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A BLAST FRAG WARHEAD FOR THE HELLFIRE MISSILE TO DEFEAT SHIPS AND BUNKERS

Michael Denigan (1), Michael Gunger (1) and John Cunningham (2)

(1) Primex / OTI Group
4565 Commercial Dr, Suite A, Niceville, FL 23578, 850-897-9700
(2) Lockheed Martin Electronics & Missiles
5600 Sand Lake Rd, MP-65, Orlando, FL 32819-8907, 407-356-9204

This paper reports the successful development and performance of a multipurpose warhead for the Hellfire missile. This blast-frag warhead was designed to perforate a target wall and detonate inside the compartment. The new warhead extends Hellfire's defeat capability to patrol boats and MOUT targets. The paper presents performance requirements, hydrocode and analytical analyses, and test results of the explosive load and warhead body. Test results include:

- Half scale gun tests – that evaluated perforation and ricochet performance of two nose shapes against RHA, mild steel, and fiberglass targets
- Full scale dynamic sled tests – that demonstrated successful perforation of steel and brick targets with a missile guidance section
- Static arena tests – that demonstrated two different fragment shapes plus a safe-separation test to prove that the launch platform is safe from aft fragments.

This program was internally funded by Lockheed Martin and PRIMEX-OTI in 1997 and 1998. Following this effort, the US Navy funded a qualification program.

1. INTRODUCTION

Primex / OTI Group has designed a Hellfire Blast Frag Warhead for Lockheed Martin (LMC) to integrate into the Hellfire II and Longbow missiles. The warhead is required to perforate:

- Corvette ship hulls at up to maximum missile range and $\alpha°$ obliquity.
- MOUT brick wall at up to maximum missile range and $\beta°$ obliquity

An analysis of potential target vessels from adversarial countries revealed that typical corvette class ship side hull and main decks are relatively thin steel. Frigates are only slightly thicker. Therefore, to be conservative, the program concentrated on perforating mild steel targets associated with frigate class thicknesses. It is not implied that a single warhead in this size category would destroy such a large vessel. Rather, the missile's primary role would be against close shore patrol type vessels.

PRIMEX-OTI designed the warhead case, baseplate, fuze well, incendiary, and explosive. (The electronic delay fuze is supplied by a third vendor.) The warhead has the following features:

- Weight = 12.5 kg
- Length = 342 mm
- Outside diameter = ∅114 mm
- Anti-ricochet nose
- Insensitive Munition qualifiable explosive load (PBXN-109), with venting
- Incendiary follow-through fire start of cellousic and hydrocarbon fuels
- Controlled fragmentation

Figure 1 shows the warhead body and baseplate prior to painting and explosive loading.

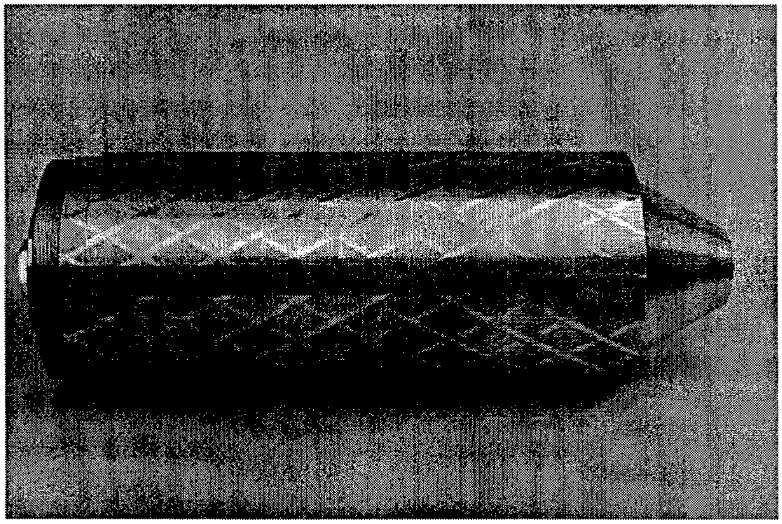

Figure 1. Blast Frag Warhead

Since the warhead is smaller in diameter and slightly heavier than the existing Hellfire Main charge, LMC designed a special missile bracket to hold the warhead within the missile section. The bracket is designed to fail when the missile impacts a target.

