmental efforts will concentrate on obtaining satisfactory sealing performance at a lower weight penalty.

The information herein will be of use to aircraft designers and tacticians who must trade off the increased ballistic protection provided by the material against its increased weight and cost.

During the ballistic testing of the tank material, severe hydraulic ram damage to the simulated helicopter structure surrounding the tank was observed. If this tank material is adopted to provide 14.5mm API protection, it is recommended that additional measures be taken to ensure that the potential hydraulic ram forces generated by this round will not damage critical airframe components.

Mr. Charles M. Pedriani of the Military Operations Technology Division served as project engineer for this effort.

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INTRODUCTION

The self-sealing fuel tanks installed in current rotary-wing aircraft are ballistically tolerant against impacts by projectiles up to .50 caliber armor piercing. With the introduction of the 14.5mm API threat, it is mandatory to develop a qualified fuel tank construction that is both crashworthy and resistant to the 14.5mm API projectile.

The objective of Task I was to conduct a design study for the selection of an optimum fuel cell construction for fabrication of crashworthy, 14.5mm API self-sealing fuel cells. On the basis of this study, a construction was selected that showed favorable results in preliminary testing. This construction was further evaluated in Task II.

The objective of Task II was to prove the ballistic tolerance of the selected construction by gunfire evaluation of a simulated full-sized fuel tank in the size, shape, and capacity proposed for rotary-wing aircraft.

FUEL TANK MATERIAL DESIGN STUDY (TASK I)

Three candidate constructions were designed for evaluation (see Table 1). The designs incorporated materials of minimum weight and thickness and maximum strength and elongation based on Goodyear's past experience in crashworthiness and ballistic performance.

TABLE 1 - CANDIDATE CONSTRUCTIONS

Construction	Weight (lb/ft^2)	Approx Gage (in.)
DX-681	1.517	0.338
DX-682	1.597	0.343
DX-701	1.801	0.417

Each candidate construction was fabricated into 24-inch by 24-inch panels. The gunfire system included a panel of candidate construction, a panel of Goodyear BBC-3 backing board, and a panel of aluminum honeycomb. Each panel system was attached to a gunfire structure furnished by the Eustis Directorate (see Figures 1 and 2). The gunfire structure, with test panel attached, was filled three-fourths full of JP-4 fluid at ambient temperature and impacted with a 14.5mm API at 0-degree obliquity and 90-degree yaw. The yawed impact was obtained by firing the projectile at service velocity from a 5-foot-long smooth-bore barrel located 27 feet from the specimen (see Table 2 for gunfire test results). Construction DX-682 was selected for further evaluation in Task II on the basis of the ballistic test results.

TABLE 2 - PANEL GUNFIRE TEST DATA				
Panel	Round	Wound Size (in.)	Result	Rating*
DX-682	1 entry	2.25	Medium seep	3
DX-701	2 entry	2.31	Medium seep	3
DX-681	3 entry	1.50	Medium seep	3
DX-682	4 exit	1.31	Slow seep	2
DX-701	5 exit	1.50	Medium seep	3
DX-681	6 exit	2.00	Fast seep	4

*Leakage ratings used by USAAMRDL, where dry seal = 0; damp seal = 1; slow seep = 2; medium seep = 3; fast seep = 4; slow leak = 5; medium leak = 6; and fast leak = 7.

QUALIFICATION OF CONSTRUCTION (TASK II)

Preproduction testing of DX-682 was initiated based on its superior performance over DX-701 and DX-681. However, during testing of ARM 066 (DX-680) under a separate program, it was observed that the performance of DX-680 was better than DX-682. It was then mutually agreed between Goodyear and the Eustis Directorate that the rest of the program (preproduction testing and tank fabrication) would be conducted with DX-680 instead of DX-682.

The following paragraphs relate to MIL-T-27422B and Amendment 1 and present the qualification procedures and resulting data. The indicated test fluids conform to TT-S-735. All testing was conducted by The Goodyear Tire & Rubber Company, Akron, Ohio; all tests were completed satisfactorily (see Table 5).

Inspection (Paragraph 4.6.1)

Each test cube was examined in accordance with Paragraph 4.6.1 to ensure that the cube conformed with the Goodyear building specification regarding proper materials and methods of construction. Workmanship of the test cube was inspected in accordance with ANA Bulletin Nos. 107 and 112.

Seam Adhesion (Paragraph 4.6.4.6)

Seam adhesion was tested in accordance with Paragraph 4.6.4.6. The test was performed along the length of the seam by the stripback method and used a jaw separation rate of 2 inches per minute as detailed in Federal Test Method Standard No. 601, Method 8011. The seam was tested before and within 4 hours after immersion in Type III test fluid for 72 hours at 135 degrees F.

Seam adhesion in the original condition was 25.8 pounds per inch and after immersion was 15.9 pounds per inch, as opposed to a minimum requirement of 6 pounds per inch.

Slit Resistance (Paragraph 4.6.4.7)

Slit resistance was tested on a sample of the composite construction in accordance with Paragraph 4.6.4.7. A 1-inch slit down to the depth of the sealant was made in the inner liner. The sample was bent 180 degrees and clamped in a vise, with the jaws parallel to and 1 inch from the slit. The sample was held for 1 hour with the slit growth not exceeding 0.25 inch. There was no growth in the slit on the sample tested.

Inner Liner Adhesion (Paragraph 4.6.4.8)

The adhesion of the inner-liner ply, with barrier, to the adjacent ply was tested by the stripback method and used a separation rate of 2 inches per minute as detailed in Federal Test Method Standard No. 601, Method 8011. Adhesion averaged 9.5 pounds per inch.

Stress Aging (Paragraph 4.6.4.9)

Ten samples of the inner-liner ply, each 4 inches square, were double folded, with the point of the double fold located in the center of the samples. The samples were held in the folded condition with paper clips located 0.5 inch from the double-folded edge. The folded samples were soaked in Type III fluid for 7 days at 160±3 degrees F and then air dried for 7 days at 160±3 degrees F. There was no evidence of blistering, cracking, separation, or other material failure.

Constant Rate Tear (Paragraph 4.6.5.1)

Twenty composite cell construction specimens in accordance with Figure 4 of MIL-T-27422B were conditioned for 24 hours at 77±5 degrees F and relative humidity of 50 to 65 percent; they were tested at a jaw separation rate of 20 inches per minute using metal clips. Force versus jaw separation was plotted, and the separation energy was determined by the area under the plotted curve. The energy for complete separation of each specimen exceeded the required minimum of 400 foot-pounds. The data given in Table 3 was generated during the constant rate tear test.

