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The Lightweight Artillery Projectile

by James M. Bender

ARL-TR-2573 September 2001

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ARL-TR-2573 **September 2001**

The Lightweight Artillery Projectile

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Abstract

This report discusses the logistical advantages of using composite materials as a substitute for steel in 155-mm cargo-carrying artillery shells. A weight savings of 25–30% per projectile can be realized. Combined with the weight savings offered by the XM777 lightweight howitzer, Light and Rapid Deployment Forces can be equipped with the firepower of the 155-mm cannon utilizing projectiles with a four-to-one lethality advantage over their 105-mm counterpart, while weighing approximately twice as much. The system of lightweight howitzers and projectiles offers these forces a substantial increase in lethality as measured by kills per logistical ton.

Acknowledgments

Mr. Robert Kaste and Mr. James Garner performed extensive analysis and design work on the fin assembly of the subject projectile. Their efforts were key to the success of the prototype. Mr. David Spagnuolo is hereby commended for his excellent fabrication of the composite shell resulting in a first-time success. Mr. Peter Dehmer's and Ms. Melissa Klusewitz's work on the fin protector cup was exemplary and resulted in a potentially patentable item. Lastly, Mr. Gary Sprenkle's work manufacturing the fin assembly was up to his usual standard of excellence.

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1. Introduction

Cannon-launched artillery projectiles have a long history of being made chiefly of steel and containing varying amounts of explosive for blast and fragmentation effects. Steel shells ranging from 40 to 240 mm dominated the battlefield in World War I (WWI) and World War II (WWII) with some carrying cargo other than high explosives, i.e., smoke and gas agents. Just before and during the Vietnam War, cargo-carrying artillery shells that carried small grenades were developed and increased the lethality of shells significantly when brought to bear on certain targets. With this modernization came a logistical penalty in the form of increased weight. The M198 towed howitzer weighs in at 15,800 lb (7,182 kg) with shells weighing nominally 100 lb (45 kg). Modern warfare has, through the necessity to rapidly emplace firepower, given birth to Rapid Deployment and Special Forces that require lightweight, air-transportable and mass-efficient weapons, resulting in higher lethality per logistical ton. These forces carry the name "Light," and must be capable of projecting lethal fires with minimal logistical burden within 18 hr virtually anywhere in the world. Large prime movers are not among their assets and they must compete for heavy lift aircraft when deploying. Thus, light forces are constrained by weight yet must be rapidly deployed and highly lethal.

Modern composite materials are being exploited to fill many roles in the U.S. Army initiative to "Lighten the Force." They can be found in weapons such as sabots, armor, vehicle structures, and transport containers, to name a few. State-of-the-art analysis and cutting edge manufacturing processes have given rise to high-strength composite materials that are unidirectionally as strong as steel in a particular application, yet weigh 1/5 as much per unit volume. The High Capacity Artillery Projectile (HICAP) program was the first of its kind to employ off-the-shelf carbon/epoxy composite materials for fabrication of artillery shells. The prototypes had to withstand over 13,000 g's of axial acceleration and be compatible with the highest charge in the 155-mm system. The technology from that program has been used extensively by the Navy (Best Buy program) and by the Army in the current lightweight artillery shell effort, the "75-lb shell" which delivers submunitions.

Much attention has been focused on reducing the weight of the launcher as evidenced by the 40% reduction in weight from the M198 towed howitzer to that of the XM777 system described in the next section. However, the projectiles make up the largest part of the logistical burden and their weight alone dismisses them from consideration for use in Light Forces application even though a 155-mm shell can carry proportionally more payload by weight (3.5 times per round) and has greater range. The 75-lb shell, on the other hand, can carry even

more payload than the M483 made possible by the reduced thickness of the shell. The inside diameter of the M483 is 5 in (127 mm) compared to 5.5 in (139 mm) for the 75-lb shell. This provides approximately 24 in^3 (387 cm^3) more payload volume. Thus, the 75-lb shell can carry four times as many M80 grenades than the new XM915/916 105-mm projectile while weighing only twice as much. This significantly increases mass efficiency and reduces crew fatigue in comparison to current 155-mm steel shells.

