ARMY RESEARCH LABORATORY

Results of 35-mm Airburst Demonstration

by Timothy G. Farrand

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Results of 35-mm Airburst Demonstration

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Abstract

The U.S. Government and several industry representatives collaborated to initiate a demonstration of the current 35-mm airburst technology. The U.S. Government gathered an initial baseline database of "off-the-shelf" airburst technology, while industry was given the opportunity to demonstrate the performance of their airbursting munitions to U.S. and foreign government organizations and to numerous users.

Two 35-mm airburst projectiles were evaluated, the Oerlikon Contraves AHEAD projectile and the Diehl high-explosive - time fuse (HE-TF) projectile, for basic function properties and against targets representing several combat scenarios (i.e., troops in the field, troops in a covered antitank guided missile [ATGM] site, a helicopter, and the optics of a lightly armored vehicle). The basic function evaluation included the burst location, number and location of fragments, and the perforation ability of the subprojectiles against thin-steel sheets and celotex. Most of the personnel impacted in the simulated targets, some with helmets and jackets, were incapacitated to some degree. The impacts to the helicopters would have resulted in some level of mission degradation (abort), and the optics on the lightly armored vehicle were effectively damaged, making them unusable.

Acknowledgments

The author wishes to acknowledge those who helped considerably on the execution of this program. Thanks are extended to the Program Manager (PM) for the Tank Main Armament Systems (TMAS) (now Tank and Medium-Caliber Armament Systems [TMAS]) and for the Bradley Fighting Vehicle (BFV) for sponsoring the effort. Also, thanks go to the contractors that supplied their ammunition and their much-needed support for the test, Oerlikon-Contraves Pyrotec (Messrs. Pierre Freymond, Klaus Muenzel, and Allan Buckley) and Diehl (Mr. Stephan Kerk). The German Government representatives also added much-needed support throughout the testing. The test facilities and crew at the Aberdeen Test Center (ATC) were vital in the successful completion of the demonstration/evaluation, especially Mr. Andrew Rose, the test director. Mr. Rose performed an outstanding job arranging the test schedules and completing the test.

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1. Introduction

1.1 Overview. The capability of "off-the-shelf" medium-caliber ammunition has been advertised extensively. As the decision for the main armament for upcoming medium-caliber platforms approaches, more definitive independent analyses of the advertised systems are being conducted based on available data. To enhance the database, an evaluation of current 35-mm off-the-shelf medium-caliber ammunition was coordinated between an industry conglomeration, Team 35/50, and the U.S. Government. The evaluation culminated in 1 1/2-day demonstration to present to the users (U.S. Army Infantry Center [USAIC], U.S. Army Armor Center [USAARMC], U.S. Marine Corps [USMC], U.S. Air Force [USAF], etc.) and other government organizations (Office of the Secretary of Defense [OSD], U.S. Army Tank-automotive and Armaments Command [TACOM], U.S. Army Armament Research, Development, and Engineering Center [ARDEC], U.S. Army Materiel System Analysis Activity [AMSAA], Operational Test and Evaluation Command [OPTEC], program managers [PMs], etc.) the capability of several current ammunition technologies.

Team 35/50 consist of several contractors that have joined forces to develop a candidate system for the future medium-caliber platforms. Team 35/50 consist of ammunition suppliers (Rheinmetall/Mauser, Oerlikon-Contraves Pyrotec, and Alliant Techsystems) and the gun developer (Boeing Ordnance). The PMs for the Tank Main Armament Systems (TMAS) (now Tank and Medium-Caliber Armament Systems [TMAS]) and the Bradley Fighting Vehicle (BFV) sponsored the evaluation. The evaluation was supported by ARDEC and AMSAA. It was performed by the U.S. Army Research Laboratory (ARL) and the Aberdeen Test Center (ATC) at Aberdeen Proving Ground (APG), MD in October 1998, with the demonstration on the 20th and 21st.

The evaluation was divided into two sections, the antiarmor or kinetic energy (KE) and the antipersonnel or high-explosive (HE) ammunition. Due to the releasability and classification of the data from the various sections, the documentation is also separated into the two respective sections. This unclassified volume will address the HE portion.

1.2 Background. A joint-forces concept has downplayed the role of the antiarmor KE projectile in many battlefield scenarios. Thus, as mission requirements for the newer vehicle platforms are being developed, the HE task or antipersonnel is becoming increasingly more important and perhaps may be the primary driver in gun caliber selection. Initial "paper" studies of various caliber antipersonnel projectiles have been conducted. These compare the current fielded point-detonating (PD) HE projectile with airbursting munitions. The concept of an airbursting munition is to burst the munition in the air above the target, or in front of the target, putting many more of the fragments on the target area, as opposed to depositing them in the ground. An analogy would be that of a single-shot rifle to a shotgun; numerous smaller pellets have a greater probability of hit than a single slug. This also gives them the capability of engaging more targets with each shot. The smaller fragments, however, must still be capable of "defeating" their target.

The initial paper studies were based on the only existing U.S. airbursting ammunition data, the handheld 20-mm objective individual combat weapon (OICW), and the tripod/vehicle-mounted 25-mm objective crew-served weapon (OCSW). These systems are very low velocity and have low accelerations, as compared to an automatic-cannon system (i.e., 25-mm M242 Bushmaster chain gun). The projectiles, therefore, would be designed considerably differently than those for the high accelerations in the autocannon environment. Ammunition suppliers were requested to design possible medium-caliber (25-mm, 30-mm, and 35-mm) airburst projectiles. Due to lack of any more representative data, the contractors were forced to extrapolate from the OICW and OCSW projectiles to estimate the performance of larger caliber autocannon-fired airbursting munitions. From these initial studies, estimates/conclusions were drawn on the effectiveness of airbursting munitions, as compared to PD and with respect to caliber (size). A sample comparison of the number of fractional casualties (a standard measure of effectiveness) for the 25-mm PD and the 35-mm PD and airbursting rounds is shown in Figure 1. Figure 2 takes this one step further, showing the number of stowed kills, given a typical stowage volume. Stowed kills is highly dependent on the target scenario and the particular lethality model. It also assumes that the vehicle expends all of its ammunition. Time to kill is a more dynamic measure of the systems effectiveness. As can be seen, the lower caliber PD projectile performs rather well for this stowed-load scenario because it has considerably more "stowed" projectiles available, as compared to the larger calibers.

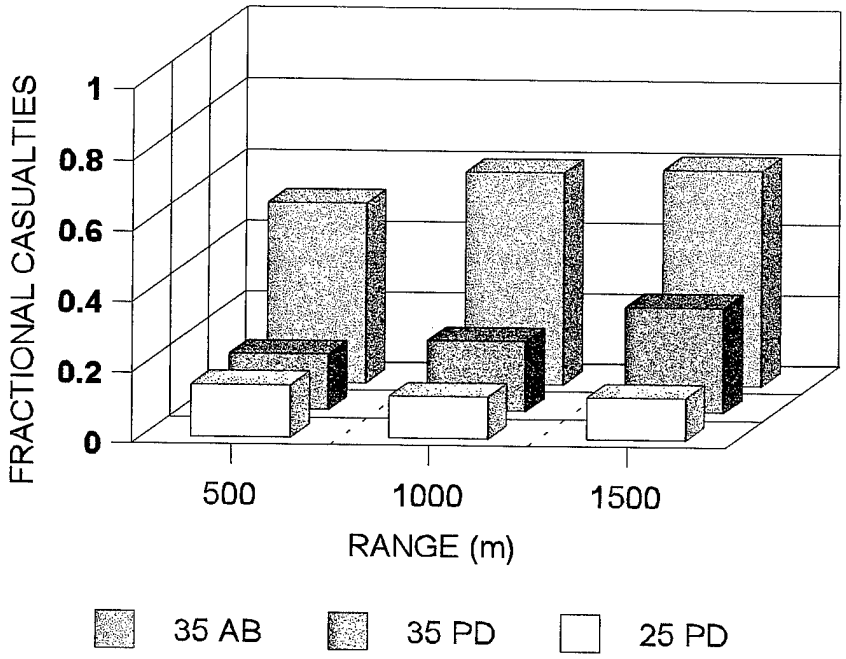


Figure 1. Sample Fractional Casualties.

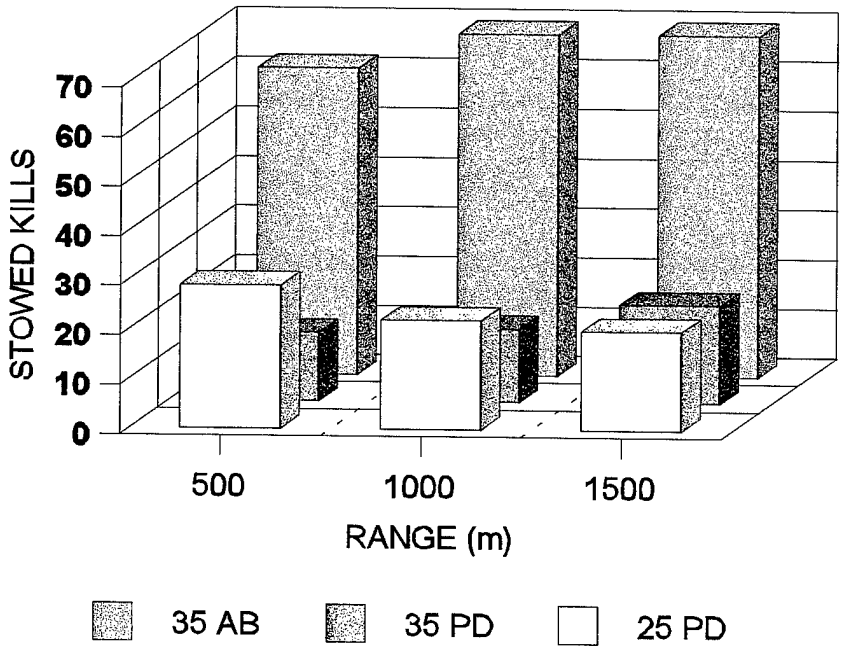


Figure 2. Sample Stowed Kills.

However, when comparing solely the PD vs. the airbursting projectiles, the airburst is much more effective (Corley 1997).

Given these results, based on the "scaled" OICW and OCSW, it was realized that some real data for current medium-caliber projectiles were needed. The current rounds are not designed like upscaled OICW or OCSW projectiles. The current projectiles are designed more as mission specific (i.e., troops, light armor, air craft, missiles, etc.). Typically, they will have some fragmenting capability, along with some heavy metal elements for "harder" targets (vests, light armor, helicopters, etc.). Most designers have concluded that the 25-mm caliber is too small to incorporate many of the airbursting designs; the "smart" fuse, sufficient HE, and adequately fragmenting material require too much additional space to be an effective overall projectile.

In an effort to gather data on these representative technologies, the U.S. Government and the aforementioned industry representatives collaborated to initiate a demonstration of the airburst technology. The U.S. Government would gather an initial baseline data of off-the-shelf technology, while the industry would be given the opportunity to demonstrate the performance of their airbursting munitions to U.S. and foreign government organizations and to the users.

2. Projectiles

This program was designed to gather preliminary performance data on two existing technologies, the Oerlikon-Contraves Pyrotec (a Swiss company) advanced hit efficiency and destruction (AHEAD) and the Diehl (a German company) high-explosive - timed fuse (HE-TF) projectiles. Both of these projectiles are currently designed for the 35-mm gun systems, although the technology could easily be converted to another medium-caliber size.

2.1 AHEAD. The AHEAD projectile was initially designed as an air defense system, in conjunction with the 35-mm twin gun, primarily to defeat cruise missiles. This was demonstrated in 1993, in the Skyguard Fire-Control/35-mm Twin Gun Air Defence System Demonstration in

Austria. The AHEAD projectile is currently touted as defeating or deterring many other systems, including precision-guided munitions, remotely piloted vehicles, tactical fighter aircraft, attack helicopters, and armored fighting vehicles.

The projectile has five major parts: the programming coil and fuse, the ejection charge, the heavy metal subprojectiles, and the outer shell. The fuse consists of a setback generator and electronic time module (ETM) and a safe-and-arm unit. A photograph of an AHEAD cutaway is shown in Figure 3. The fuse is set at the muzzle exit. A muzzle brake system, consisting of three coils, is located at the end of the barrel. The first two coils measure the actual velocity of the projectile exiting the barrel. Using the actual velocity of the projectile and the desired range to the burst, the fire-control system calculates the time required to initiate the ejection charge. The final coil, using electrical induction, sets the timer in the projectile. In contrast to typical HE projectiles, the AHEAD uses very minimal HE, 0.9 g. This explosive is used to break the outer shell, allowing the subprojectiles (3.3-g length-to-diameter ratio of ~1) to be released. The contractor states that each of the subprojectiles is spin stabilized as it is dispersed from the original package. The subprojectiles create a narrow spread of fragments, cone of ~10° at close ranges but expanding up to 18° at larger ranges (4 km). The AHEAD projectile and the muzzle setting system are illustrated in Figure 4.

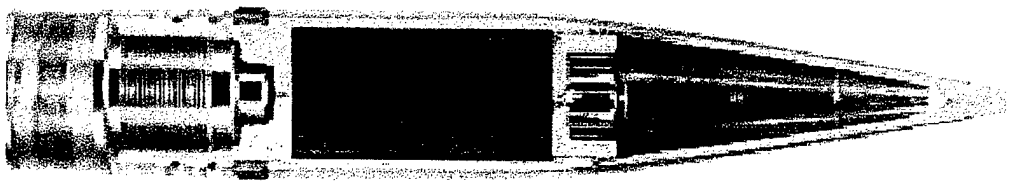


Figure 3. Photograph of AHEAD Cutaway.