This Blast Frag Warhead does not use the Hellfire precursor shaped charge. The precursor was removed from the missile to reduce weight and complexity.

In 1998, two full-up warhead missile sections were fired on a rocket sled against steel and brick targets. Both warheads successfully perforated and detonated behind the targets. This paper summarizes some of the analysis used to design the warhead nose shape, baseplate, and fragmentation.

2. SIZE & SHAPE

Although the missile diameter would permit a six inch diameter warhead, the warhead weight was limited to 12.5 kg. Therefore, to improve weight-to-presented area, the warhead diameter was reduced to 114 mm. At this weight and diameter, the estimated ballistic limit was near a frigate class thickness of hardened steel. An OTI*HULL simulation of the warhead impacting a frigate class steel plate at minimal missile velocity, Figure 2, showed that the perforation performance was marginal. The performance against thinner targets would then be more than adequate. Penetration could be improved by further reducing the diameter; however, such a modification significantly reduces the explosive load while increasing the cost. Additional costs would be incurred because decreasing the diameter without the ability to increase the length requires adding expensive tungsten weights to the nose.

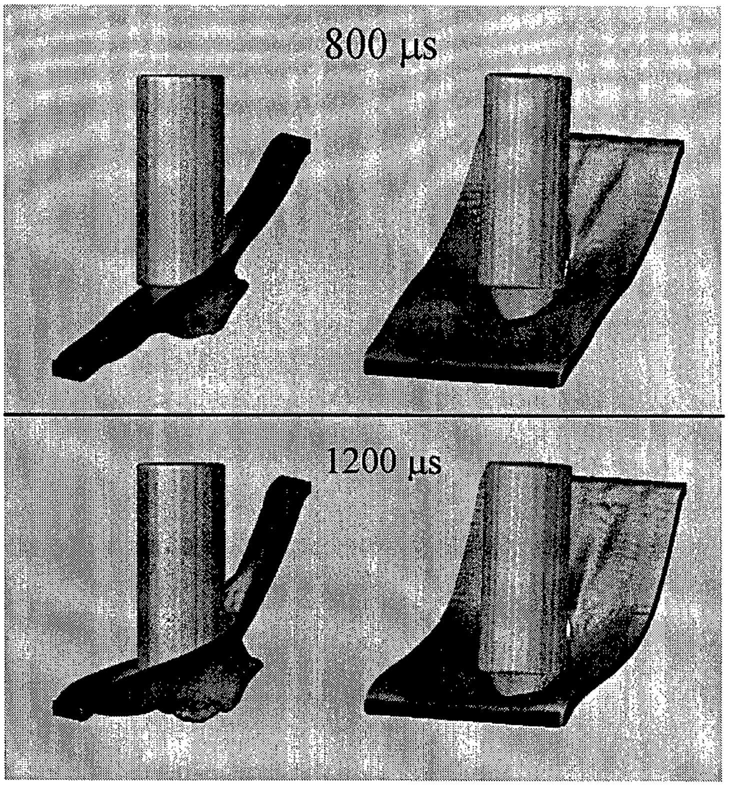

Figure 2. OTI*HULL Simulation of the Warhead Perforating Frigate Class Mild Steel at Minimum Velocity.

Given that a 12.5 kg, 114 mm diameter warhead would overmatch nearly all corvette class targets, the only remaining concern was ricochet. Since a hydrocode analysis cannot easily investigate ricochet tendencies, we conducted half scale gun tests to assess ricochet and confirm our low velocity perforation modeling.