2. "Lighten the Force" Initiative Applied to Artillery

Two grenade-carrying artillery shells currently in the 155-mm inventory are the M483A1 and the M864, both 155 mm—the latter being a base-burn assisted, longer range, slightly less lethal version of the former since 16 grenades are removed to accommodate the base-burn module. Each delivers a payload of M42/M46 grenades and disseminates them over the target area. A similar 105-mm version is the XM915 which carries the new M80 grenade—a smaller version of its predecessor, the M42, with the comparable antiarmor capability and a new self-destruct fuze. Grenades are many times more effective as a distributed group at defeating certain enemy targets than single-point high-explosive rounds like the M107. This type of round is highly desired by Light Forces, which currently employ 105-mm howitzers for the direct support mission.

The U.S. Army and the United Kingdom are developing a lightweight towed 155-mm platform, the XM777 (Figure 1), which will weigh 40% less than the M198 towed howitzer. This weapon will be capable of firing all current projectiles in the 155-mm inventory and their propelling charges. Still, it weighs more than twice as much as the 105-mm howitzer with ammunition that weighs three times as much per shell, though each is substantially more lethal than a 105-mm shell. Light and Rapid Deployment Forces must consider a choice: heavier and lethal (155 mm) or lighter and substantially less lethal per round (105 mm). Whether the Light Forces will use the new 155-mm system or retain the 105-mm system or both is beyond the scope of this report.

Table 1 illustrates the difference between a 155-mm lightweight shell and a comparable 105-mm shell. They are compared in two ways: by projectile and by mass efficiency. A current 155-mm steel cargo shell, the M483A1, is included for reference.

Figure 1. The XM777 155-mm lightweight towed howitzer.

Table 1. Comparison of artillery system mass efficiency.

Caliber (mm)	Projectile	Cargo Mass (lb/kg)	Non-Cargo Mass (lb/kg)	Total Mass (Projectile + Propulsion Charge) (lb/kg)	Mass of Cargo/ Total Mass of Projectile (Mass Efficiency)
105	XM915	12.0/5.5	32.0/14.5	44.0/20.0	0.27
155	75-lb shell	48.0/21.8	50.0/22.7	98.0/44.5	0.49
155	M483A1	40.0/18.4	92.0/41.8	132.00/60.0	0.30

The table illustrates that the logistical burden is drastically reduced, mostly due to the reduction of parasitic mass—the amount of non-cargo mass that inflicts no damage. The expected fractional damage per logistical ton is nearly doubled, due to the use of composite materials in the shell. This claim assumes that the grenade density on the ground is the same for each round. Another viewpoint would be that the forces have the same number of stowed kills onboard transportation assets at approximately half the current weight. As for the advantages of composite materials in place of steel in a 155-mm system, a 26% weight savings is realized, since the cargo would be the same.