As a means to compensate for the small angle of fragment spread, the capability of each AHEAD projectile to be set independently is utilized. Therefore, each projectile can be programmed to be initiated at different ranges for a burst fire (three, five, six, eight rounds, etc.) (i.e., the string of pearls concept). This increases the lethal area considerably. In addition, the system can be combined with the newer fire-control systems to spread the string of pearls over a

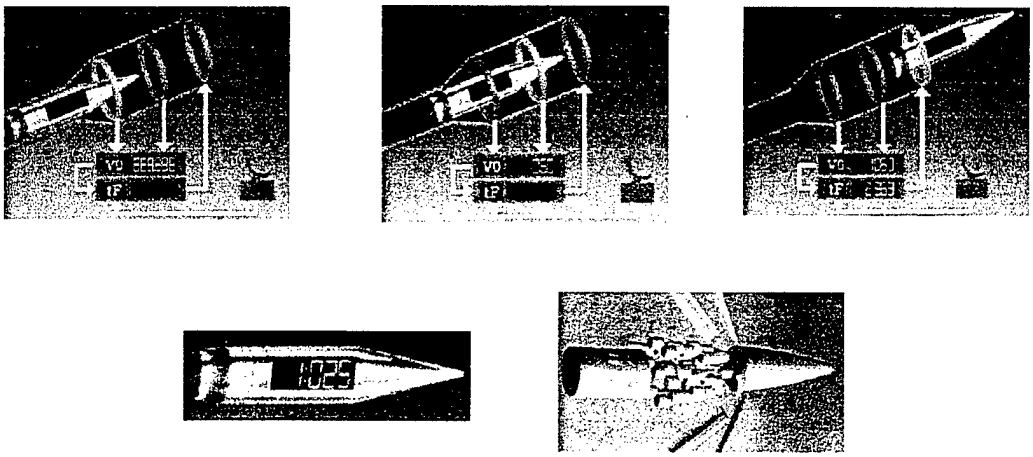


Figure 4. Schematic of AHEAD Muzzle Set System.

wider area. The azimuth of the gun can be varied rapidly, and the timing of the shots can be set at intervals to spread the burst over a larger area, covering both range (string of pearls) and azimuth (rapidly varying gun direction).

Development of the AHEAD projectile began in 1988 and was presented in Switzerland in 1992. It was then demonstrated several times from 1993 to 1997. Production to customers began in 1996, with delivery to Canada and several other customers (Buckley and Muenzel 1998–1999, Oerlikon-Contraves 1996).

2.2 HE-TF. The second projectile examined was the Diehl HE-TF projectile. Diehl Stiftung and Company is a part of Rheinmetall Industrie. Rheinmetall has been developing the 35-mm KE penetrator cartridge since the early 1990s. They developed a 50-mm supershot projectile as growth to the 35-mm projectile. This involves changing the barrel to a larger caliber (50 mm). The system was designated the RH503 gun system. The 50-mm supershot cartridge has the same cartridge envelope as the 35-mm conventional system; therefore, the system aspects, feed system, training, etc., are not affected. The outer diameter of the cartridge (50 mm) is extended over the length of the cartridge (i.e., replacing the necked-down portion on conventional ammunition). The projectile is encased in the cartridge shell, and, for the KE, the propellant surrounds the long rod penetrator, utilizing a pull-type sabot. A photograph of the 35-mm conventional cartridge and the 50-mm

supershot technology is shown in Figure 5. The 35-mm Rheinmetall KE projectile was evaluated in the antiarmor portion of this study.

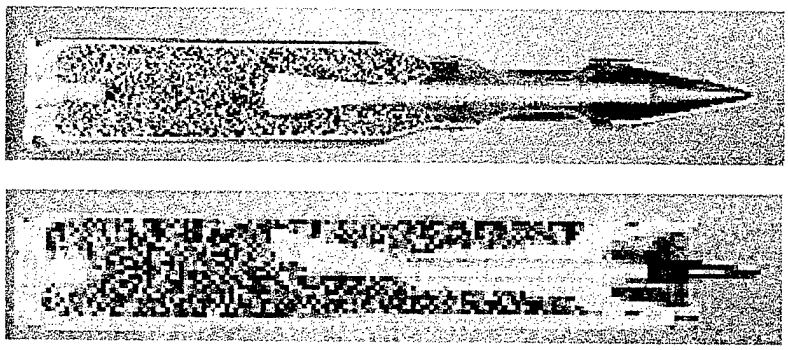


Figure 5. Photograph of the 35/50-mm Projectile.

The HE-TF projectile, developed by Diehl, was designed to be shot from this Rheinmetall RH503 gun system. Research began in 1987, with a contract to Diehl in 1991. The contract was complete in 1998. The HE-TF ammunition is designed for both the 35-mm and 50-mm cartridges, the 35-mm × 228 HE-TF DM41 and the 50-mm × 330 HE-TF M-DN 181, respectively. Although the two projectile concepts are very similar, this discussion concentrates on the 35-mm DM41, as evaluated here. The Rheinmetall/Diehl company views the 50 mm as growth to the 35 mm and is mostly a "paper" design at this point. In contrast to the AHEAD, the HE-TF projectile is designed more as ground support, suppression to troops, infantry, missile site, lightly armored vehicles, and, also, through effectiveness against sensors and optics, suppression of heavily armored vehicles, and attack helicopters.

The projectile consists of six major parts: the programming coil, the fuse, the HE, the heavy metal subprojectiles, the nose cap, and the outer shell. The HE-TF projectile is programmed in the breech, using a coil system mounted in the nose of the projectile. A schematic of the projectile is shown in Figure 6. The time to burst is based on the nominal muzzle velocity and the range to target. There is not any compensation for actual muzzle velocity of the individual projectiles. Table 1 shows the technical specifications for both the AHEAD and the HE-TF projectiles. As can be seen, the HE-TF contains considerably more HE, 65 g as compared to 0.9 g for the AHEAD

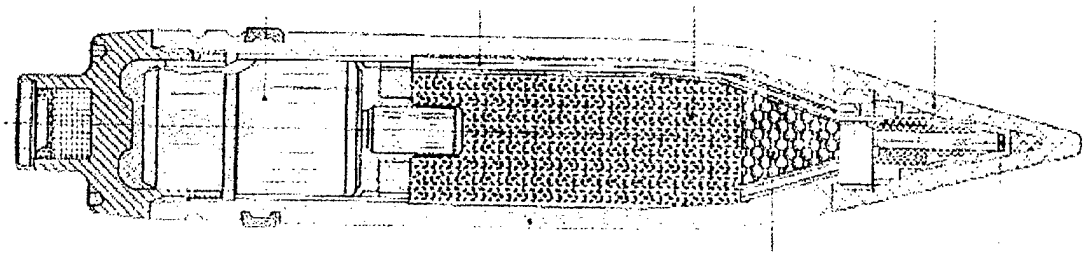


Figure 6. Schematic of HE-TF Projectile.

Table 1. Technical Specifications for the 35-mm Airburst Projectiles

Projectile	HE-TF	AHEAD
Projectile Mass (g)	610	750
Muzzle Velocity (m/s)	1,150	1,050
Payload Mass (g)	~50 [a]	~500
Number of Subprojectiles	325	152
Mass of Subprojectile (g)	0.15	3.3
Mass of HE (g)	65	0.9
Fusing	Time function - Breech Set Hit Function Self-Destruct	Time Function - Muzzle Set Hit Function Self-Destruct

[a] Approximate tungsten pellets mass.

projectile. Because it has a different mission, spreading fragments over a much larger area, there are over two times as many fragments (325) and they are much smaller (0.15-g, 2.5-mm-diameter tungsten balls) than the AHEAD projectile. The greater amount of HE and lighter fragments allows them to spread over a much larger area. Again, as with the AHEAD, these can be utilized in the string-of-pearls fashion to produce a large lethal area.

The Diehl HE-TF DM-41 projectile is currently being type-classified (qualified) with the German Army. It can be ready for production in 1 1/2 yr after a contract is signed (Kerk 1998a, 1998b).

3. Evaluation Matrix

An arena test is the preferred method to gather the maximum fragmentation data from a HE projectile. This is a static test that collects all of the individual fragments after the projectile explodes. The HE projectile is placed in the center of witness packages consisting of steel, celotex, plywood, and other media designed to gather the fragments after the HE is detonated. The direction, mass, and perforation ability of the individual fragments can be assessed. This is a very labor-intensive and, hence, a very expensive procedure. The cost of an arena test, in combination with the desired demonstration, was prohibitive for the 35-mm ammunition. A representative dynamic test of the projectile firing over the target and bursting was therefore devised. The function of the projectile was broken down into several steps: the function of the fuse (does it function properly and at its desired range), the fragmentation spread (the area covered by the fragments), and the fragments perforation ability. To gather all of this data in a demonstration environment is not recommended. The test was therefore divided into an initial evaluation and the actual demonstration. The initial evaluation also gave the contractors the opportunity to see how the demonstration was to be conducted and what was to be expected during the actual demonstration.

The initial evaluation was also segmented to gather specific information on fuse function, fragment spread, and perforation ability. As described in the test data report by Mr. Andrew Rose (1999), the fuse function was determined by firing five shots each, desired to burst at 1,250-m range, and recording the actual location of their burst. This arrangement was designed to measure how near the burst exploded to where it was programmed. This measure can be used in estimating the error budget of the projectiles. Next, the fragment spread was determined by firing two shots over a cloth tarp (20 m × 30 m), centered at 1,250-m range. After each shot, the location of each fragment impact was surveyed. By knowing the location of the burst and the location of all of the individual fragments, the spread, as related to the burst location, can be determined. Finally, the perforation was determined by firing two shots each at witness panels, also located at 1,250-m range. The witness panels consisted of two each 2-ft × 6-ft (0.61 m × 1.83 m) × 1/16-in-thick (1.6 mm) mild-steel plates, one vertical and one horizontal, and two 4-ft × 8-ft (1.2 m × 2.4 m)

celotex packages, consisting of five each 1-in (25.4 mm) celotex panels backed by 2 in (50.8 mm) of plywood. These also had one standing vertical and one laying horizontal on the ground. A first-order analysis of the perforation ability can be surmised as a "go" or "no go" if the package is perforated or not, respectively. Also, the fragment locations were again surveyed after each shot, increasing the database for the fragment spread.

In addition to the data gathered from the initial evaluation, very pertinent data can also be retrieved from the demonstration matrix. As touted by the contractors, and desired by many users, the matrix consisted of primarily the infantry threat. This included troops in the open and troops covered in an antitank guided missile (ATGM) site. As the program progressed, the matrix was quickly expanded to include a makeshift lightly armored vehicle with optics and a helicopter silhouette, which was later changed to an actual "stripped" helicopter, no engine or fuel. So the final targets included a helicopter, an old BMP with makeshift optics, and troops standing in an open nine-man squad, traveling column formation, and three soldiers in a covered ATGM site.

Several of the infantry personnel were to have standard Kevlar helmets and fragment protective vests, as funding would allow. The troops in the open were arranged in a nine-man squad, traveling column formation, as described by the USAIC, Fort Benning, Field Manual 23-1, and as shown in the schematic in Figure 7. The squad members were E-type silhouettes, made from celotex and plywood. The thickness of the celotex was adjusted so the vests would fit completely around the silhouettes. A photograph of the setup is shown in Figure 8. The squad was to be placed on a cloth tarp, 30 m × 55 m, with the center located at 1,100-m range. Two three-round bursts, or six individual shots, were to be fired over the squad. Again, the spread of the fragments and the effect (perforation) on the vests and helmets could be assessed.

The three infantry personnel in the ATGM site were also approved by USAIC, with one member set on either side of the weapon and one set further to the rear. The bunker was made from sandbags and wood. The bunker was 1 m high and 4 m wide, with an opening approximately 2 m wide × 0.5 m high. The actual arrangement is shown in Figure 9, and a photograph of the setup

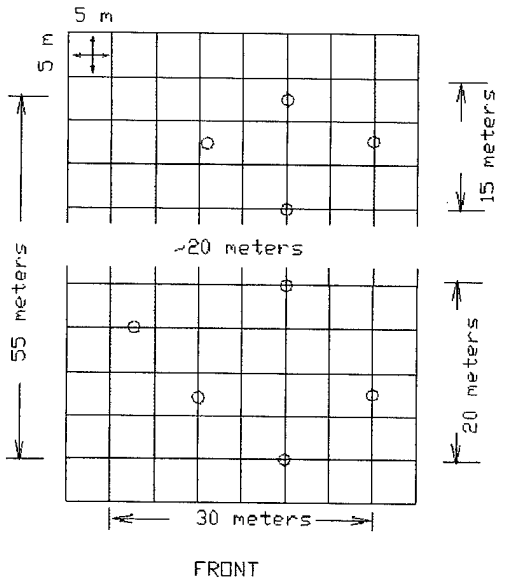


Figure 7. Schematic of Infantry Squad Traveling Column Formation.

Figure 8. Photograph of Infantry Squad Traveling Column Formation.

can be seen in Figure 10. As can be seen, the E-type silhouettes are cut in half, from the torso up, to represent the personnel being "dug in." The standard flack vests did not fit on the 1/2 silhouette; therefore, the height of the member in the back was increased so a vest could be applied. As can be seen in the photograph, the figure with the vest extends slightly above the bunker. The bunker was to be engaged at 1,250-m range, with one three-round burst, or three individual shots. This target will show the effect of the fragmenting projectile on a well-protected squad, which would be difficult to hit with the standard point-detonating round at this range.