Impact Penetration (Paragraph 4.6.5.2)

Twenty composite cell construction specimens in accordance with Figure 5 of MIL-T-27422B were conditioned for 24 hours at 77±5 degrees F and relative humidity of 50 to 65 percent; the specimens were tested by impacting them with a 5-pound chisel from a height of 15 feet. Five of the specimens were positioned so that the warp direction of the exterior ply was at an angle of 0 degrees, 45 degrees right, 45 degrees left, and 90

TABLE 3 - ENERGY OF SEPARATION (FT-LB)							
Angle (deg)	Energy	Angle (deg)	Energy	Angle (deg)	Energy	Angle (deg)	Energy
0	774	45R	1000	45L	1132	90	927
0	1235	45R	790	45L	1200	90	937
0	967	45R	1230	45L	1090	90	1105
0	1060	45R	1230	45L	1210	90	1048
0	1080	45R	1060	45L	985	90	958

degrees with the chisel. All samples were impacted on the exterior sides. The interior side of each sample was pressurized with 5 psi air, and the exterior side was checked with a soap solution. There was no evidence of leakage in any of the 20 samples.

Impact Tear (Paragraph 4.6.5.3)

Twenty composite cell construction specimens in accordance with Figure 6 of MIL-T-27422B were conditioned for 24 hours at 77±5 degrees F and relative humidity of 50 to 65 percent; the specimens were tested by impacting them with a 5-pound chisel from a height of 10 feet into a V-notch in the specimen. There was no tear in any of the 20 specimens.

Panel Strength (Paragraph 4.6.5.4)

Six composite cell construction specimens were tested as shown in Figure 7 of MIL-T-27422B. A 4-inch-diameter plunger was forced into the center of the test panel at a rate of 20 inches per minute until failure occurred. The average ultimate load of the three highest samples was 33,450 pounds. Table 4 gives the results of the panel strength calibration test.

TABLE 4 - ULTIMATE FORCE (LB)	
Inner Liner	
Up	Down
31,000	33,200
34,150	31,250
33,100	26,350

Fitting Strength (Paragraph 4.6.5.5)

Four test panels, each containing 4-inch outside diameter fittings built into the composite construction, were tested in a drop test apparatus as shown in Figure 8 of MIL-T-27422B. The lowest recorded load was 30,000 pounds, which is greater than 80 percent of the panel strength in Paragraph 4.6.5.4. Actual values are 30,000, 30,500, 31,000, and 30,750 pounds.

Fuel Resistance of Exterior Surfaces (Paragraph 4.6.6.1)

Since this test is performed on the stand test cube, it was performed after the stand test to preclude the possibility that the soaked exterior might cause false stain of the stand test indicator paper. Test cube serial number 1359 was tested for fuel resistance of exterior surfaces as detailed in the specification; there was no evidence of deterioration or failure.

Crash Impact (Paragraph 4.6.6.2)

Test cube serial number 1364, with cover plate attached to the fitting, filled with 770 pounds of water, and with all air evacuated, was placed in a web sling as shown in Figure 9 of MIL-T-27422B. The cube was lifted to a height of 65 feet measured from the bottom of the cube and was held in a horizontal position. The release mechanism was actuated, and the cube was allowed to drop freely onto a concrete surface. There was no evidence of rupture or spillage.

Slosh Resistance (Paragraph 4.6.6.3)

Test cube serial number 1359 was tested for slosh resistance by installing it in a suitable container and mounting it on a rocker assembly. The assembly was rocked through an angle of 15 degrees on each side of the level position at 17.25 cycles per minute for 25 hours with the cube two-thirds full of Type III fluid. The test fluid was maintained at 110 degrees F throughout the test.

There was no evidence of leakage or failure.

Stand Test (Paragraph 4.6.6.6)

Following the slosh resistance test, test cube serial number 1359 was completely filled with Type III fluid. The cube was inspected after completion of the 90-day stand test and showed no evidence of failure.

Fuel Contamination (Paragraphs 4.6.4.1 and 4.6.4.2)

Fuel contamination tests were performed according to Paragraphs 4.6.4.1 and 4.6.4.2. A sample of the inner liner was diced into 0.062-inch squares, was placedin a flask containing 250 milliliters of Type III fluid, and was allowed to stand for 48 hours at 77±3 degrees F.

The contaminated test fluid was decanted, and the residue was determined by Method 3302 of Federal Test Method Standard No. 791, except the evaporation time was 45 minutes instead of the 30 minutes specified in Standard No. 791. After the test beakers cooled, they were weighed and the gum content was determined. The beakers were then placed in a muffle furnace and maintained at 572±9 degrees F for 30 minutes. After the beaker cooled to room temperature in a closed container, it was weighed and the stoved gum determined.

The fluid contamination can be no greater than 60 milligrams per 100 milliliters of contaminated fluid; upon stoving, it can be no greater than 20 milligrams per 100 milliliters of contaminated fluid. Duplicate samples were run with 11.0 and 13.0 milligrams of nonvolatile gum residue per 100 milliliters of test fluid; 6.0 and 7.0 milligrams of stoved gum residue per 100 milliliters of test fluid were determined.

Inner Liner Strength (Paragraph 4.6.4.3)

Inner liner strength tests were performed in accordance with Paragraph 4.6.4.3. The tensile strength of the inner-liner ply, without barrier, was determined according to Federal Test Method Standard No. 601, Method 4111, before and after immersion in Type III fluid for 72 hours at 135±3 degrees F and after immersion in a solution of 25 percent MIL-I-27686 inhibitor and 75 percent water, by volume, for 72 hours at 135±3 degrees F. The tensile strength should not be reduced more than 50 percent for Type III immersion and 20 percent for water and inhibitor immersion, calculated on the basis of the original cross-sectional area. The average reduction in tensile strength was 41.9 percent in Type III fluid and 18.9 percent in water inhibitor.

Permeability (Paragraph 4.6.4.5)

Samples of the inner liner with barrier were prepared in accordance with Paragraph 4.6.4.5.1 and assembled on test cups containing 100 milliliters of Type III fluid. The tests were conducted per Paragraph 4.6.4.5.2 with the cups weighed to the nearest 0.005 gram. For the first 24 hours, the faces of the cups were upward and were reweighed to check the integrity of the seal. The cups were then inverted and weighed at the end of the third, fifth, and eighth day period, and absorption was expressed as fluid ounces per square foot per 24 hours. The permeability was to be less than 0.025 fluid ounce per square foot per 24 hours. Duplicate samples were run with the permeability at 0.003 and 0.005 fluid ounce per square foot per 24 hours.