For the half scale tests, two nose shapes were selected: a flat-nose and a bottle-nose. Sketches of the two configurations are shown in Figure 3. The only difference between the two designs was that the bottle-nose had more material removed to shape the stepped nose. Both noses were designed to have the front flat surface dig into the target and cause the warhead to pivot normal to the target, thereby reducing the effective obliquity. At high obliquity target engagements, the second, outside shoulder will dig into softer targets and mitigate ricochet.

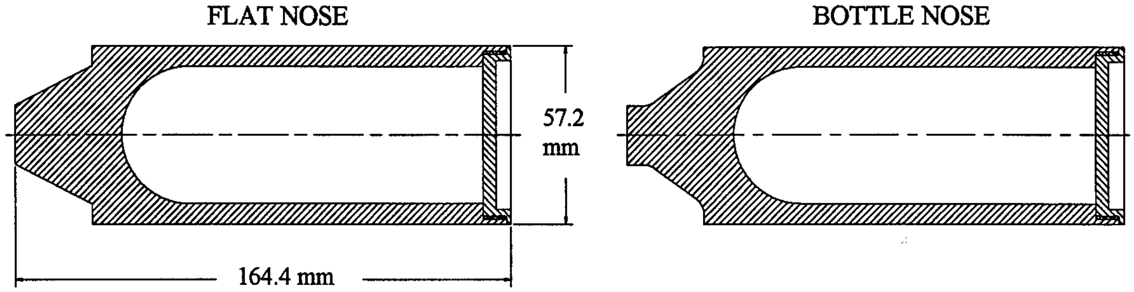

Figure 3. Nose Designs for Half Scale Gun Tests to Assess Perforation and Ricochet

The saboted penetrators were fired from a 91 mm smooth bore gun. Although a high speed camera was used to assess yaw & pitch, neither varied more than a few degrees for all tests. A total of eleven tests were fired against 6.35 mm RHA and A36HR mild steel at normal and maximum obliquity and minimum and maximum velocity. A twelfth test was fired against 12.7 mm of G-10 fiberglass at maximum obliquity. All tests perforated the targets, except for one rebound against 0° RHA at minimum velocity. (A second test at the same condition barely perforated the RHA plate.)

The results showed that both flat-nose and bottle-nose penetrator shapes were more than capable of defeating the thickest mild steel and fiberglass targets found on frigates. PRIMEX-OTI selected the flat-nose design over the bottle-nose because it had a slightly higher exit velocity and was easier to fabricate. The design was robust. No ricochets ever occurred, and the penetrators exhibited only slight damage after perforation. Even the greatest deceleration, approximately 47,000 g's, which occurred during the rebound off the RHA target, resulted in only slight damage to the nose. All penetrators could be re-used for additional testing.

The penetrators easily perforated the G-10 fiberglass at minimum velocity. The penetrator lost only 12% of its velocity exiting the fiberglass. At these low velocities, mild steel was much easier to perforate than RHA. The penetrators perforated the mild steel plates at minimum velocity and maximum obliquity ($\alpha°$), even though the target was much thicker than the RHA tests at normal impact. Note that RHA has a tensile strength that is 2.1 to 3.3 times that of hot rolled A36 mild steel. Material strength is significant at these low velocities.

Later in the program, full scale penetrators were built and fired down a sled track. The results substantiated the half scale results.

3. BASEPLATE

The baseplate functions as a fuze well, an IM vent channel, a fuze interface, and a missile lock ring interface. Six vent holes in the baseplate provide a path for expanding explosive gases generated during either fast or slow cook off tests. The vents are plugged by polyethylene after the main charge is cast. The deflection temperature of the vent plugs is approximately 46 C (115°F) at 66 psi, whereas the initiation temperature of PBXN-109 is approximately 150 C (300°F). The plugs will quickly fail if the internal pressure builds.

Thermal analysis showed that the vent area is adequate to prevent propulsion outside the 15 m limit. The adequacy of the vent area was assessed by assuming that the explosive acts as a propellant and burns from the aft section to the nose through a nozzle — a reasonable assumption for heat conduction during fast cook-off.