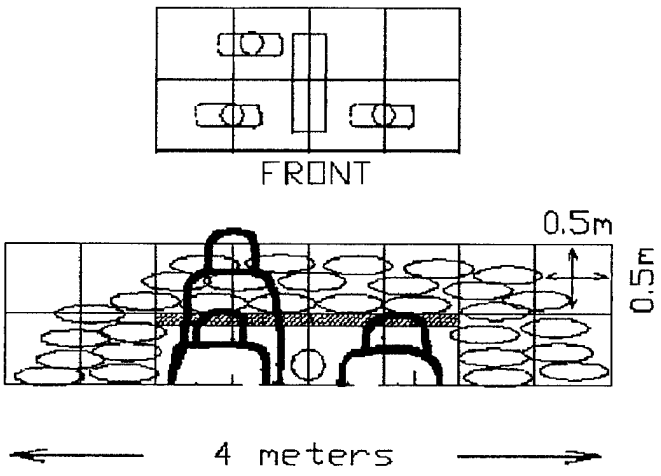


Figure 9. Schematic of ATGM Site.

Figure 10. Photograph of ATGM Site.

The helicopter targets were stripped. All had the engines removed and most of the fluids drained. Many of the other interior components were intact. The helicopters were placed on stands 1.5 m high at a 45° azimuth angle and were to be located at 1,400-m range. Two shots were fired at each helicopter.

The BMP target used was a stripped vehicle, which had numerous perforations from previous tests. Two or three optics (vision blocks) from other representative vehicles were set on top of the vehicle. The effect of the impact of the fragments on the optics could then be assessed. The BMP was set for a broadside impact at about 1,200-m range. Two shots were fired at the optics.

Due to terrain constraints, and the fear that some targets may be inadvertently impacted if the fuses from other demonstration tests did not function properly, the engagement ranges were changed. The helicopter was at 1,450-m range, the infantry troops in the open were at 1,250-m range, the BMP was at 1,135-m range, and the ATGM site was set the closest at 1,035-m range.

Also added for comparison was the 25-mm HE PD projectile, the M792. This is the current 25-mm HE projectile, typically fired in a burst mode and notorious for having a low probability of hit. It would have been ideal to evaluate this projectile against all of the same targets as the 35-mm airbursting projectiles to get a complete analysis. However, due to the time and funding constraints, the simplest (least expensive) target was chosen, the ATGM site. From the targets evaluated, the effectiveness of the 25-mm M792 PD round would appear greatest against the ATGM site because of the destruction of the bunker, sandbags, ATGM, etc., if the M792 could hit the bunker. Although the 25-mm M792 is notorious for having a low probability of hit, the target it is being compared against was the closest and was set on top of a berm, both of which increases its probability of hit. The regular mode of fire of the 25-mm autocannon is burst. For this test, however, it was fired in a single-shot mode and the aim was corrected after each shot. This again increased its probability of hit. Finally, for a correct storage volume comparison, a 3 to 1 ratio of 25 mm to 35 mm was used, so nine 25-mm M792 projectiles were fired for the three 35-mm shots. Thus, many advantages were inadvertently given to the 25-mm M792 projectile.

4. Test Procedure

The program was executed at the ATC H-field facility, Edgewood Area, APG, MD. The AHEAD projectile was fired from the 35-mm Bushmaster III gun, mounted on an existing BFV

turret and hull. Since this was just being used as a gun mount, an actual feed system and the electronics associated with a BFV A3 were not incorporated in the turret. This did illustrate, however, that, with some modifications, the 35-mm Bushmaster was capable of being mounted in the existing BFV. By adding the AHEAD muzzle system, the function ability of the complete 35-mm system was demonstrated. The muzzle set system for the AHEAD projectile was controlled by a laptop computer located inside the BFV hull. The 25-mm M792 was fired from a standard BFV with a 25-mm Bushmaster gun.

The Diehl HE-TF projectile was fired from the Rheinmetall 35-mm Mann barrel. A photograph of all three gun systems is shown in Figure 11. Whereas the 35-mm Bushmaster III, when mounted on the BFV turret and hull, has full mobility (elevation and azimuth), the Mann barrel only had elevation mobility. Since only elevation was available, all targets for the HE-TF must be on the same firing line. This also eliminated the possibility of dispersing the fragments side to side with an azimuth correction. Since this was fixed for the Diehl HE-TF system, the decision was made not to adjust the azimuth for the AHEAD firings either. This is more detrimental to the AHEAD projectile, since it has a much smaller cone of fragment spray then the HE-TF projectile.

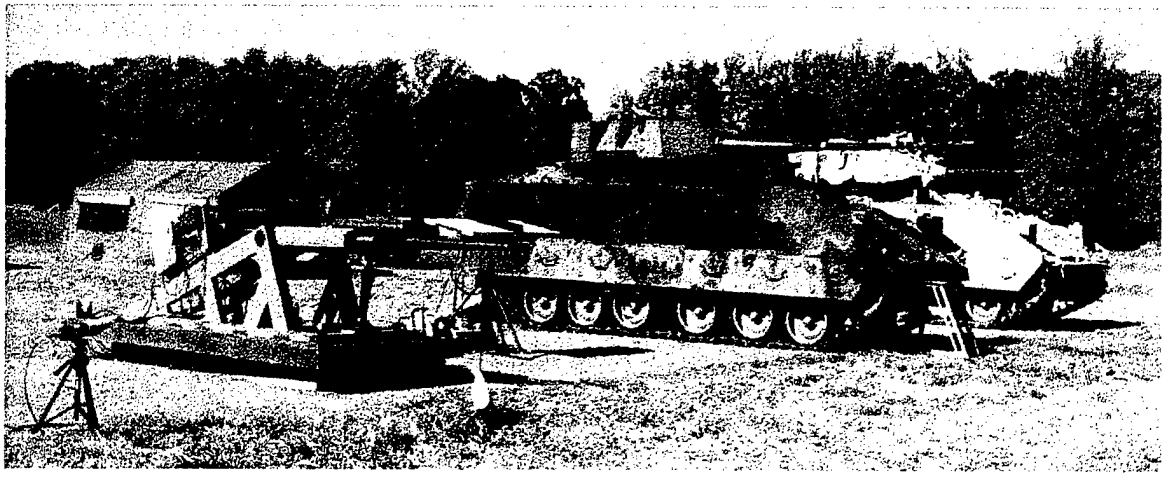


Figure 11. Photograph of Gun Arrangements.

Two firing lines were constructed, one for the AHEAD projectile and one for the HE-TF projectile. A third short range was included for the 25-mm M792. Since the HE-TF could not correct for azimuth and only one BMP was available, it was set on the HE-TF firing lane and the AHEAD, which could correct for azimuth, fired across to the HE-TF firing line. A photograph of the AHEAD shotline is shown in Figure 12.

Figure 12. Photograph of All Targets for AHEAD Shotline.

As described in the data report by Rose (1999), a Weibel radar system was used to record the muzzle velocity of the projectiles, the velocity at range, and the burst location. This system measures velocities within (±5 m/s in this velocity range). However, because the burst height was so near to the ground, "clutter" or noise made it difficult to pinpoint the burst location as precisely, especially in the vertical plane. An error band of ±5 m is probably applicable in the horizontal plane and 1–2 m in the vertical plane. Video was also used to record the burst. The camera was located approximately perpendicular to the expected burst location, if possible. Three to four foot stakes were placed along the shotline to be used to assess the location and height of the burst. The burst in the video was very difficult to see, especially for the AHEAD projectile, which has minimal explosive charge. As previously mentioned, the location of all fragments on the cloth tarps was surveyed after the test. The fragment number and location on the witness panels were assessed and, if possible, recovered. The optics (vision blocks, etc.) were assessed for damage (i.e., broken glass). The helicopter targets were assessed by the air vehicle assessment branch of the Survivability/Lethality Analysis Directorate (SLAD) at ARL.

5. Results/Discussion

5.1 Evaluation Targets. The results of the predemonstration evaluation are separated into the three categories, range errors (plus or minus burst range), number and location of fragments on the cloth tarps, and perforation of witness panels.

The first series of targets was designed to determine how accurate the burst location can be timed. The burst was to explode at 1,250-m range. The AHEAD projectile's muzzle system sets the time to burst at the muzzle, based on the actual muzzle velocity of the individual projectile. So, for the AHEAD round, Table 2 shows the set distance, set time, and determined muzzle velocity (muzzle brake) and then the muzzle velocity, burst time, and burst distance, as recorded by the Weibel radar system. The last column shows the miss distance from the desired burst range to the actual burst range (plus for long and minus for short of the actual range). The range of miss distances was from 7 to 15 m for the four shots recorded with the AHEAD projectile.

Table 2. Burst Locations for the AHEAD Projectiles

Shot No.	Set Burst Parameters			Measured Parameters			
	Distance (m)	Time (ms)	Muzzle Velocity (m/s)	Muzzle Velocity (m/s)	Time (ms)	Distance (m)	Distance Error (m)
1	1,250	1,371	1,029	1,029	1,367	1,241	-9
2	1,250	1,365	1,034	1,028	1,363	1,235	-15
3	1,250	1,360	1,038	1,032	1,358	1,235	-15
4	1,250	1,367	1,032	1,030	1,368	1,243	-7

For the Diehl HE-TF projectile, the burst distance is set using the nominal muzzle velocity and a set time. For this round, Table 3 lists the set distance and set time and then the muzzle velocity, burst time, and burst distance, as recorded by the Weibel radar system. Several more shots were taken with the HE-TF on burst location, simulated each target range. In general, the first shots at

Table 3. Burst Locations for the HE-TF Projectiles

Shot No.	Set Burst Parameters		Measured Parameters			
	Distance (m)	Time (ms)	Muzzle Velocity (m/s)	Time (ms)	Distance (m)	Distance Error (m)
1	1,250	1,277	1,148	—	—	—
2	1,250	1,277	1,153	1,307	1,277	+27
3	1,250	1,277	1,157	1,273	1,252	+2
4	1,250	1,277	1,155	1,274	1,252	+2
5	1,250	1,277	1,148	1,274	1,245	−5
6	1,450	1,513	1,167	1,506	1,457	+7
7	1,440	1,505	1,168	1,499	1,449	+9
8	1,440	1,505	1,172	1,498	1,440	0
9	1,440	1,505	1,164	1,521	1,462	+22
10	1,440	1,505	1,163	1,492	1,444	+4
11	1,440	1,505	1,160	1,498	1,440	0
12	1,440	1,505	1,162	—	—	—
13	1,800	2,000	1,166	1,992	1,823	+23
14	1,800	2,000	1,164	1,990	1,816	+16
15	1,030	1,020	1,169	1,014	1,039	+9
16	1,030	1,008	1,168	1,002	1,028	−2

Note: Dashes indicate instrument failure - no data recorded.

each simulated range missed the desired burst location the farthest. Also, the farther the range, the greater the miss distance (i.e., 1,800-m range). The miss distance for the HE-TF for the shots at 1,250-m range was 2-m to 27-m range. These errors are based on dialing in the distance; there is no added error due to the system parameters (i.e., range finder, etc.). However, weather conditions (temperature, humidity, barometric pressure, etc.) are included in these errors.

The second series of test was designed to measure the number and location of the individual fragments from each projectile. After each shot, the location of each fragment impact on the tarp was recorded (surveyed). The results of the shots are listed in Tables 4 and 5 for the AHEAD and HE-TF, respectively. The settings and measured burst distances for each projectile are listed in the same manner as previously done in Tables 2 and 3. The burst errors for the AHEAD projectile were −1 m to −9 m and, for the HE-TF projectile, were −2 to +13 m in range. The total number of fragments impacting the tarp are listed in the tables. The impacts on the tarp are shown graphically for the burst in Figures 13 and 14 for the AHEAD projectile and in Figures 15 and 16 for the HE-TF projectile. The burst location is shown on the plots of the HE-TF projectile. This illustrates how near the fragment pattern the projectile actually burst. The burst location for the AHEAD is listed at the bottom of the plots. As can be seen, to maximize the number of fragments on the tarp, the AHEAD projectile burst 5–10 m before the tarp. The differences in the fragment patterns between the two projectiles is obvious. The HE-TF projectile produces 5–7 times as many perforations (greater than 300) than the AHEAD projectile (approximately 40). Also included in the tables are the determined cone angle for the AHEAD projectile, at the maximum range obtainable on the tarps, and the area covered for the HE-TF. The AHEAD pattern is also much more concentrated on the shotline, remaining on the advertised 10° fragment cone angle, whereas the HE-TF covers most of the tarp laterally but not as much down range. Most of the fragments are close to the shotline, with many projecting forward when the HE burst. These fragments near the shotline will probably be the most lethal because they should have the higher impact velocities. These plots cannot directly show the difference in the size of the fragments impacting the tarp, although a simple "scale" factor was applied to the plots to demonstrate how the AHEAD subprojectiles are indeed much larger than the HE-TF fragments.

The final series, prior to the demonstration targets, was the witness package analysis. The witness packages, two celotex and two mild steel plates, one horizontal and one vertical, were placed at the 1,250-m distance. The bursts were set by the contractors to maximize the damage to the plates. The results of these tests were also listed in Tables 4 and 5 for the AHEAD and HE-TF, respectively. These are also shown graphically in Figures 17–20, for each shot in the same manner as for the previous fragment spread tests. The witness plates are shown along with the burst

Table 4. Burst Locations/Fragment Numbers for the AHEAD Projectiles

Shot No.	Set Projectile Parameters			Measured Projectile Parameters				Fragment Characteristics		
									Cone Angle Prop.	
	Distance (m)	Time (ms)	Muzzle Velocity (m/s)	Muzzle Velocity (m/s)	Time (ms)	Distance (m)	Distance Error (m)	No.	(°)	Distance to Burst (m)
1	1,225	1,383	1,001	1,010	1,379	1,223	+2	34	7	40
2	1,215	1,346	1,025	1,022	1,343	1,214	−1	40	10	46
3[a]	1,230	1,364	1,018	1,020	1,363	1,225	−5	80	10	40
4[a]	1,230	1,349	1,029	1,025	1,348	1,221	−9	55	9	45

[a] Shots with witness panels on tarp (celotex and steel).