TABLE 5 - SUMMARY OF TESTS PER MIL-T-27422B, AMENDMENT 1			
Test	Paragraph	Requirement	Actual
Inspection	4.6.1	Examine for conformance to specification.	Serial number 1359 and 1364.
Nonvolatile gum residue	4.6.4.1	Fluid contamination not to exceed 60 mg of nonvolatile material per 100 ml of fluid.	11.0 and 13.0 mg of nonvolatile material.
Stoved gum residue	4.6.4.2	Stoved gum residue not to exceed 20 mg per 100 ml of contaminated fluid.	6.0 and 7.0 mg of stoved gum residue
Inner liner strength	4.6.4.3	Tensile strength not reduced more than 50 percent for fuel immersion and 20 percent for water inhibitor immersion based on original cross section.	Strength reduction 41.9 percent in Type III fluid and 18.9 percent in water inhibitor.
Permeability	4.6.4.5	Permeability to be less than 0.025 fl oz/sq ft/24 hr.	0.003 and 0.005 fl oz/sq ft/24 hr.
Seam adhesion	4.6.4.6	Adhesion not less than 6 lb/in. before and after immersion in Type III fluid at 135 deg F for 72 hr.	25.8 lb/in. original; 15.9 lb/in. after immersion.
Slit resistance	4.6.4.7	Growth of 1-in. slit not to exceed 0.25 in.	No growth.
Inner liner adhesion	4.6.4.8	Adhesion to be 6 lb/in. min.	9.5 lb/in. avg.
Stress aging	4.6.4.9	No evidence of blistering, cracking, separation, or other material failure.	No evidence of failure.
Constant rate tear	4.6.5.1	Minimum energy of separation, 400 ft-lb for each of 20 specimens.	Separation energy for each specimen was greater than 400 ft-lb.

TABLE 5 - SUMMARY OF TESTS PER MIL-T-27422B, AMENDMENT 1 (Concluded)			
Test	Paragraph	Requirement	Actual
Impact penetration	4.6.5.2	No leakage with 5-psi air after impact in 18 of 20 specimens.	No evidence of leakage in any specimen.
Impact tear	4.6.5.3	Length of tear not to exceed 0.5 in. after impact in 18 of 20 specimens.	No tear in any specimen.
Panel strength	4.6.5.4	Average of 3 highest samples after penetration of 4-in. plunger at 20 in./min.	Average load of 3 highest samples was 33,450 lb.
Fitting strength	4.6.5.5	Lowest recorded load to be in excess of 80 percent of panel strength in 4.6.5.4.	Lowest recorded load was 30,000 lb.
Fuel resistance of exterior surfaces	4.6.6.1	Bottom half of test cube immersed in Type III fluid for 72 hr at ambient temp.	No adverse effects.
Slosh resistance	4.6.6.3	25 hr at 110 deg F with Type III fluid.	No adverse effects.
Stand test	4.6.6.6	Test cube with Type III fluid after 90 days.	No adverse effects after 90 days.
Crash impact	4.6.6.2	Drop cube from 65 ft filled with 770 lb of water.	No leakage after 65-ft drop.

FUEL TANK GUNFIRE

Two full-sized fuel tanks were constructed of DX-680 to the capacity and shape of an actual helicopter tank. The first fuel tank, since it was intended for gunfire, had only one standard type molded access fitting. The second tank used actual fittings of the radial cord crashworthy type.

A simulated cavity structure was made of structural steel angle iron frame and aluminum honeycomb panels. The interior of the cavity structure was lined with Goodyear BBC-5 backing board on the bottom and sides in preparation for the gunfire. The fuel tank was installed in the structure and filled two-thirds full of TT-S-735 Type I test fluid at ambient temperature.

Firing was conducted in accordance with Paragraph 4.6.12 of MIL-T-5578C, Rev C, except that 14.5mm API projectiles were used instead of .50-cal AP M2. The gunfire results are given in Table 6. The impacted tank and structure are shown in Figures 2 through 14.

CONCLUSIONS

The following conclusions are made regarding the 14.5mm API tolerant fuel cell construction:

1. Goodyear fuel tank construction ARM 666 (DX-680) met the Phase I test requirements of MIL-T-27422B, Amendment 1.

2. The crashworthy and ballistic response characteristics of construction DX-680 demonstrate its acceptability as a 14.5mm API ballistically tolerant crashworthy construction.

3. Goodyear BBC-5 backing board in conjunction with construction DX-680 demonstrated excellent ballistic response against 14.5mm API projectiles.

TABLE 6 - FUEL TANK GUNFIRE RESULTS

Round	Entry (deg)	Mode	Entrance	Exit	Structural Damage
1	90 to RH side	SI	Damp seal	FT damp seal at 1 min	LH panel split vertically at 1X.
2	90 to RH side	FT	Damp seal	No exit	Hydraulic ram damage to entry panel; frame bowed at rear panel.
3	45 to LH side	SI	Damp seal	FT SS to damp seal at 2 min	Extensive petaling at exit; RH panel bulged.
4	45 to aft side	SI	Damp seal	1/2T leakage not determined	Petaled panel at exit; bottom panel bulged.
5	90 to LH side	SI	Damp seal	1 1/2-in. wound FS at 2 min	RH honeycomb panel edge fastening failed.
6	45 to forward	SI	Dry	4-1/4-in. wound SS to drip at 2 min	Panel damaged by slicing shot at exit.
7	90 to RH side	3/4T	Dry	1-1/4-in. wound; damp seal	-
8	45 to bottom	SI	Dry	FT; no visible leakage	Blew open LH forward corner angle reinforcement.
9	90 to aft side	SI	Dry	3/4T damp seal at 1 min	4-1/2-in.-diameter hole in panel plus extensive petaling.