4. INCENDIARY

A zirconium incendiary mixture was added to the warhead to augment fuel initiation. Films of the arena tests showed the incendiary fragments continued to burn for more than a second, Figure 4. Since the target was never specifically defined during this phase of the program, no tests were performed to specifically substantiate the fuel starting capability. At the end of the development program, diesel fuel jerry cans were placed behind the MOUT brick target on a full-up sled test. After the warhead breached the wall, the delay fuze initiated the warhead and the diesel fuel combusted.

Figure 4. Burning Incendiary Fragments are Present for About a Second

5. EXPLOSIVE LOAD COMPACTION

Early in the program, before the fuze well was defined, an axial explosive load analysis was performed to assess the potential problem of a gap developing between the fuze and the explosive. The maximum expected deceleration occurs when the penetrator strikes a thick target at minimum velocity. (Our half scale testing showed this to be about 25,000 g's in full scale.)

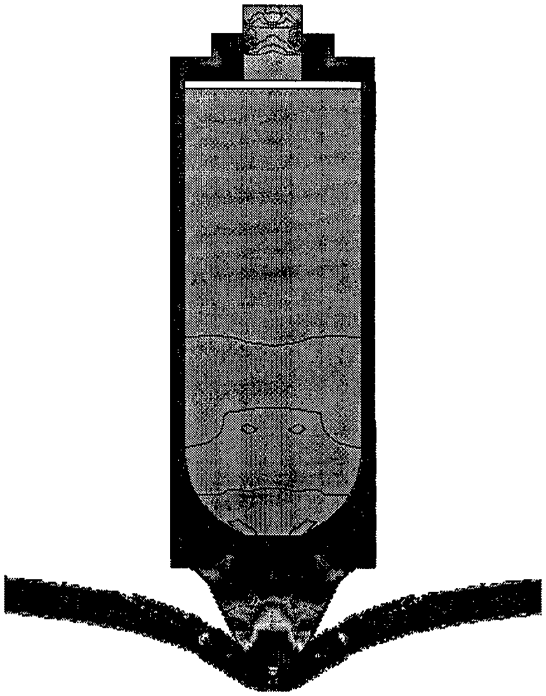

Figure 5. OTI*HULL Model of the Set Forward Compaction at Target Impact. Maximum Compression of the Explosive is about 4 mm at 400 μs.

To assess the peak pressure and resulting compaction, a porous model of the explosive fill was developed using the Piston Test to generate the required material parameters. This porous model was put into the OTI*HULL code and the result is shown in Figure 5. The peak pressure in the explosive was calculated to be 1.47 kbars at about 200 μs. An approximately 4 mm gap opened between the explosive and the baseplate at 400 μs. (The gap can be seen in Figure 5.) Since this gap is less than the booster fill overlap, no effect upon initiation is expected. Nor does the gap occur within the time frame of the delayed detonation.

6. CONTROLED FRAGMENTATION

The Blast Frag Warhead features a thick case wall and rather insensitive explosive. Upon detonation, the warhead case is expanded to about 60 μs before case fracture, Figure 6. During the initial trade studies, consideration was given to making the warhead generate heavy fragments which would perforate the hull of a ship from within the compartment already breached. The additional perforations would ensure rapid flooding of a vessel. To achieve this perforation, the fragment size must be substantial for the expected velocity. Figure 7 shows a OTI*HULL simulation in which a large steel fragment does not quite perforate a 12.7 mm target backed with water. (Again, this over-represents our target suite but was assessed for robustness.) To demonstrate a warhead with large fragments, we designed and tested an axially scored warhead that generated 24 large strips with minimal interstitial fragments. Figure 8 shows several of the recovered fragments, the longest of which was 205 mm. Upon further consideration of the expected target arrays, the program direction changed to pursue smaller diamond shaped fragments. The many smaller fragments provide greater lethality against ship components and MOUT type targets. For the second phase of the program, we used a scoring pattern that generated a good fragment distribution with the upper bound limited by a nominal diamond size, Figure 8.