Table 5. Burst Locations/Fragment Numbers for the HE-TF Projectiles

Shot No.	Set Projectile Parameters		Measured Projectile Parameters				Fragment Characteristics		
								Dimensions	
	Distance (m)	Time (ms)	Muzzle Velocity (m/s)	Time (ms)	Distance (m)	Distance Error (m)	No.	Width (m)	Length (m)
1	1,240	1,270	1,165	1,264	1,253	+13	304	20	12+
2	1,240	1,263	1,160	1,251	1,238	−2	346	15	20+
3[a]	1,240	1,263	1,168	1,257	1,251	+11	241	15	15+
4[a]	1,240	1,263	1,162	1,255	1,243	+3	242	20	20

[a] Shots with witness panels on tarp (celotex and steel).

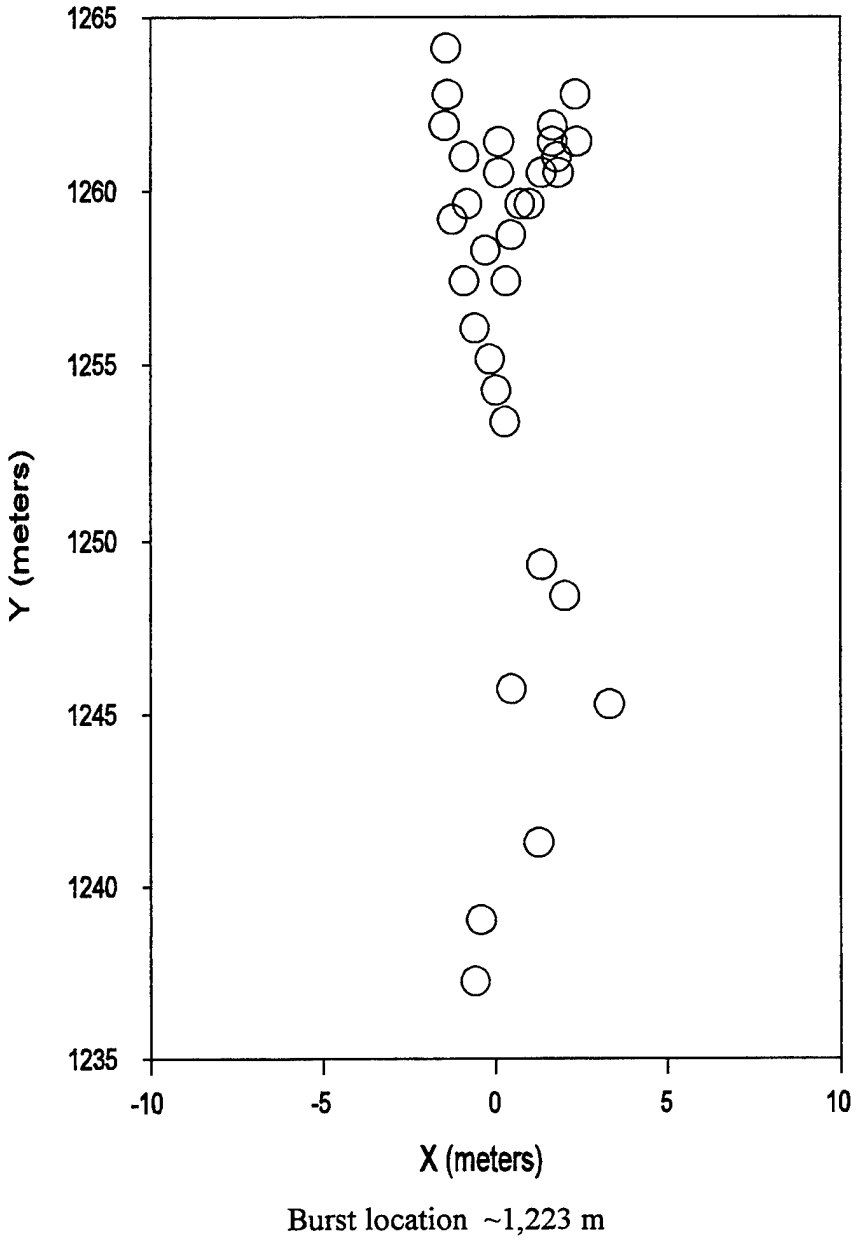
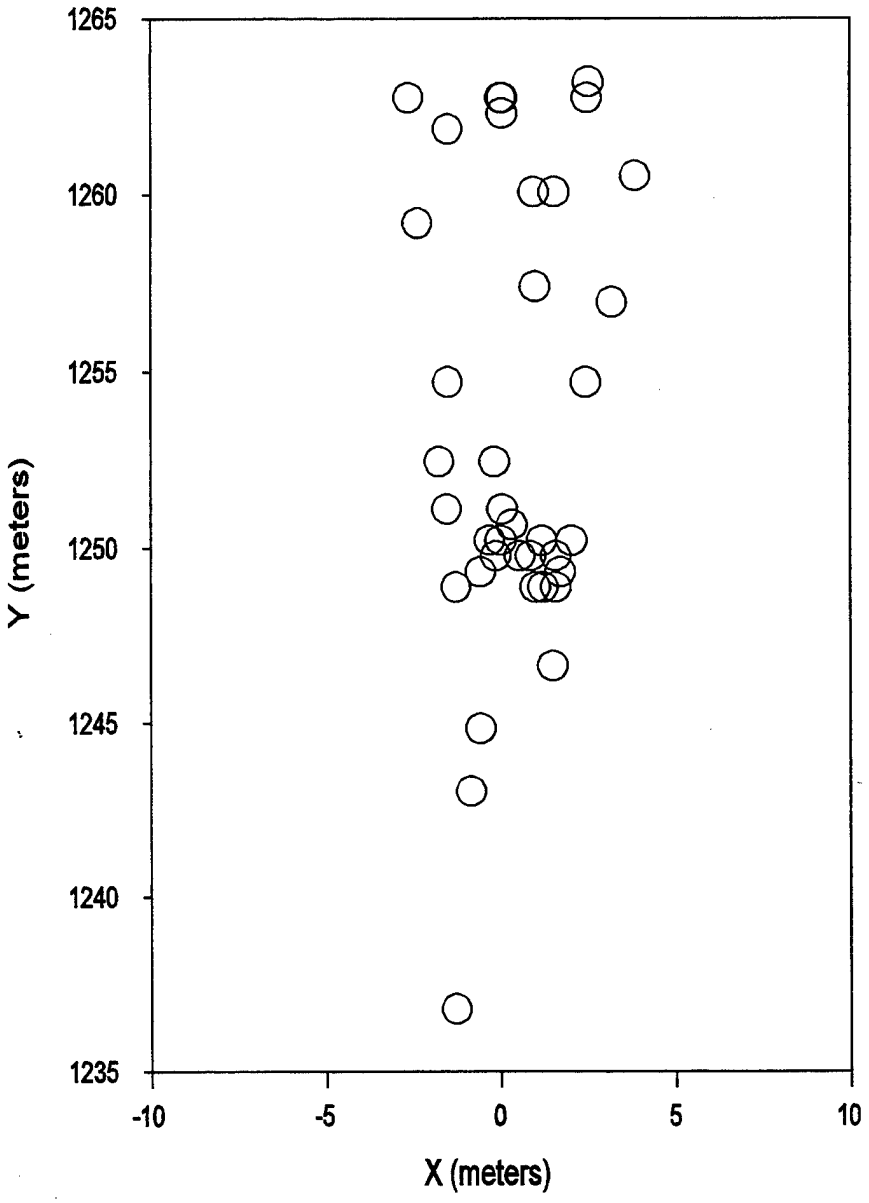


Figure 13. Fragments on 20-m × 30-m Tarp for the AHEAD Projectile (Shot No. 1).

locations for the HE-TF. Again the AHEAD burst in front of the tarps and is not visible on the plots. The total number of perforations agree with the previous tests, although they have been reduced slightly due to impacts on the witness panels for the HE-TF shots. The AHEAD projectile actually produced more fragments (55–80), probably due to a better placement of the burst height for these shots. The vertical panels had the most direct impacts. All impacts perforated the panels. The 1/16-in mild steel is roughly equivalent to personnel, with moderate protection levels (jacket).



Burst location ~1,214 m

Figure 14. Fragments on 20-m × 30-m Tarp for the AHEAD Projectile (Shot No. 2).

Both the AHEAD and the HE-TF perforated the panel and should therefore perforate the light protection for personnel. As seen in Figure 21, the AHEAD projectile easily perforated the thin-steel plate, with very circular perforations. From the two-shot burst with the HE-TF, the differences in distances of burst could be detected from the characteristics of the perforation hole. Figure 22 shows the front and rear of the steel witness panel for the HE-TF fragmentation.

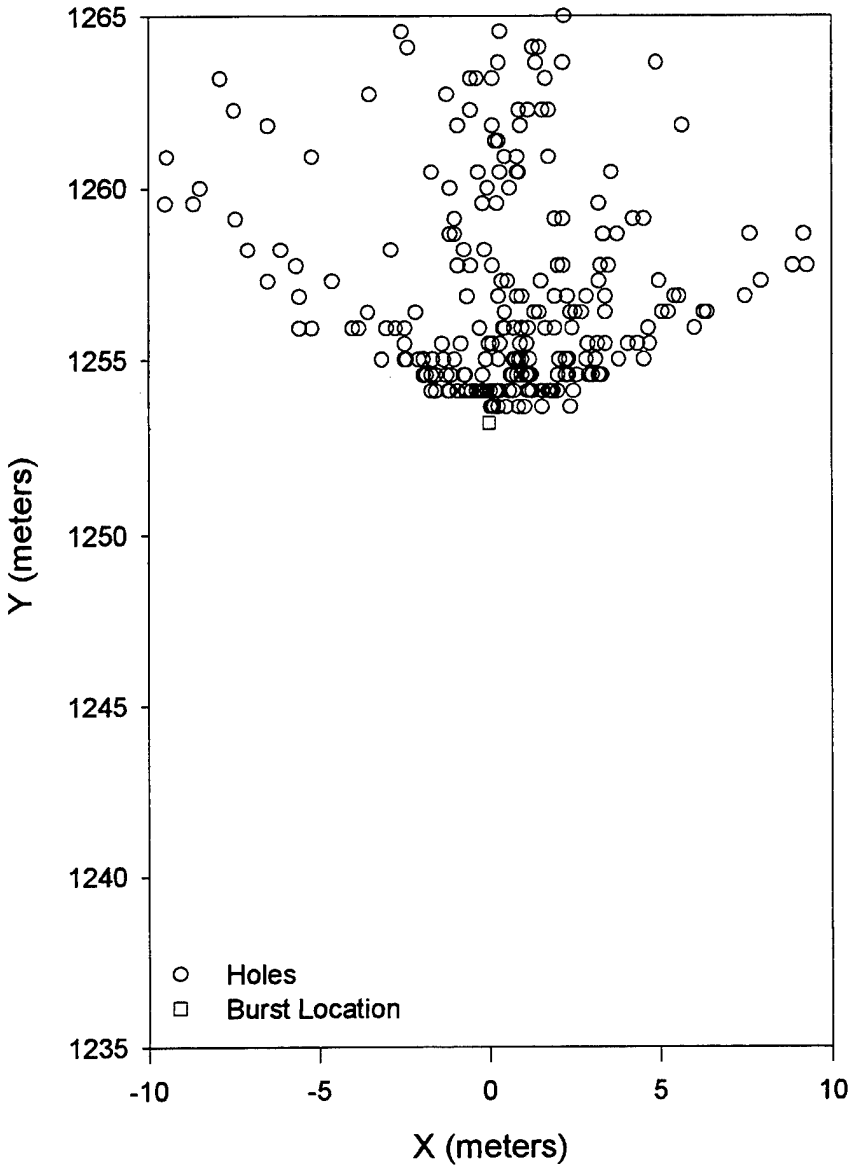


Figure 15. Fragments on 20-m × 30-m Tarp for the HE-TF Projectile (Shot No. 1).

Considerable more bulging of the plate was observed for the burst at greater distance than the burst close to the panels. The panels that were laying horizontally on the ground did not have as many impacts, and most of those did not completely perforate the panel. This flat target is very difficult to hit, especially for the AHEAD subprojectiles because the subprojectiles are going mostly forward. The HE-TF must burst close to the horizontal plate to get impacts. The overall results of the perforations of the witness panels demonstrates the perforation ability of the subprojectiles.