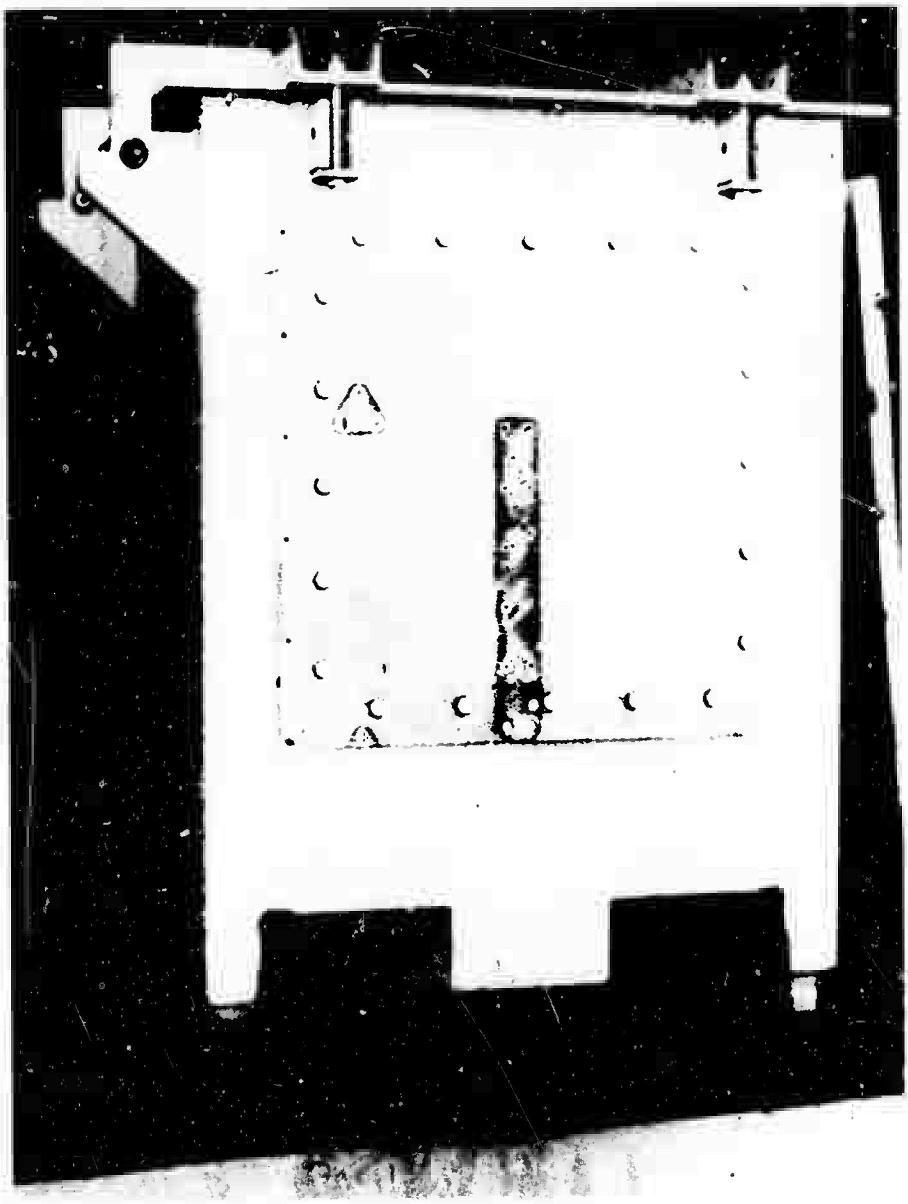

Figure 1. Panel Structure With Panel Attached.

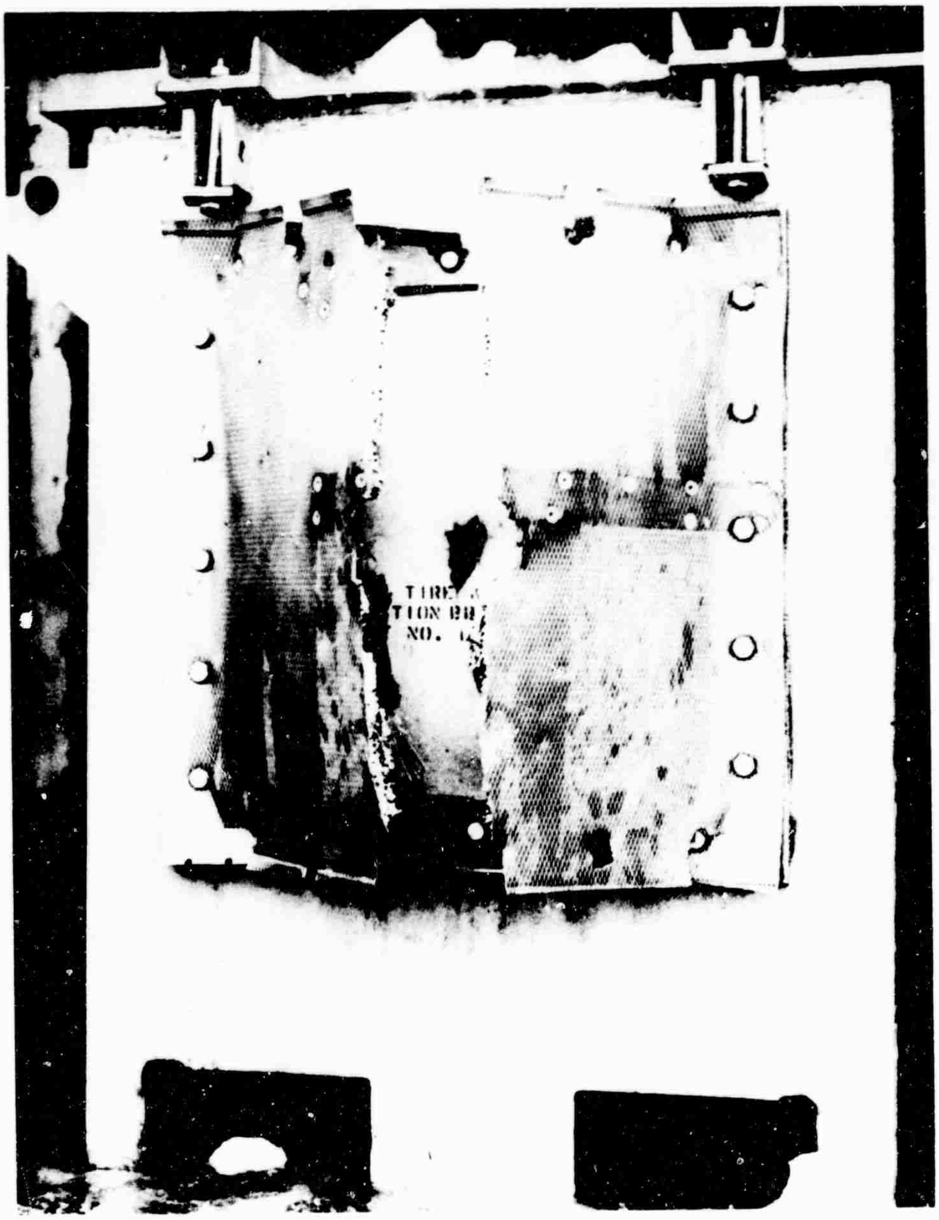

Figure 2. Panel Gunfire Structure With Panel.