3. Emerging Technology

The next generation of a lightweight artillery platform is the Future Combat System (FCS). The caliber of that system is still undergoing study, however, it will exploit lightweight materials. The technology being addressed under this program is being investigated in a 155-mm platform to be compatible with the XM777, but also applicable to other calibers that may be selected in future cannon programs. Cargo-carrying artillery shells have historically been fabricated from steel for two reasons: (1) the obvious structural requirements to sustain the setback loads from launch and, (2) the need for mass at the outer radius of the shell for spin stabilization. A composite artillery shell (Figure 2) weighs substantially less than its steel counterpart allowing an equal payload to that of steel shells at a 25-30% overall weight reduction. They do not have enough mass at the outer radius for spin stabilization and therefore require deployable fins for stability. Composite deployable fins were demonstrated with the HICAP program in June 1996 [1]. Also, a 1/4-in (6-mm)-thick composite shell was demonstrated on the same test with the top-zone (8-S) charge. In 1992, Lyle Kayser of the U.S. Army Ballistic Research Laboratory (BRL) developed a new approach to fin stabilization through a design that orients the fin's longest dimension with the air stream as an improvement over the original HICAP fin assembly. A novel design approach featuring deployable fins with an elliptical leading edge incorporated into the design resulted in lower drag with sufficient surface area for stabilization [2]. These new fins are illustrated in Figure 2 and prototypes with more detail are shown in Figures 3 and 4. A significant amount of the loss of ballistic coefficient* can likely be recaptured. However, the fin assembly intrudes into the chamber further than the M549 projectile, which has the longest boattail of all the rounds in the current inventory. The chamber intrusion would not allow the use of the M203A1 charge in the current 155-mm howitzer due to interference. The M119A2 (zone 7, red bag) charge would allow enough space for the long boattail. A systems approach is necessary so that the chamber of a new howitzer is designed to accommodate long boattailed rounds.

* Ballistic coefficient is a ration of mass-to-projectile diameter. Reducing the mass of a projectile while maintaining the diameter reduces the ballistic coefficient making it more susceptible to drag.

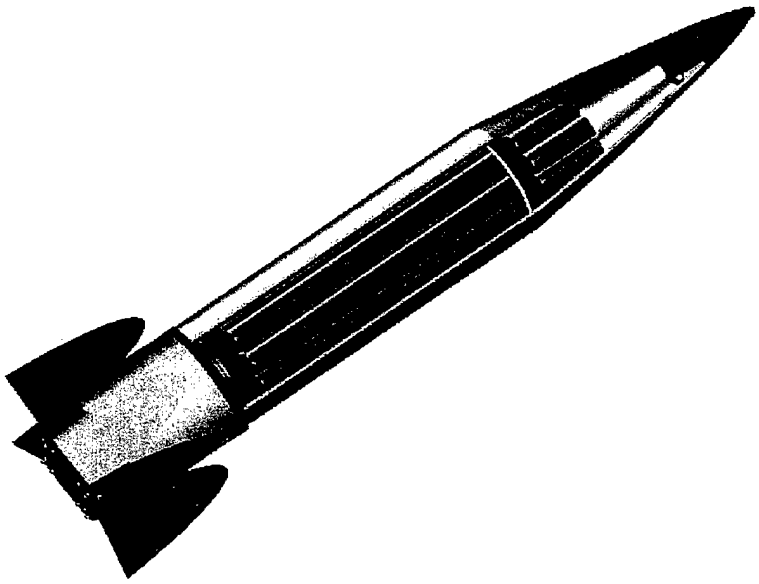

Figure 2. The lightweight 155-mm cargo-carrying projectile.

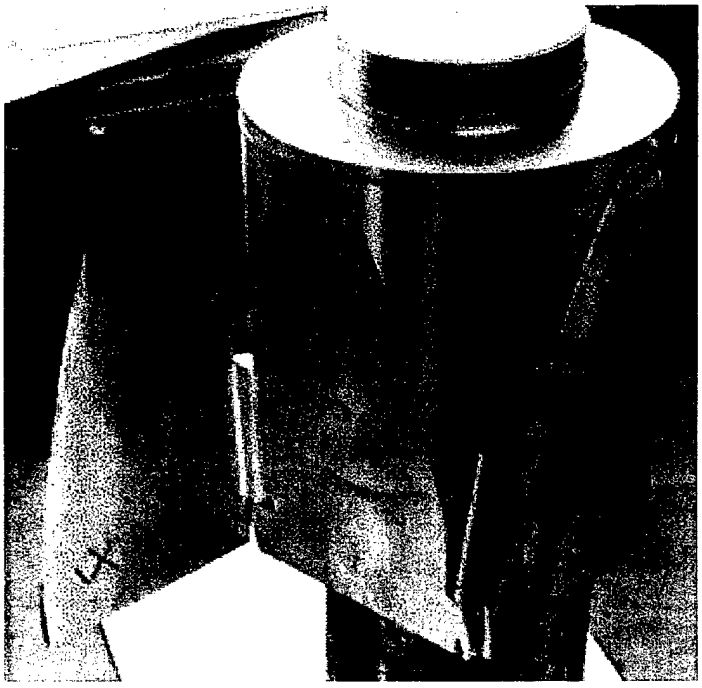

Figure 3. Kayser fin deploying.