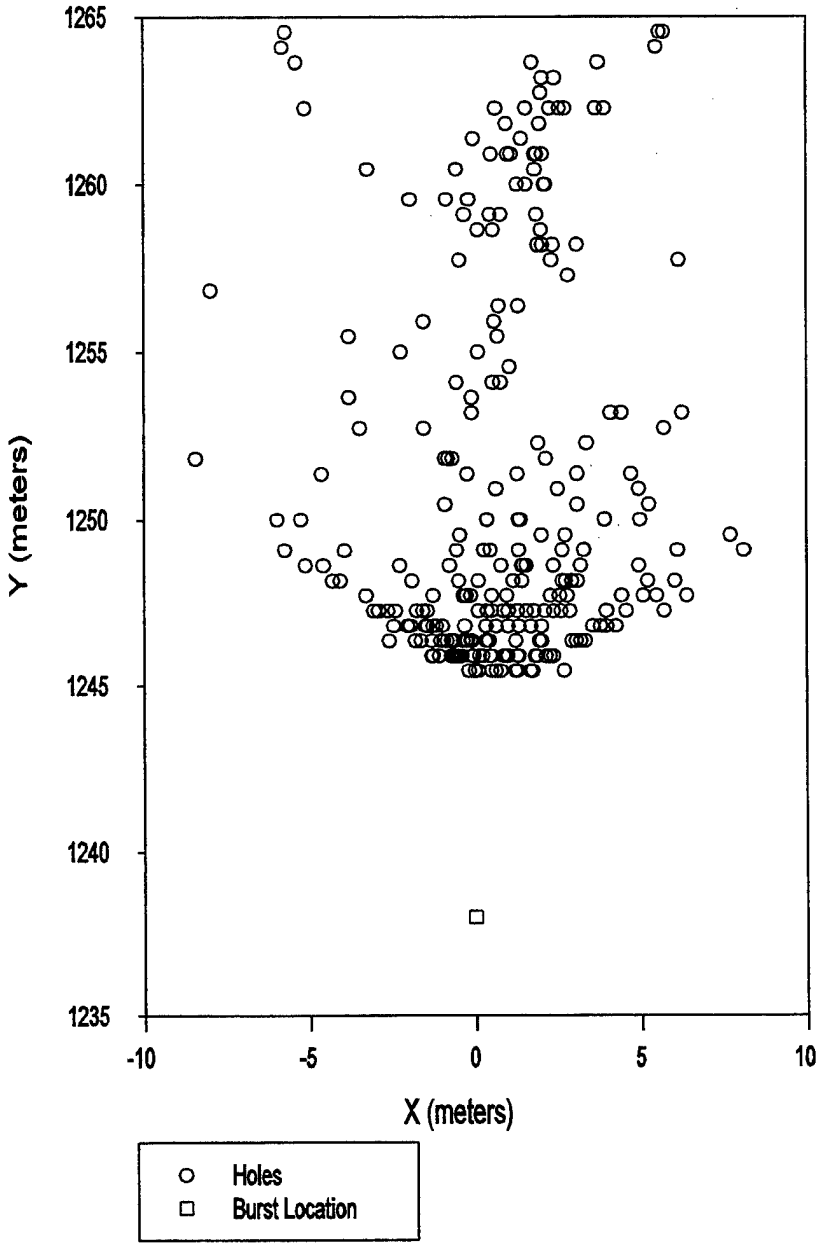
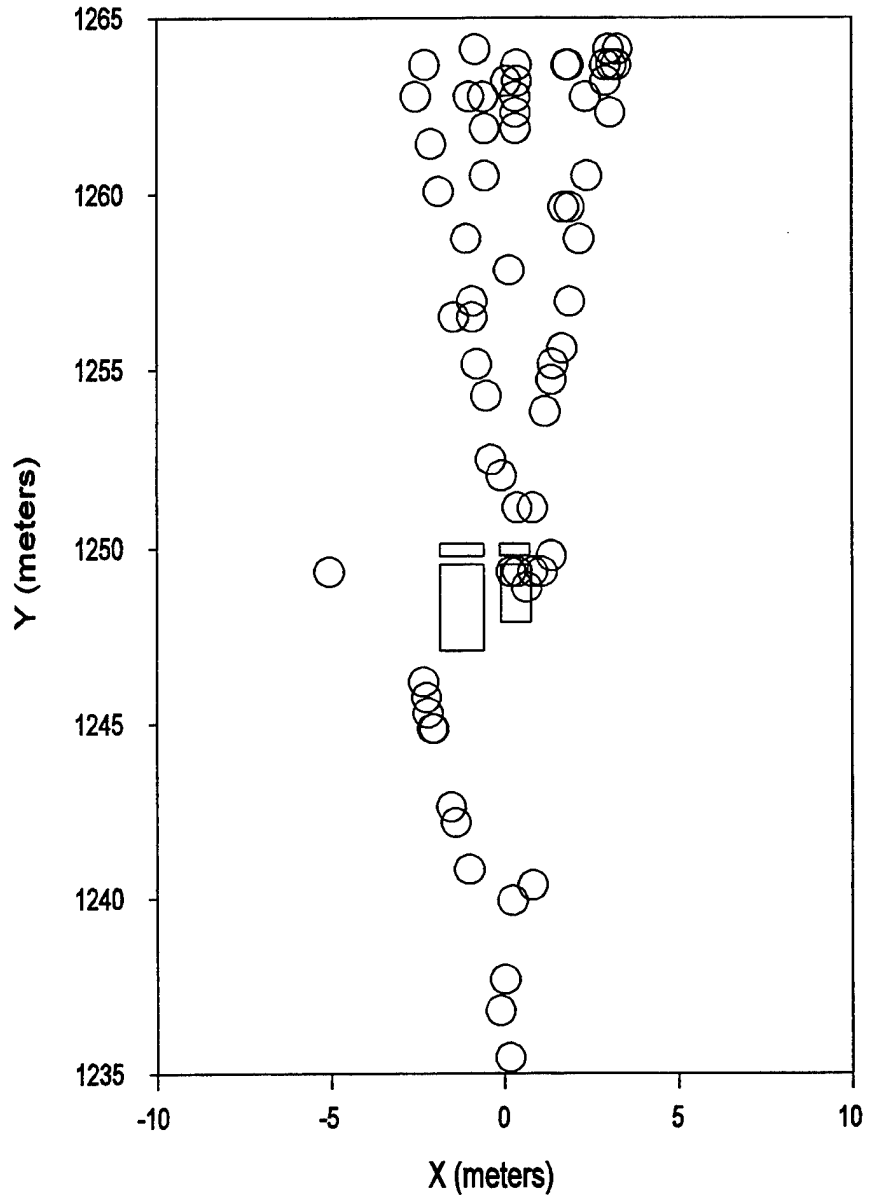


Figure 16. Fragments on 20-m × 30-m Tarp for the HE-TF Projectile (Shot No. 2).

The velocity of the subprojectiles for the AHEAD projectile is governed by the terminal velocity of the projectile when it burst. The subprojectiles are then dispersed by the spin of the original projectile in a tight spiral pattern. Since the size of the subprojectiles is fixed and the velocity is the terminal velocity of the AHEAD projectile at the time of burst, the energy in the individual fragments can be determined. For a burst at 500-m range, the initial velocity of the subprojectiles



Burst location ~1,225 m

Figure 17. Fragments for the AHEAD Projectile With Witness Panels (Shot No. 3).

would be approximately 950 m/s, giving them an energy of 1.45 kJ, approximately equivalent to that of an M16 5.56-mm machine gun projectile (1.4 kJ). At 1,250-m range, the energy would be down to 1 kJ, and then 830 J at 1,450-m range. So, a 35-mm AHEAD burst at 1,250-m range is approximately equivalent to 150 shots from a M16 at 150-m range. If the azimuth correction would be added, five or six shots in a burst would easily suppress an infantry squad.

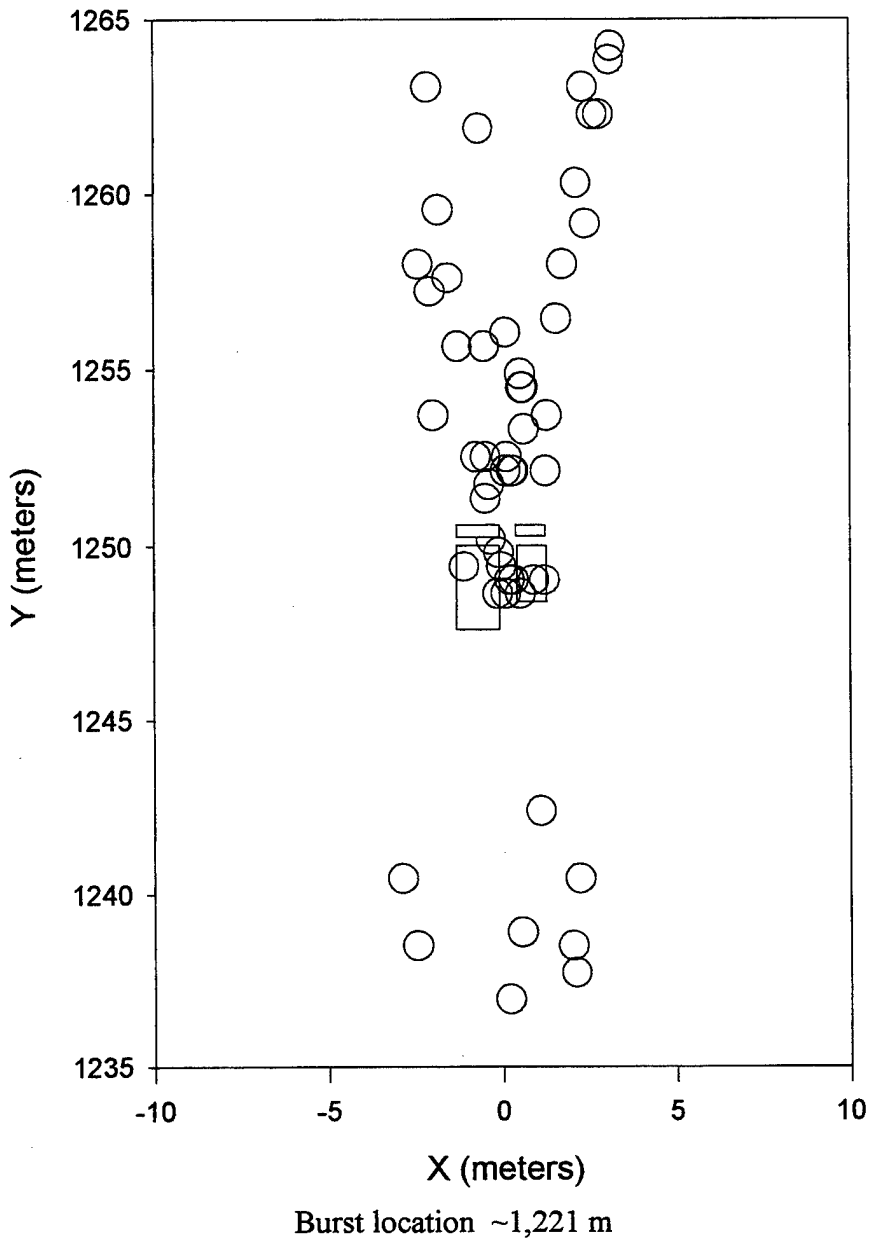


Figure 18. Fragments for the AHEAD Projectile With Witness Panels (Shot No. 4).

An estimate on the energy of the Diehl HE-TF individual fragments is more difficult. The velocity of the subprojectiles in this HE projectile is driven by the explosive charge (mass and type), not solely the terminal velocity of the projectile. Given the explosive mass of 65 g and the fragment size of only 0.15 g, the initial velocity of the subprojectiles would be substantial. An estimate for the maximum velocity of the fragments, provided by a representative from the Diehl Company, is

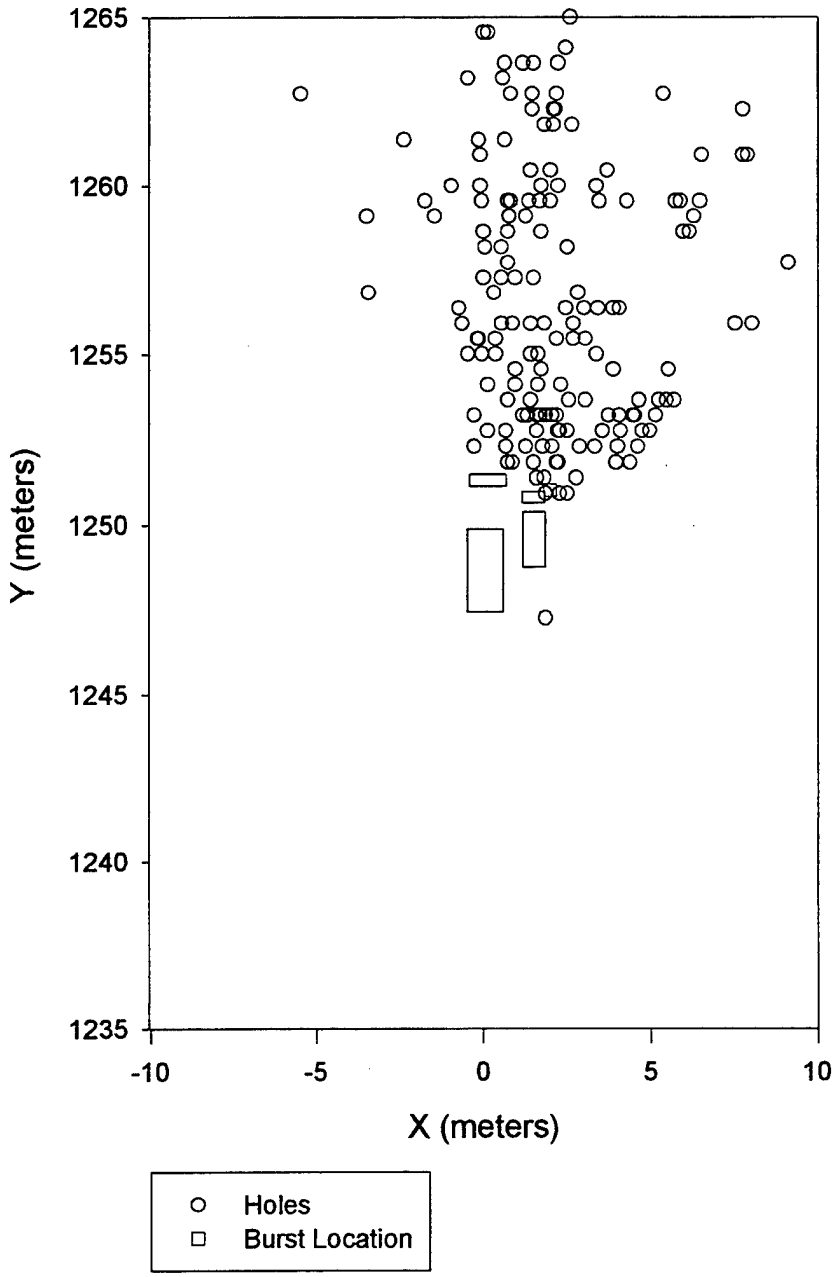


Figure 19. Fragments for the HE-TF Projectile With Witness Panels (Shot No. 3).