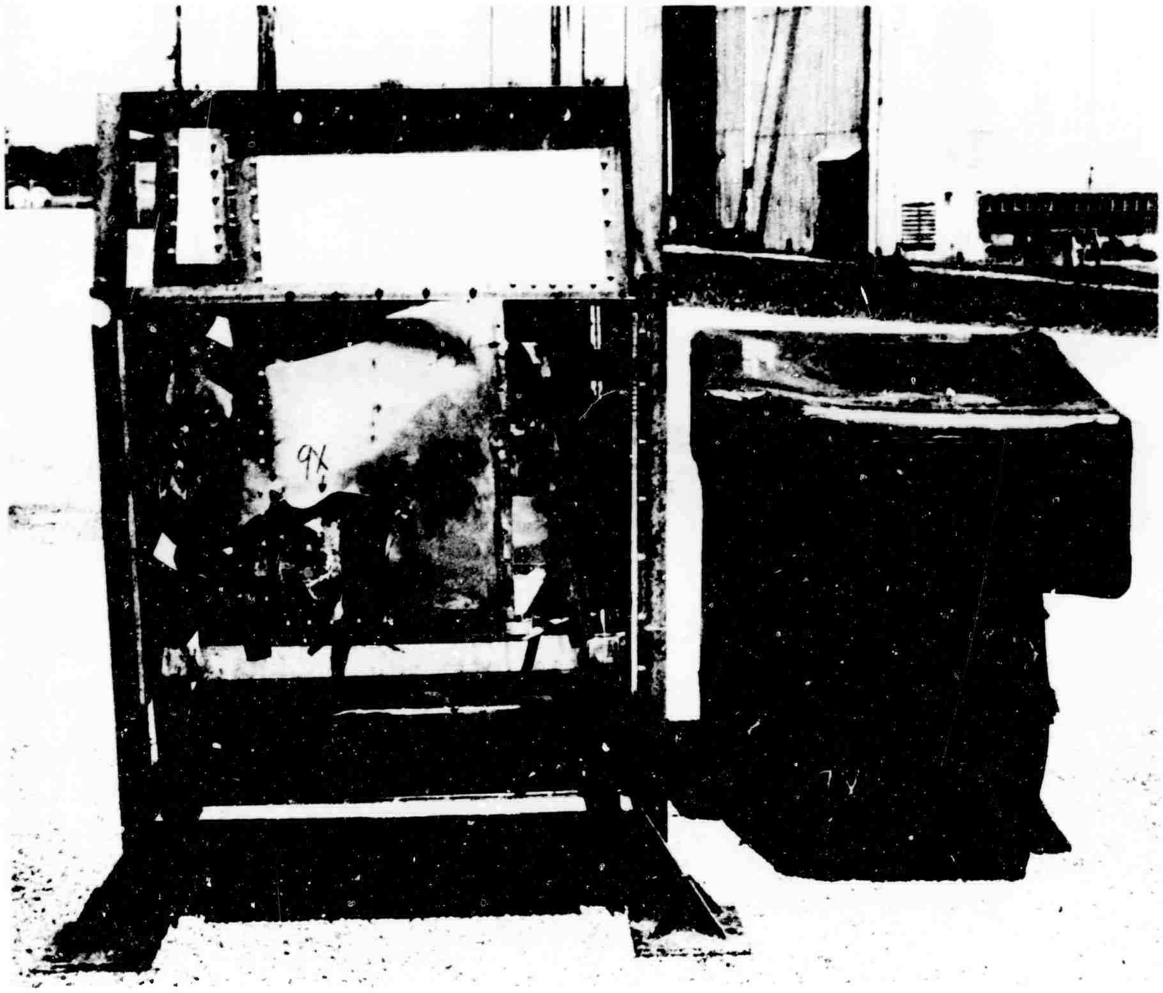

Figure 3. Tank and Structure (Forward Side) After Test Firing.

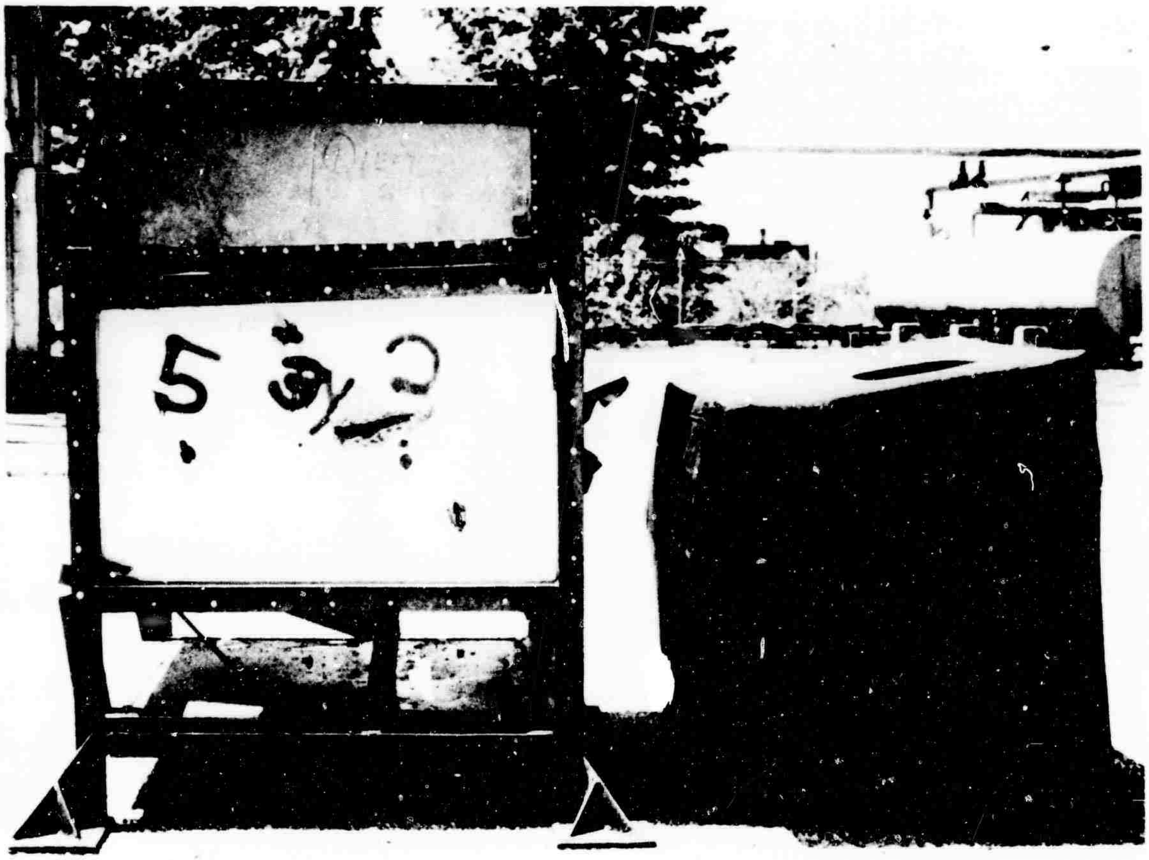

Figure 4. Tank and Structure (Left Side).