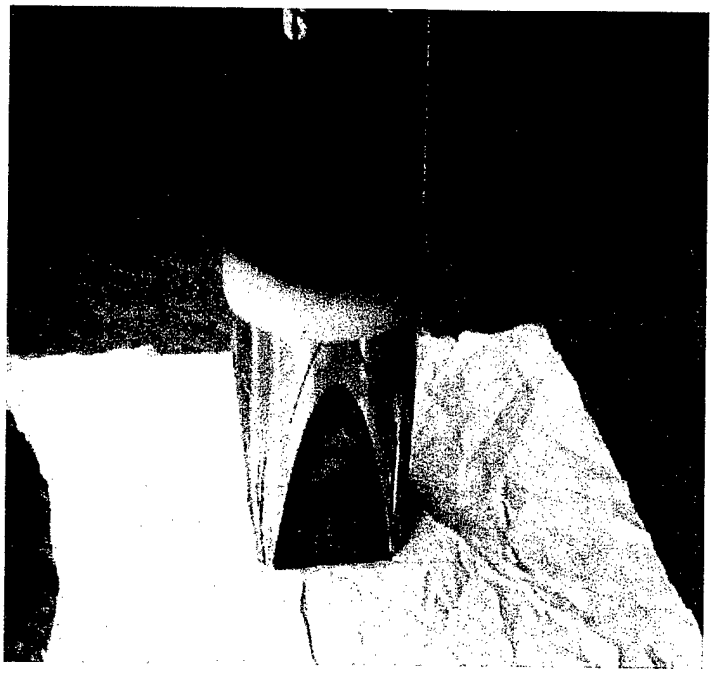

Figure 4. Kayser fins before adding fin protector cup.

The Kayser fin was modeled using ANSYS to determine the strength of design in the blast region. When the fins are in the open position and being introduced to the air stream transitioning from the blast region, they are exposed to approximately 15 psi. Given the 2° angle of attack, the estimated pressure vector normal to the fin was 15 psi (103 kPa). The results of that analysis are shown in Figure 5. The fin assembly was tested at the U.S. Army's Transonic Range Facility at ARL. The assembly was attached to a simulated projectile mass, commonly called a "slug." The total weight of the test projectile was 75 lb (34 kg). A zone 7 (red bag) charge was used to propel the projectile to a muzzle velocity of approximately 2,015 ft/s (614 m/s). Peak chamber pressure generated was approximately 40 kpsi (276 MPa). Shown in Figure 6 is a high-speed smear photograph taken at 25 ft (7.6 m) from the muzzle.

4. Technology From the HICAP Program

The HICAP program was a successful Army Science and Technology Objective (STO) and an applied research joint effort with the U.S. Armament Research and Development Center (ARDEC) from 1991 to 1996. It was the first artillery program to prove the launch structural integrity of very long (74 in [188 cm]) polymer composite artillery shells, with deployable fins and snap joint