1,500 m/s, which includes the forward velocity of the projectile. The average velocity of the fragments would be between 1,000–1,200 m/s, dependent on the departure angle from the projectile. This average velocity (1,100 m/s) equates to an initial energy of 90 J, for 325 individual spheres. In addition, the steel fragment shell provides additional fragmentation, similar to conventional

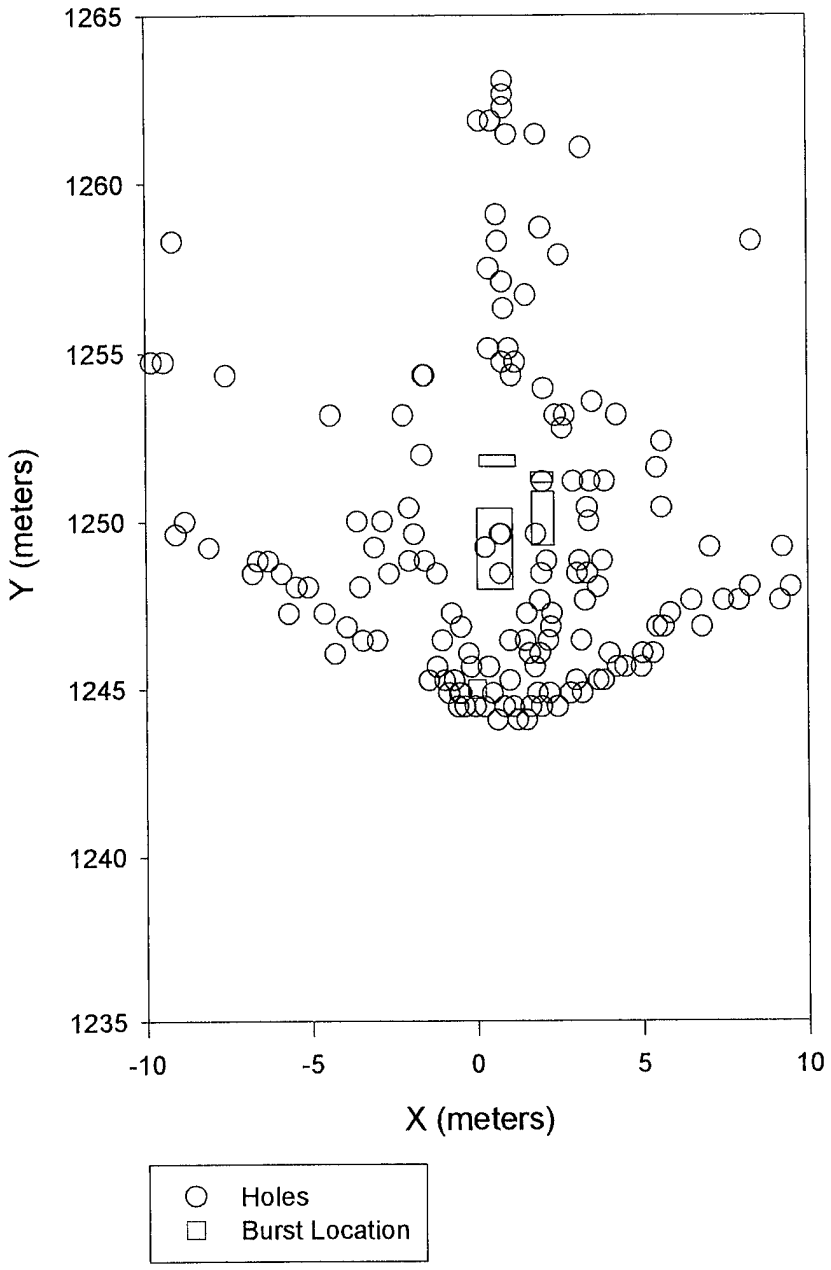


Figure 20. Fragments for the HE-TF Projectile With Witness Panels (Shot No. 4).

fragmenting projectiles. Even though these individual subprojectiles are not as lethal as the AHEAD subprojectiles, they still should have the energy to perforate flack vests, causing incapacitation to infantry squad members. In addition, these fragments already are dispersed over a much broader range. The further the fragments and/or tungsten spheres are from the burst location, the lower their

Front Rear (Close-Up View)

Figure 21. Perforations on 1/16-in Mild-Steel Witness Panel From AHEAD Projectile.

Front **Rear (Close-Up View)**

Figure 22. Perforations on 1/16-in Mild-Steel Witness Panel From HE-TF Projectile.

velocities and the less lethal they become. These velocity estimates, and those produced for the AHEAD projectile, will be implemented into the AMSAA fractional casualty models for further force on force measures.

5.2 Demonstration Targets. The first demonstration target was the UH-1M helicopter at a 45° azimuth angle of attack at 1,460-m range. Both projectiles had a two-round burst (two separate shots) several meters in front of the helicopter (9–12 m for the AHEAD and 7–11 m for the HE-TF projectile), scattering numerous subprojectiles on the helicopters. Several of the projectiles completely perforated the front and back of the helicopter. Figure 23 shows the front of the helicopter impacted with the AHEAD subprojectiles. The larger AHEAD projectiles were assessed to cause severe damage to the interior of the helicopter. The hydraulic lines, located behind crew compartment/engine bulkhead, had several perforations. The starboard-side fuel cell had perforations; however, most were small and would self-seal. There was a large perforation in the bulkhead between the crew compartment/starboard-side fuel cell that would not seal. The port-side fuel cell also had perforations. Damage was inflicted to both hydraulic systems. There probably would have been several hits on the engine, if it had been installed. The battery was damaged, and several perforations were noted in the oil cooler. The main control servos and generator control were damaged. The main electrical power wire and the "commo" wiring were severed (starboard-side behind copilot). Several impacts were on the tail rotor control rods (not severed). The blade and skids had impacts, with some perforations, but nothing that would have a structural failure. Several of the subprojectiles easily perforated the entire vehicle, front and back. Figure 24 shows the rear (port side) of the helicopter.

The smaller HE-TF subprojectiles did not inflict as much damage to the individual components, but many components had several impacts. Figure 25 shows the front of the helicopter impacted with the HE-TF projectiles. The copilot section received several perforations to the windshield and its interior. The crew compartment, starboard side, was damaged. There were several small perforations to the starboard fuel cell and also on the port side, but they probably would have self-sealed. However, there was one large hole in the port-side fuel cell, which may not have self-sealed. Several perforations were in the crew compartment/engine bulkhead, but no line

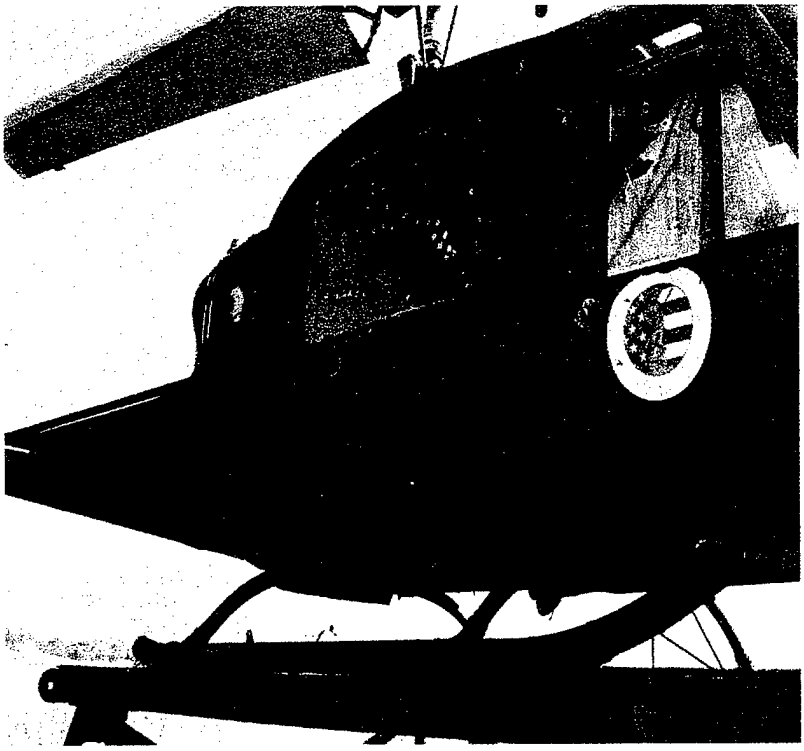


Figure 23. Photograph of AHEAD Projectile Impacts on Front of Helicopter.

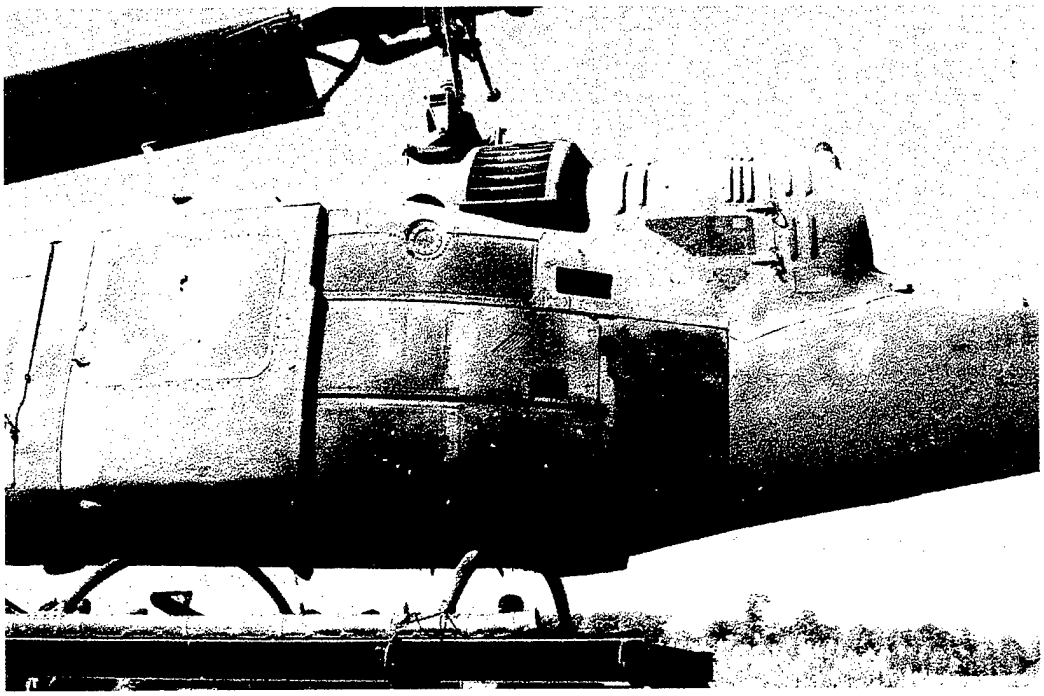


Figure 24. Photograph of AHEAD Projectile Impacts on Rear of Helicopter.

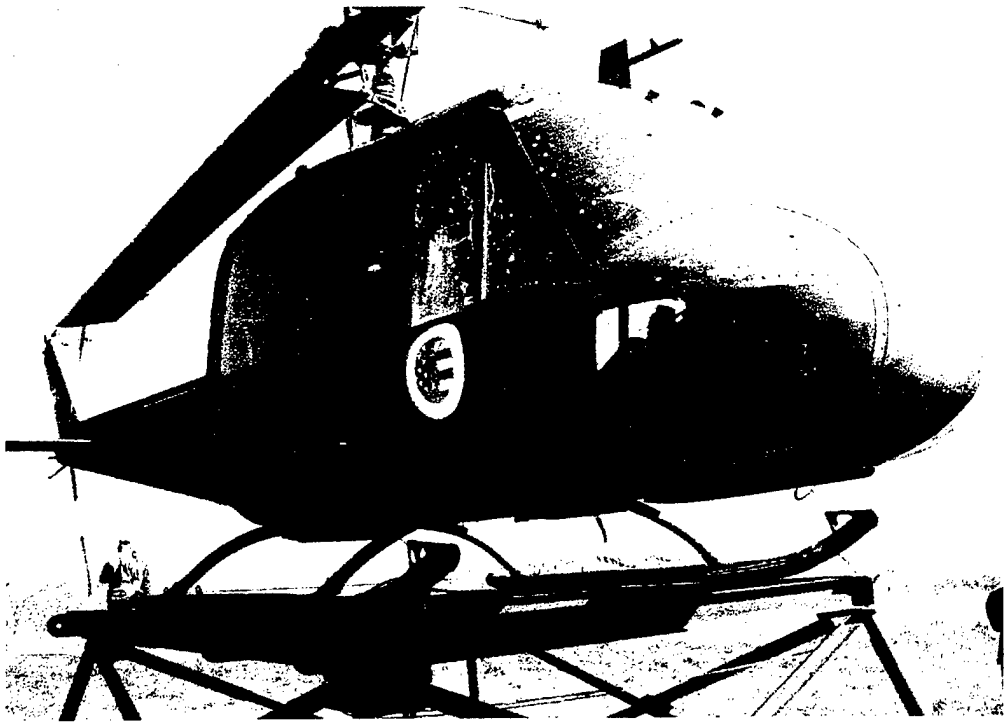


Figure 25. Photograph of HE-TF Projectile Impacts on Front of Helicopter.

damage observed. Again, there were several hits on the blades and skids, but nothing that would have caused a structural failure. As can be seen, both helicopters would have been devastated with just the two-round burst from either projectile and, dependent on the mission, would probably have suffered a mission abort.