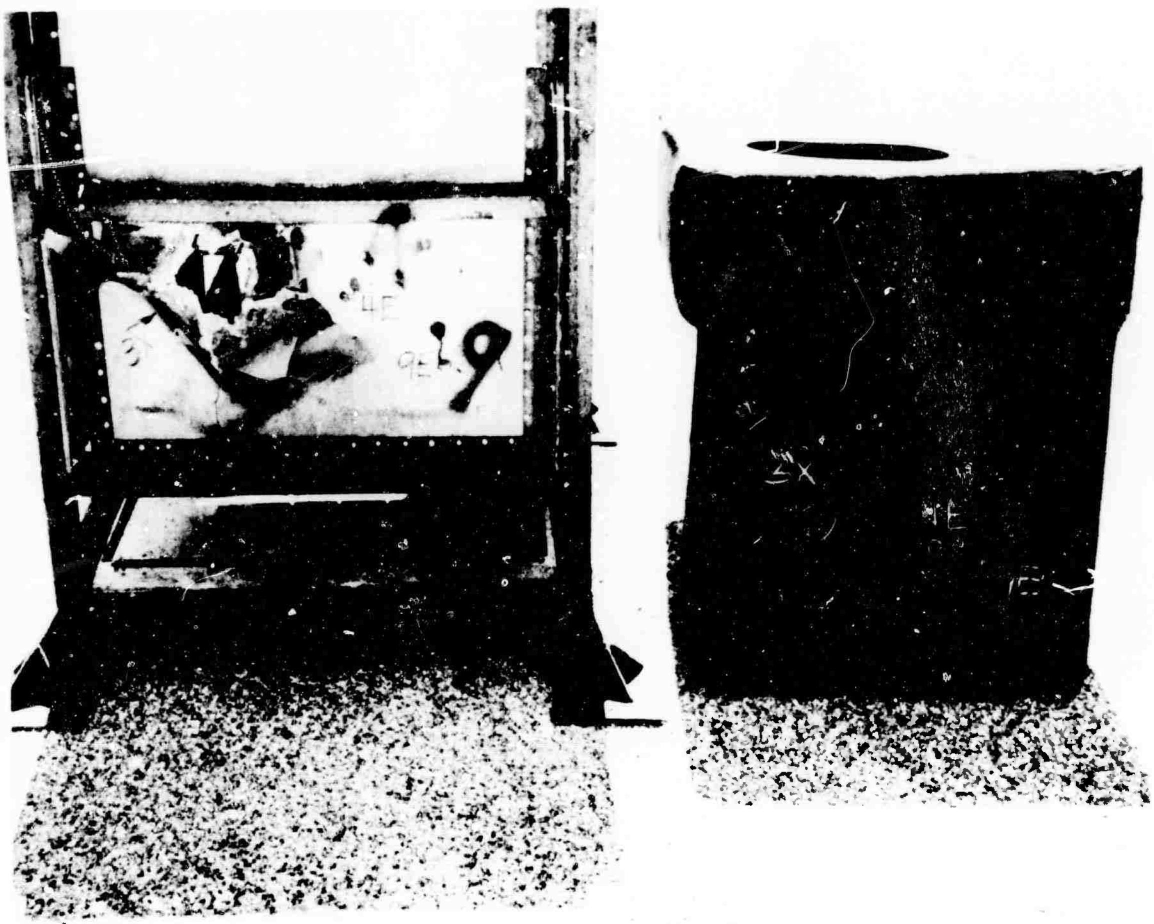

Figure 5. Tank and Structure (Aft Side).

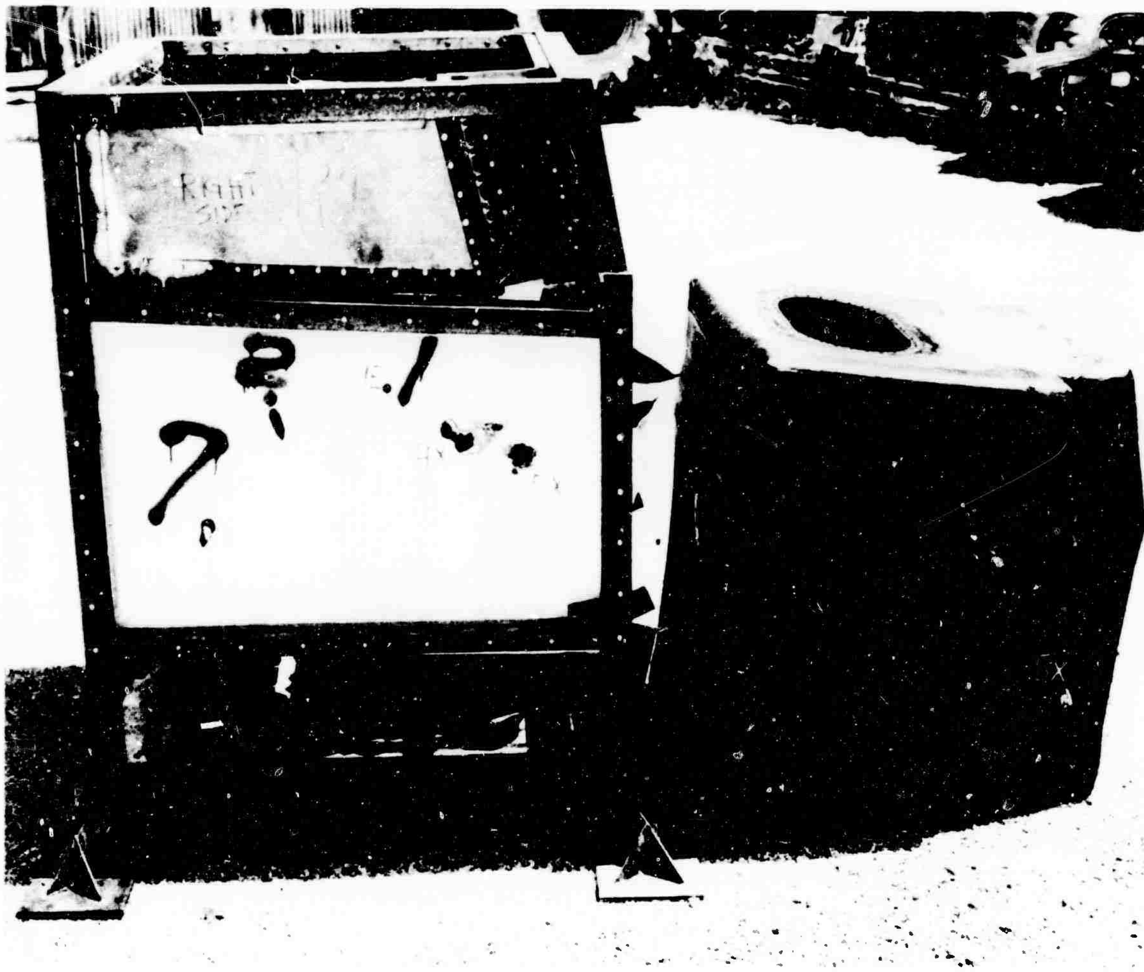

Figure 6. Tank and Structure (Right Side).

Figure 7. Tank and Structure (Bottom Side).