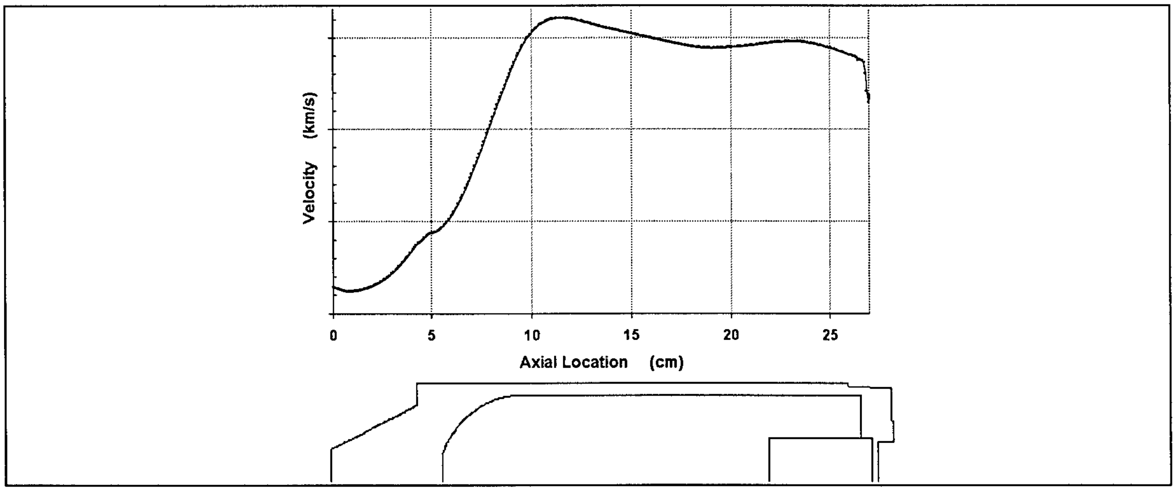

Figure 6. Case Expansion Velocity at 60 μs

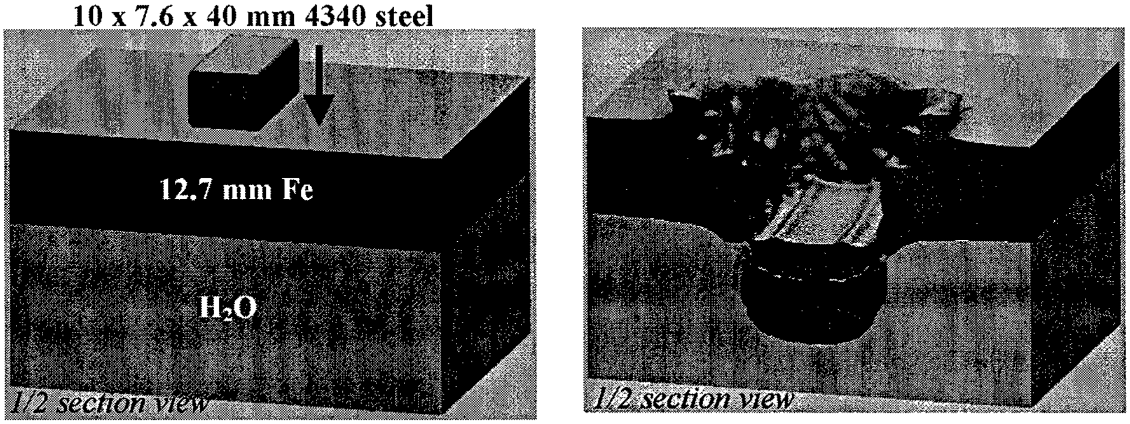

Figure 7. OTI*HULL Simulation of 10 x 7.6 x 40 mm Steel Fragment Nearly Perforating 12.7 mm of Mild Steel Backed with Water