The second target, the troops standing in the column formation (total area 30-m × 55-m tarp) was evaluated next. Figure 26 shows the impact locations for the six AHEAD rounds on the troop formation at 1,250-m range. In the figure, in addition to the location of the fragments, the location of the troops and the burst locations are shown. As can be seen, the spread of the subprojectiles was concentrated in the narrow cone angle (10°) for each individual burst. The line of fire was held constant for each shot. The AHEAD subprojectiles were very lethal, completely perforating the flack vests, front and back. Figure 27 shows the impacts on the front and back of the vests, which was originally on the second squad member. It also easily perforated the helmets. A photograph of the E-type silhouette, located in the front of the column, is shown in Figure 28. As can be seen, this squad member would probably have been killed by these impacts.

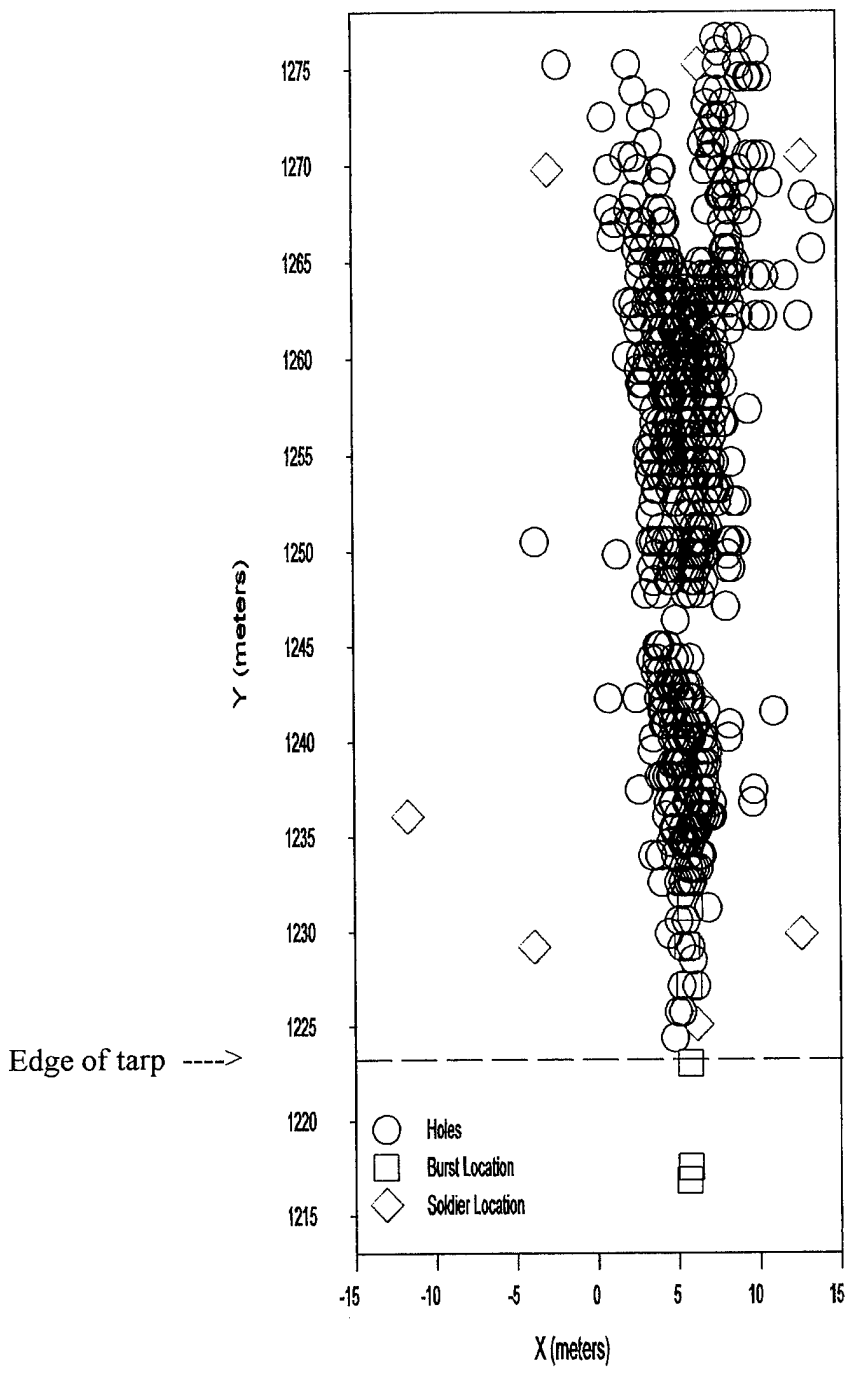


Figure 26. Fragment Impacts of Six-Shot AHEAD Projectile on Troop Formation.

The Diehl HE-TF ammunition had difficulties in the timing of the fuses for the remainder of the demonstration. These difficulties were traced down from the history of the ammunition lot. Two lots were available for the testing. The first was used in the preliminary shots and against the

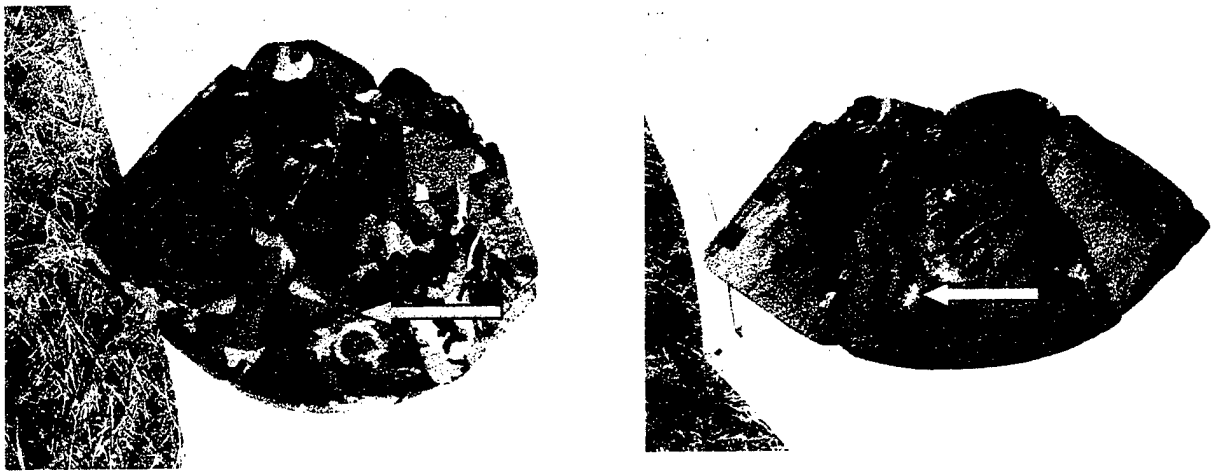


Figure 27. Perforations of Flack Vest From AHEAD Projectile.

Figure 28. Photograph of Troop Formation Silhouette With AHEAD Projectile.

helicopter target and functioned extremely well. The second lot was opened at the beginning of the troop formation evaluation. The history of the second lot showed that it had been through several environmental tests (temperature, humidity, etc.). Since this is still preproduction ammunition and

all of the conditioning preparation was not complete, there were numerous shots where the fuses malfunctioned. To complete the demonstration and gather as much lethality information as possible, extra shots were fired at the remaining targets to ensure bursts over the targets. In the consideration of time and funding, the burst location was not measured for all of these tests. It must be stressed that this ammunition was still in its developmental phase.

The results of the troop formation for the HE-TF are shown in Figure 29, in a similar manner as shown for the AHEAD projectile. Again, the locations of the squad members are shown. As mentioned, the locations of the burst were not recorded for these tests. As seen with the preliminary shots, the fragment pattern from the highly explosive HE-TF projectile almost completely covers the tarp, even without traversing the barrel during testing. Figure 30 shows a close-up of one of the squad members; again, this soldier would have probably been killed by the impacts. Although the individual fragments are not as lethal as the AHEAD subprojectiles, they still had enough energy to perforate the front of the flack jackets and enter into the silhouette, causing internal injury.

The ATGM site, located at 1,035-m range, was impacted with three rounds. The location of the individual fragments was not recorded for these targets. However, a quick assessment of the silhouettes was made. The greater energy of the AHEAD subprojectiles was evident on this target. Figure 31 is a photograph of the entire bunker impacted by the AHEAD projectile. As can be seen, the AHEAD projectiles had numerous impacts on the sandbags, spilling sand in front of the target. Also, all of the silhouettes had impacts on them, even the simulated ATGM launcher. The helmet, which was actually slightly above the bunker, had perforations in it also. The ATGM site would most probably have suffered a complete loss of function.

The smaller individual fragments from the HE-TF, although dispersed over a greater area, were not as lethal. As can be seen in Figure 32, a photograph of the ATGM site, the bunker had several impacts, but the sandbags were not destroyed. However, again, all of the personnel had at least one impact on them, which would have caused some degree of incapacitation and a complete loss of function at the site.

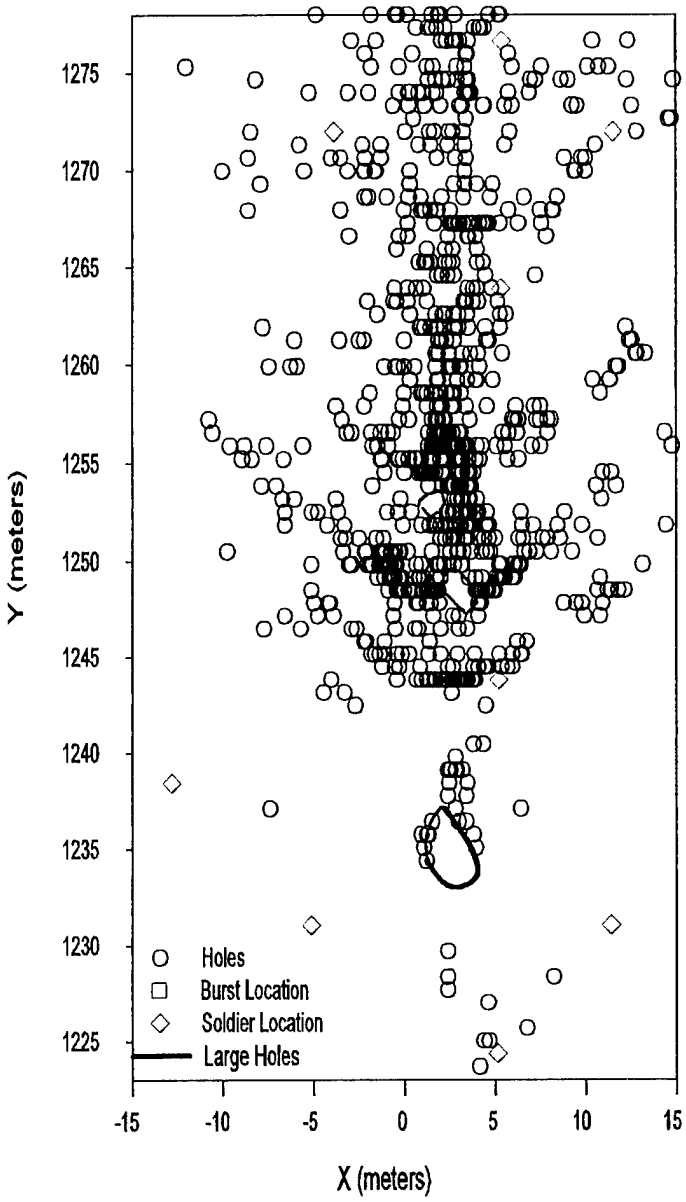


Figure 29. Fragment Impacts of Multishot HE-TF Projectile on Troop Formation.

As mentioned, the ATGM site was also impacted with the 25-mm M791 point-detonating projectile. This is the current ammunition for the 25-mm Bushmaster chain gun. For an equal ammunition volume comparison, nine of the 25-mm M792 projectiles were fired to compare to the three 35-mm projectiles. Several other modifications were made for this test arrangement as compared to a typical engagement. The location of site, 1,035 m, and, due to the terrain restrictions, the fact that it was set up on a berm, allowed for a more easily assessable target. The target was

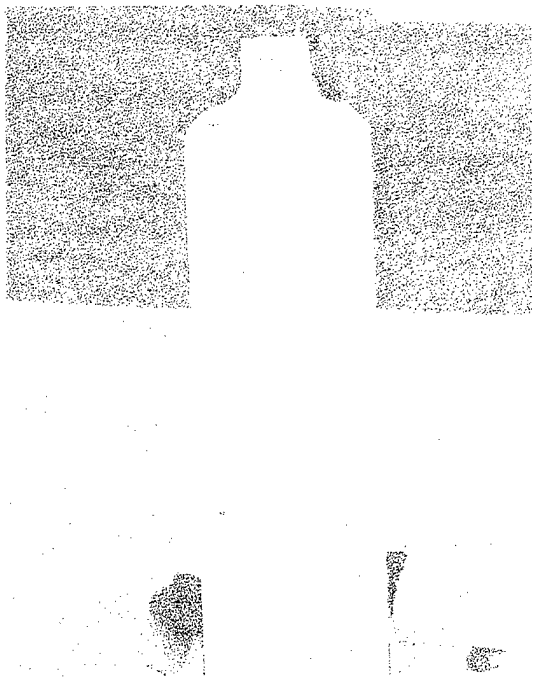


Figure 30. Photograph of Troop Formation Silhouette With HE-TF Projectile.