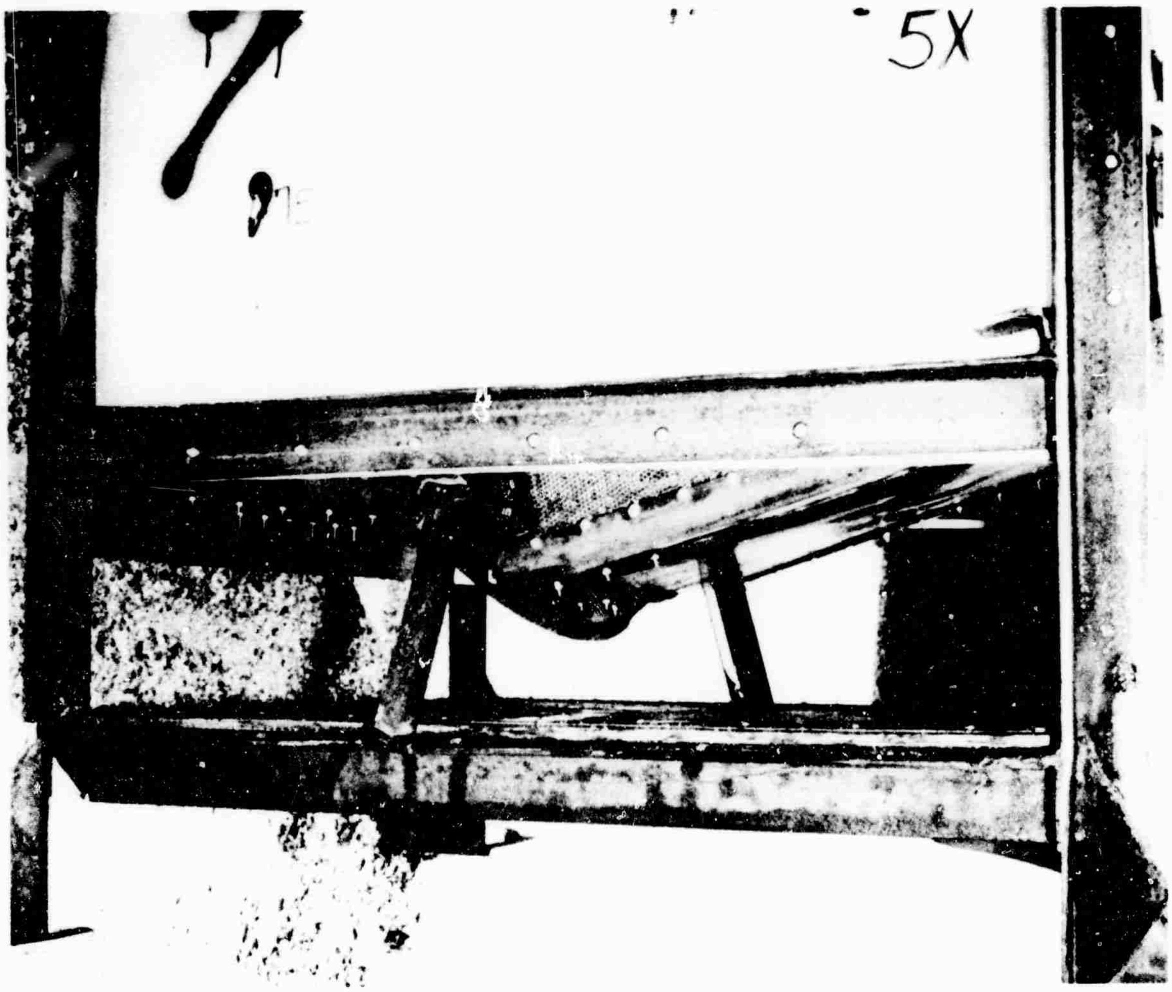

Figure 8. Damaged Structure (Bottom).

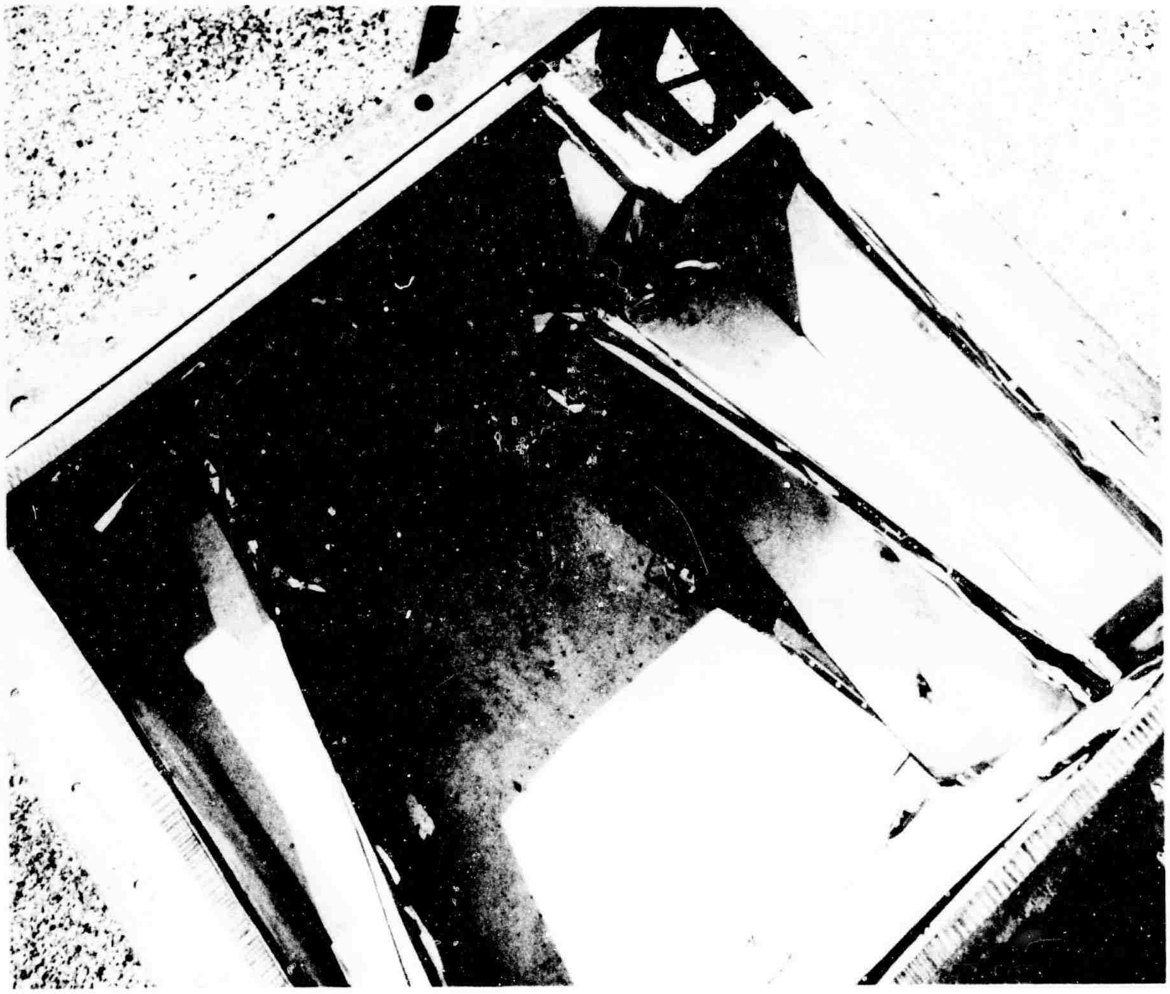

Figure 9. Interior of Structure With Backing Board.