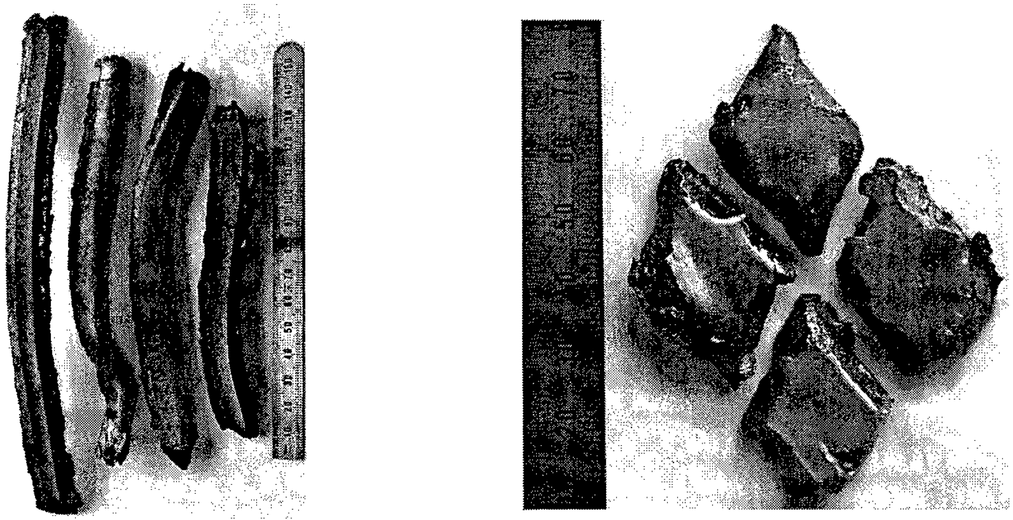

Figure 8. Axial and Diamond Fragments can be Easily Achieved by Controlling the Case Fracture

Although only two fragment patterns were tested in this program, nearly any controlled fragmentation approach can be implemented that does not adversely affect the integrity of the penetrator.

7. ARENA TEST FOR SAFE SEPARATION

A safe separation test was conducted to ensure that the launch platform was safe from aft warhead fragmentation. For this test, the whole aft portion of the missile, Figure 9a, was fired in an arena with 22 gage steel witness panels 5.8 m behind it, Figure 9b. The witness panels covered an area 2.4 m high and 4.9 m long. High speed film showed the rocket motor slowly traveling toward the witness panels at about 33 m/s, Figure 9c. There were no perforations through the steel panels. The rocket motor was recovered after it hit the sand bag ricochet barrier. The motor absorbed the warhead's baseplate and remained intact, Figure 9d.

8. DYNAMIC SLED DEMONSTRATION

PRIMEX-OTI conducted four dynamic sled verification tests. The results are summarized in Table 1.

Test #	Objective	Conditioning?	Fuze	Impact Velocity	Target	Target Perforated?	Warhead Condition?
RT97-332	Explosive Survivability	none	Inert	min	X+ mild steel α°	yes, but rebounded	reusable
RT98-249	Structural Integrity	none	Inert	max	X mild steel α°	yes	reusable
RT98-334	Full-up Demo	Trans-Vib	Live	mid	X mild steel α°	yes	delayed detonation
RT98-335	Full-up Demo	Trans-Vib	Live	mid	brick β°	yes	delayed detonation

Table 1: Dynamic Sled Verification Tests

The objective of the first full scale warhead test was to validate the half scale gun tests and ensure that the PBXN-109 main charge would not react during target deceleration. The first test provided a higher deceleration than anticipated. The warhead and missile section rebounded off the target after the warhead had already perforated a full diameter hole. The warhead and missile section came to rest a few feet away from the target. The warhead did not break away from the retaining ring. Subsequently, LMC redesigned the retaining ring to fail at a lower threshold. Had the warhead been fuzed, it would have detonated and destroyed the target before rebounding and falling away.