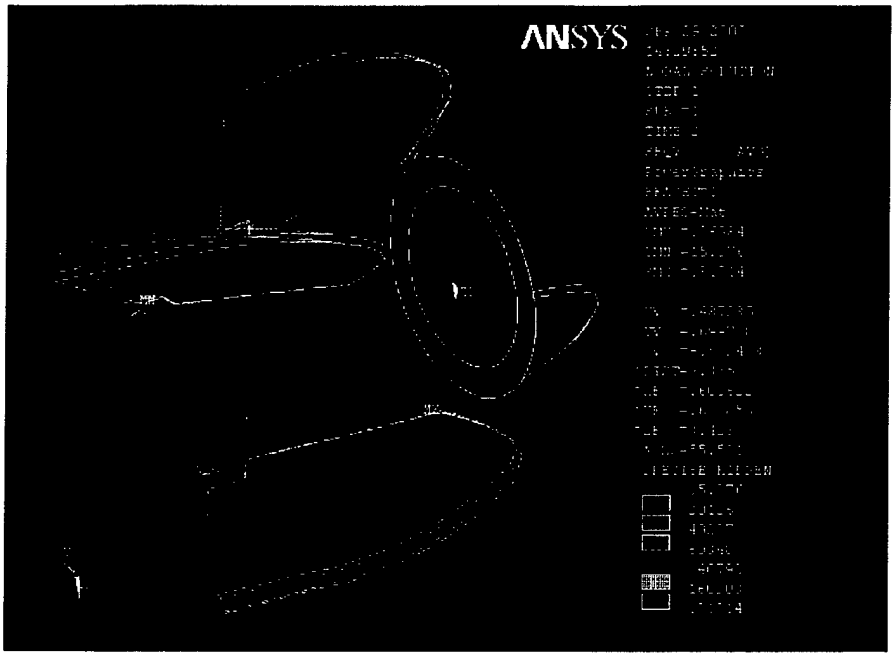

Figure 5. Stress on fin due to aerodynamic loads.

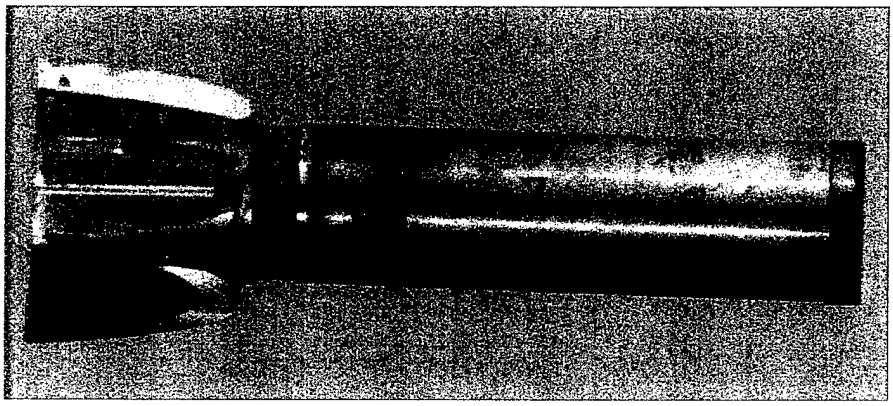

Figure 6. Pre-test of Kayser fin assembly.

construction. The HICAP is shown in Figure 7. In October 1995, the HICAP was proven structurally sound with the M203A1 charge in a launch integrity test at the ARL's Transonic Range. Figure 8 is a muzzle exit high-speed photograph of the prototype HICAP. In June 1996, five HICAP projectiles were flown to full range using the M203A1 charge, completing the demonstration program. The grenade-dispense system had been tested prior to full-range flight tests. When over the target area, the rear section dispenses similarly to the M483A1 by ejecting the grenades through the base. The forward shell is pressurized and bursts so the grenades are dispersed at various radial velocities and fall to the

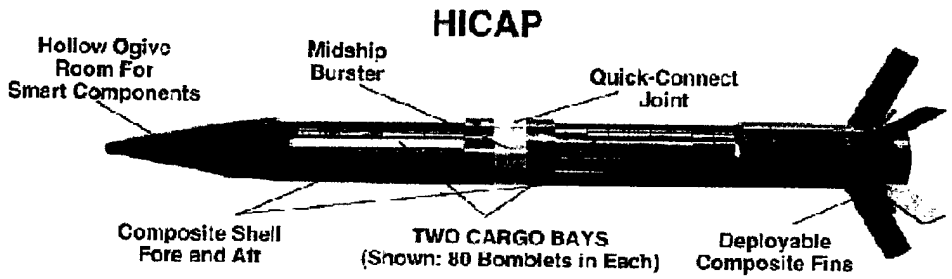

Figure 7. The HICAP.