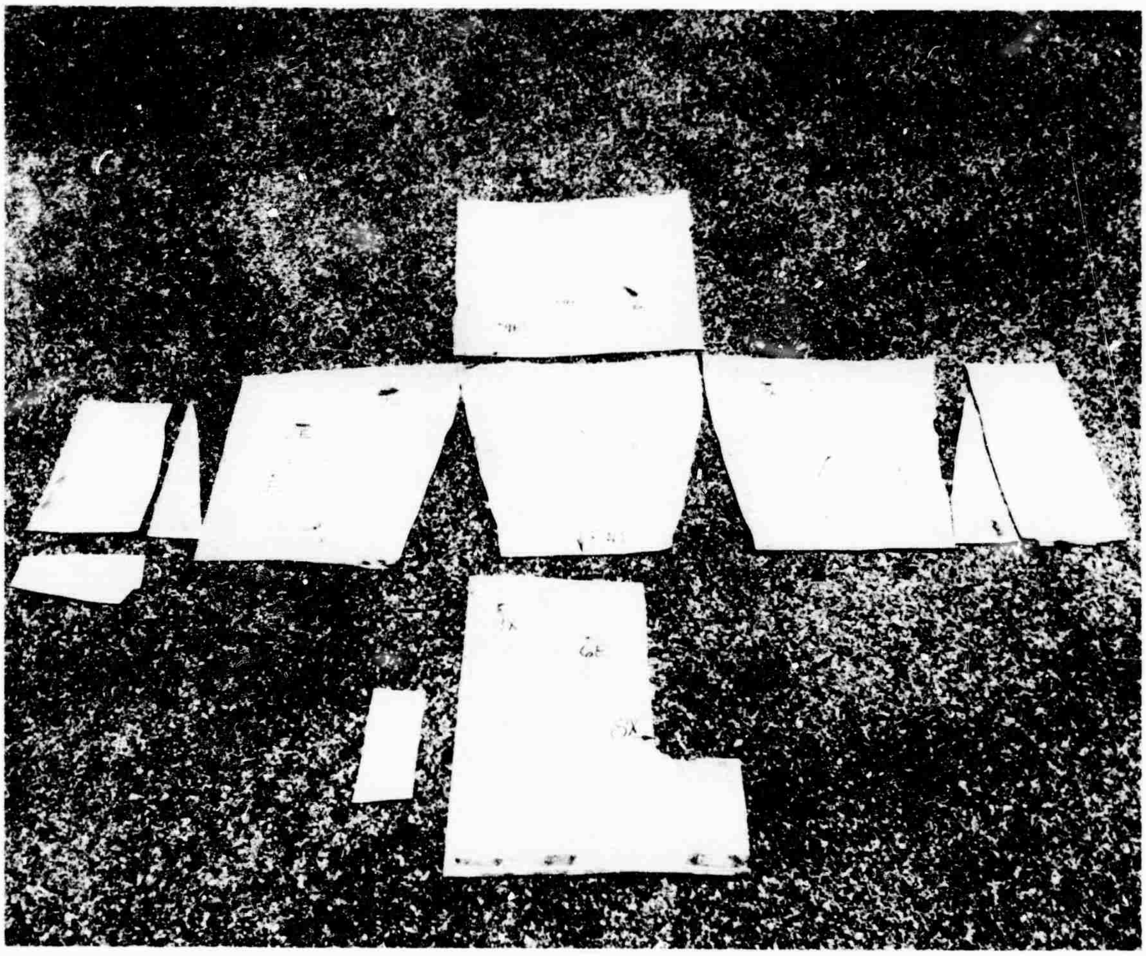

Figure 10. Backing Board Used in Gunfire Test.

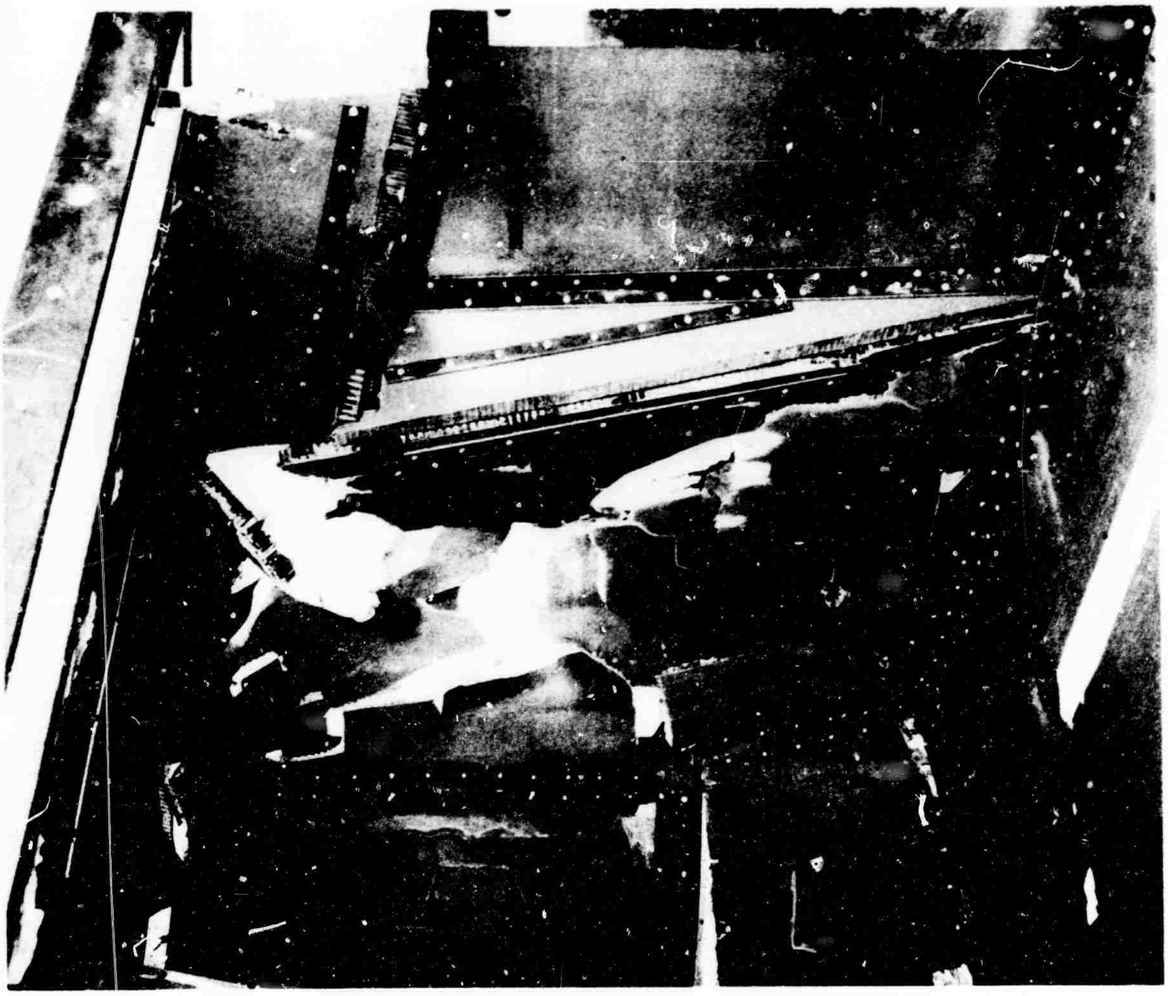

Figure 11. Honeycomb Panel of Structure (RH Side).

Figure 12. Honeycomb Panels of Structure
(LH Side, Aft Side, Bottom Panels).

Figure 13. Damaged Structure From Exterior Side (RH, Front Corner).

Figure 14. Damaged Structure From Exterior Side (LH, Front Corner).