The overall penetration performance was considered roughly similar to the half scale tests even though similar half scale tests perforated — albeit with low exit velocities. At these low impact velocities, the test variables (e.g. target hardness and penetrator attitude) cannot be controlled well enough to obtain much better than a 100 m/s noise level.

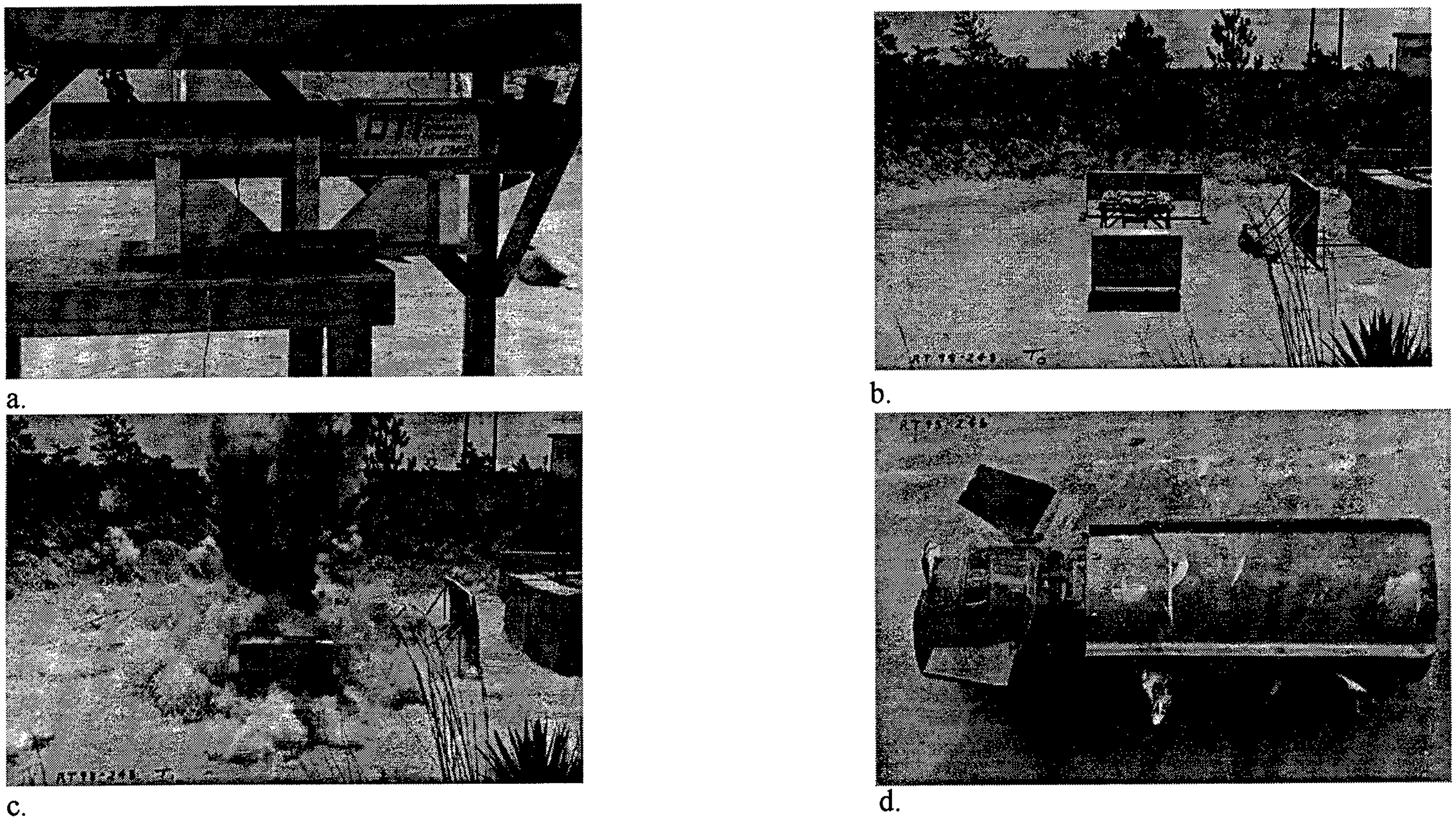
a. b. c. d.