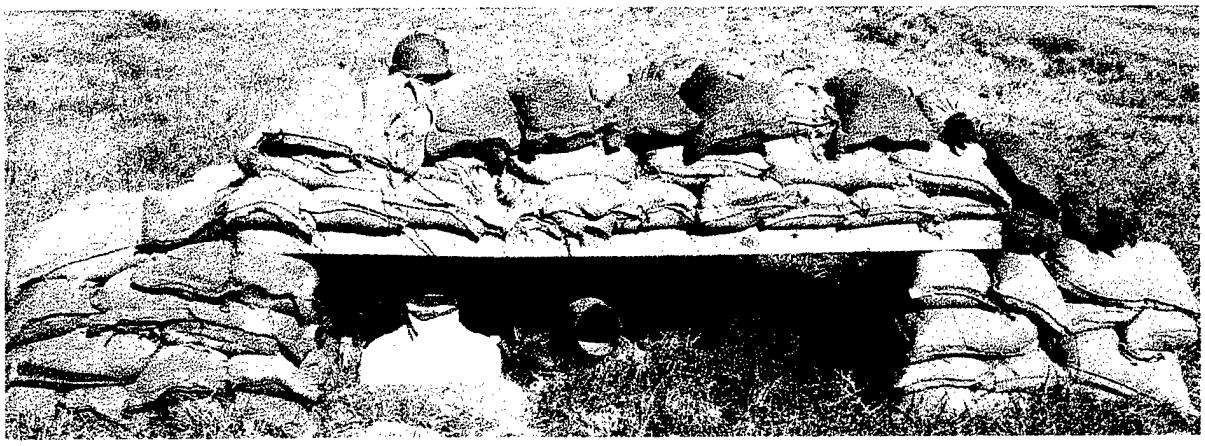


Figure 31. Photograph of ATGM Site Impacted With AHEAD Projectile.

engaged in a single-shot mode, which would typically be engaged in a burst mode. Also, by using the single-shot mode, the aim was corrected for each shot. The nearness of the target, its location, the single-shot mode, and the correction to aim allowed for a total of five shots to have direct impacts on the site out of the nine total shots. This hit probability is much greater than expected for

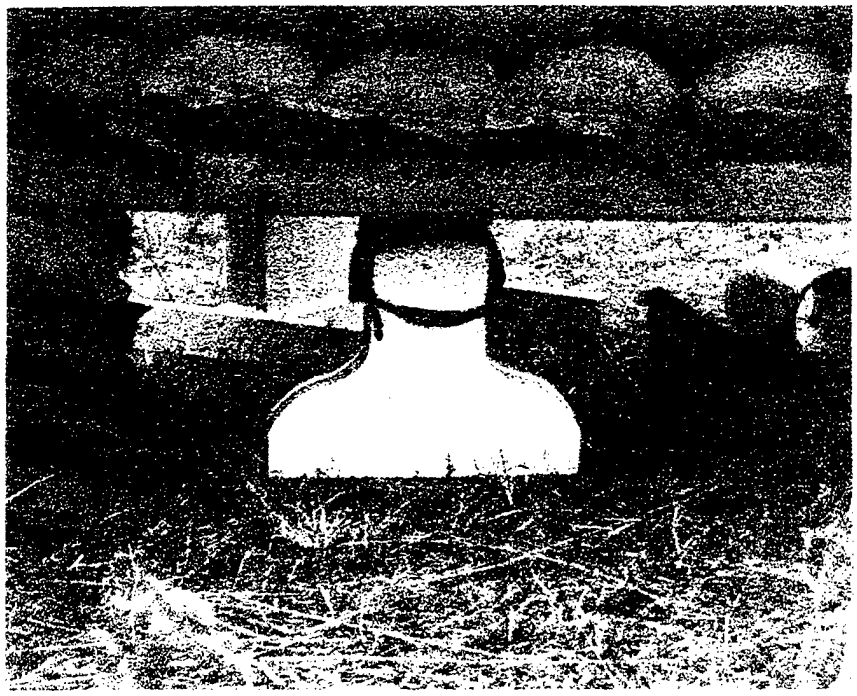


Figure 32. Photograph of ATGM Site Impacted With HE-TF Projectile.

Figure 33. Photograph of ATGM Site Impacted With M792 PD Projectile.

a typical engagement. Given the five impacts, the target was completely destroyed (see Figure 33). One of the soldiers had a direct impact, the other site members were hit by some fragments, and the sandbags were severely damaged. Also, the target area caught on fire, burning a considerable area. Again, in an "actual" engagement with the 25-mm M792, it is expected that considerably more rounds would be required to cause this much damage. Most rounds would not be direct impacts, due to the low probability of hit of the M792 in "typical" engagements.

The final target evaluated was to examine the effect of one shot each from the bursting munitions on the optics of a BMP fighting vehicle. An extra shot was made for the HE-TF because it did not burst at the desired location. The BMP was located at approximately 1,135-m range. The vehicle had several optics set on top of the hull to see if the subprojectiles would indeed "blind" the vehicle. As mentioned, the vehicle was set on the HE-TF shotline and the AHEAD was fired across range to impact the vehicle. Figure 34 shows the side of the BMP vehicle. This photograph was taken after the vehicle had been in the weather, and many of the impacts on the steel hull show signs of weathering (rust). However, numerous impacts by the two projectiles can be seen on the vehicle. Figure 35 shows the aluminum engine cover of the BMP. This photograph shows several impacts; many probably entered into the engine compartment, but probably did not have enough energy at that point to cause much internal damage. One or two impacts did hit the barrel and possibly may have shortened the life of the barrel. The AHEAD subprojectiles had two good hits on the optics. The first was on the infrared device, Figure 36. As can be seen, there is one fragment perforation to one of the optic areas, making the device unusable. This is similar to an accurate shot with an M16 rifle. The vision blocks were also hit with the AHEAD subprojectiles, also shown in Figure 36. Again, the glass was shattered, making the vision blocks inoperable. There were not any direct hits with the HE-TF projectiles on the optics, but some did cause damage to the exterior of the vehicle, and a few glancing impacts broke some of the glass. One of the HE-TF projectiles impacted the right side of the turret without bursting, a direct impact. This was not planned for these test, but it is one of the options of the ammunition. The intact projectile completely perforated the BMP turret; see Figure 37. This shows the energy of the intact projectile and another possibility for its use.

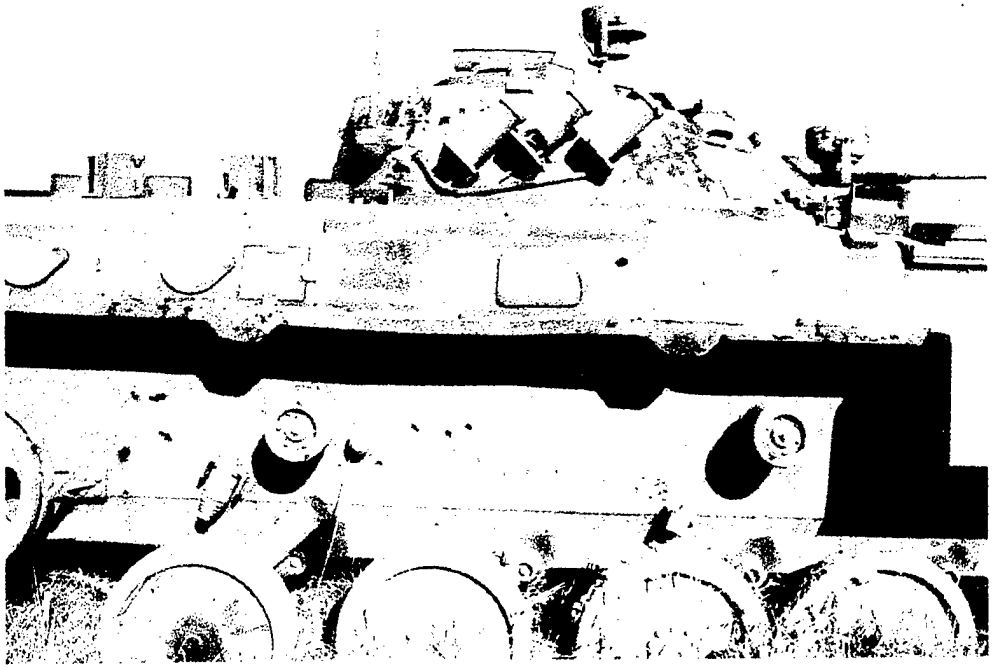


Figure 34. Photograph of BMP Vehicle From Side Impacted With AHEAD and HE-TF Projectiles.

Figure 35. Photograph of BMP Vehicle Engine Cover Impacted With Both Projectiles.

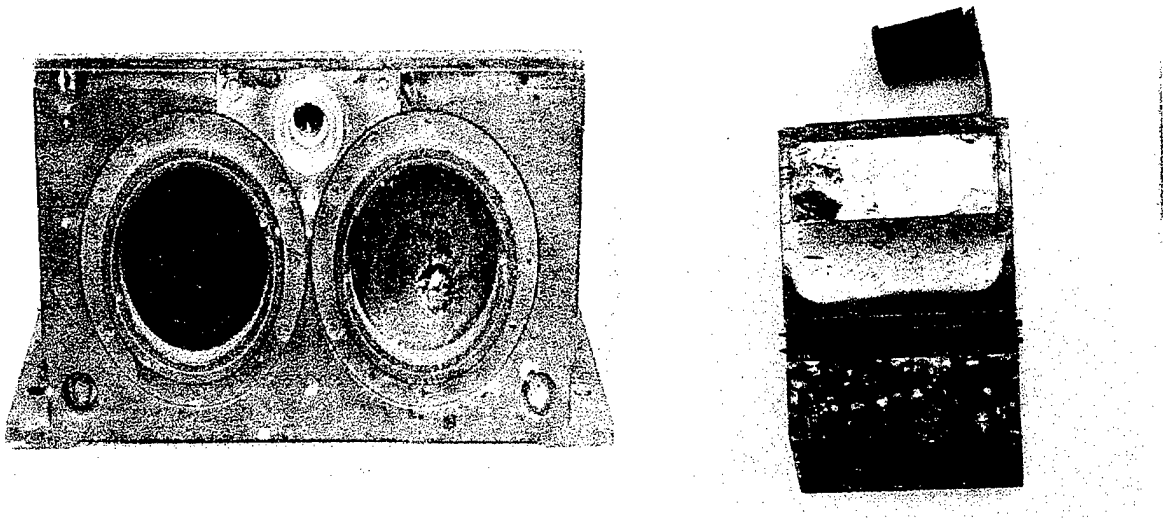


Figure 36. Photograph of BMP Vehicle "Optics" Impacted With AHEAD Projectile.

Figure 37. Photograph of BMP Vehicle Turret With Direct Impact of HE-TF Projectile.

6. Summary

The evaluation and demonstration of the 35-mm airburst ammunition was successfully completed. An initial assessment of the capability of two different off-the-shelf airburst technology concepts was accomplished. The evaluation shots will add much-needed actual data to enhance the current fractional casualty lethality models. The demonstration was very useful to the contractors, Oerlikon-Contraves, Diehl (Mauser and Rheinmetall), and Boeing, allowing them the opportunity to show their capabilities to the technical community and many of the U.S., UK, and Canadian users.

The AHEAD projectile was very effective at inflicting damage to the target matrix. The heavy projectiles, with energies approximately equivalent to that of the ammunition from an M16 rifle, were very lethal, perforating flack vests (front and back), helmets, helicopters, and optics and inflicting heavy damage to the bunker site. The minimal number of projectiles available and the low cone angle would require that the gun be incorporated into the fire-control system, spreading the projectiles over a wider azimuth area. With the incorporation of the fire-control system and the assessment of the damage observed in this evaluation, the AHEAD round would successfully defeat all of these type of targets.

The HE-TF projectiles are also very effective against all of the targets. The increased number of fragments available in the HE-TF and the much greater amount of HE naturally spread the fragments over a greater area and increased its probability of hit considerably. However, the individual fragments are not as lethal. In all of the tests performed in this analysis, the fragments did indeed inflict sufficient damage to defeat the targets; however, it was not as readily visible as with the AHEAD subprojectiles.

Over all of the targets considered, the airbursting ammunition is much more lethal than an equivalent mass point-detonating projectile. Even with the greater number of rounds available of the smaller caliber, 25-mm PD vs. 35-mm airburst, the lethality against most of these targets should

be greater for the airburst, due primarily to its greater probability of hit. Again, it is analogous to the shotgun vs. a rifle, numerous pellets of the shotgun, and one slug from a rifle. Finally, these actual data will be incorporated into the lethality models at AMSAA for future analysis to confirm these hypotheses.

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Government and several industry representatives collaborated to initiate a demonstration of the current 35-mm airburst technology. The U.S. Government gathered an initial baseline database of "off-the-shelf" airburst technology, while industry was given the opportunity to demonstrate the performance of their airbursting munitions to U.S. and foreign government organizations and to numerous users.

Two 35-mm airburst projectiles were evaluated, the Oerlikon Contraves AHEAD projectile and the Diehl high-explosive - time fuse (HE-TF) projectile, for basic function properties and against targets representing several combat scenarios (i.e., troops in the field, troops in a covered antitank guided missile [ATGM] site, a helicopter, and the optics of a lightly armored vehicle). The basic function evaluation included the burst location, number and location of fragments, and the perforation ability of the subprojectiles against thin-steel sheets and celotex. Most of the personnel impacted in the simulated targets, some with helmets and jackets, were incapacitated to some degree. The impacts to the helicopters would have resulted in some level of mission degradation (abort), and the optics on the lightly armored vehicle were effectively damaged, making them unusable.

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