Figure 9. Safe Separation Test:
a) Warhead in missile section with spent rocket motor
b) Test arena with witness panels & Celotex panels on the right
c) After detonation, the rocket motor can be seen flying into the witness panels. (Note the fragment impacts around the arena, but none aft of the warhead.)
d) Rocket motor absorbed the warhead baseplate and remained intact

The test demonstrated good warhead integrity and insensitivity. The damage to the warhead was cosmetic. The warhead was recovered, cleaned up, and set aside for future tests.

The second sled test was used to verify the structural integrity of a modified warhead with a new retaining ring. At the higher velocity, both the warhead and the missile perforated the slightly thinner target. While the missile skin stopped at the Celotex® behind the steel plate, the warhead continued to penetrate eight feet of Celotex® before hitting concrete. The warhead was recovered and cleaned. Again, the only blemish was scratches on the warhead nose.

The development program ended with two full-up dynamic demonstration tests. The sled tests were conducted after the warhead missile sections had successfully completed ambient Transportation-Vibration testing.

Since the ESAF could not easily be fired on a sled track, an EBW (exploding bridgewire) detonator was substituted. To fire the detonator, an electric switch was placed on the face of the target. One missile section was fired against mild steel at maximum obliquity (α°), and the other against brick at β°. Both warheads perforated and detonated behind their respective targets. The exit hole in the brick is shown in Figure 10.

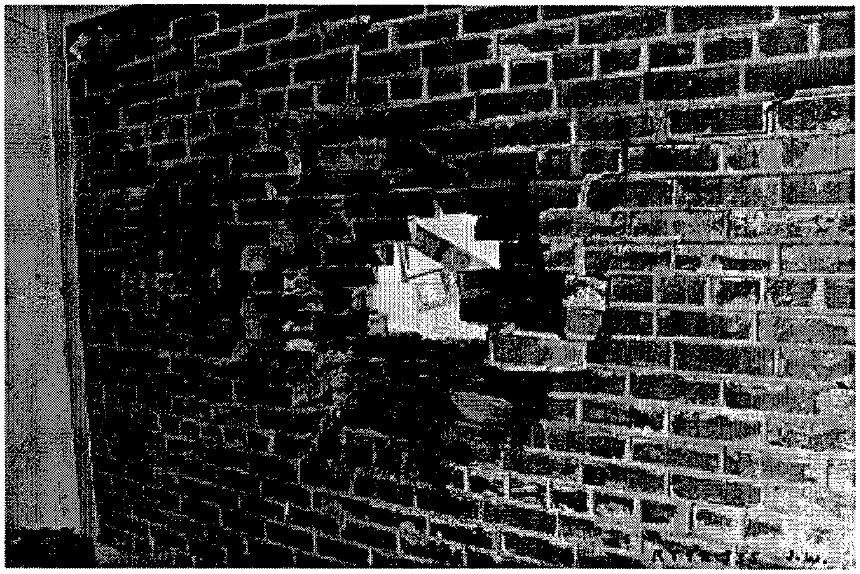

Figure 10. Perforation through Brick at β°, Test RT 98-335

9. CONCLUSIONS

The half scale and full scale dynamic testing demonstrated that the Blast Frag Warhead will perforate Corvette class ship hulls and MOUT brick targets. The launch platform is also safe from aft fragmentation. After this internal development program was completed, the US Army awarded a contract to Lockheed Martin with Primex-OTI as the warhead subcontractor. Currently, program is in the EMD phase with the first production deliverables due in January 2000.

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