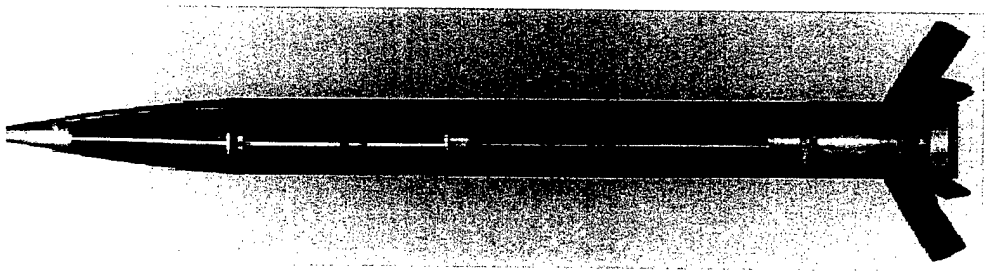

Figure 8. Muzzle exit high-speed photograph of HICAP.

ground. Figure 9 shows the results of a laboratory burst test with M42 grenades as payload. The radial expulsion velocity of the grenades was optically measured and averaged at 200 ft/s (61 m/s), considered favorable for an acceptable density on the ground to achieve the desired fractional damage. Many technologies from HICAP can be applied to a unitary lightweight shell for the Light Forces. In the present effort, the forward shell from HICAP was used. It is fabricated using carbon-epoxy material and is only 0.25 in (6 mm), and thereby maximizes payload volume when compared to the M483A1 in which the shell is 0.5 in (13 mm) thick. It must sustain only its own weight plus a fuze and expulsion charge. The method of attachment to the base and the expulsion system were also adapted from the HICAP program. However, the 75-lb shell will use the new M80 grenade and therefore more of them can be placed in the shell due to their smaller diameter.

5. Prototype Testing

The first prototype testing of the lightweight artillery shell was performed at ARL's Transonic Range in April 2000. The fin assembly, aeroshell, fin protector cup and all related hardware were manufactured at ARL. The payload of 168 M80 grenades was simulated by an equivalent mass of aluminum. The projectile is shown in Figure 10, broken down by components for clarity. The fin protector

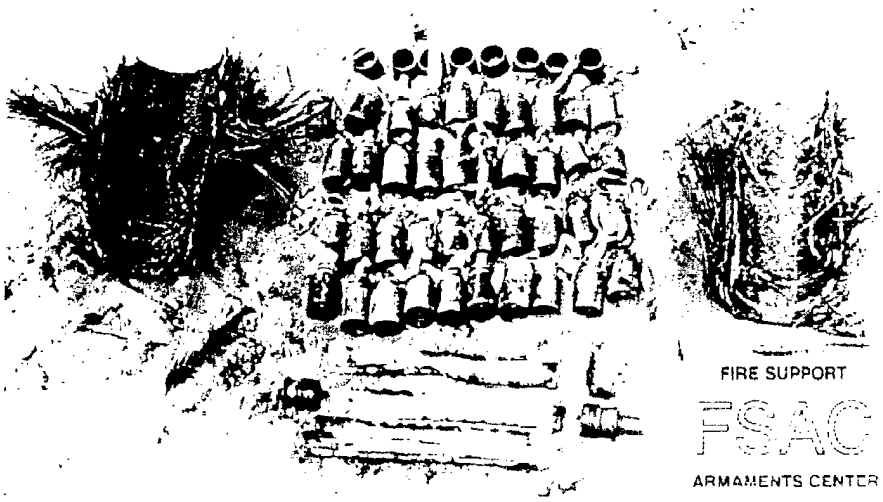

Figure 9. Result of grenade-dispense burst of forward shell.

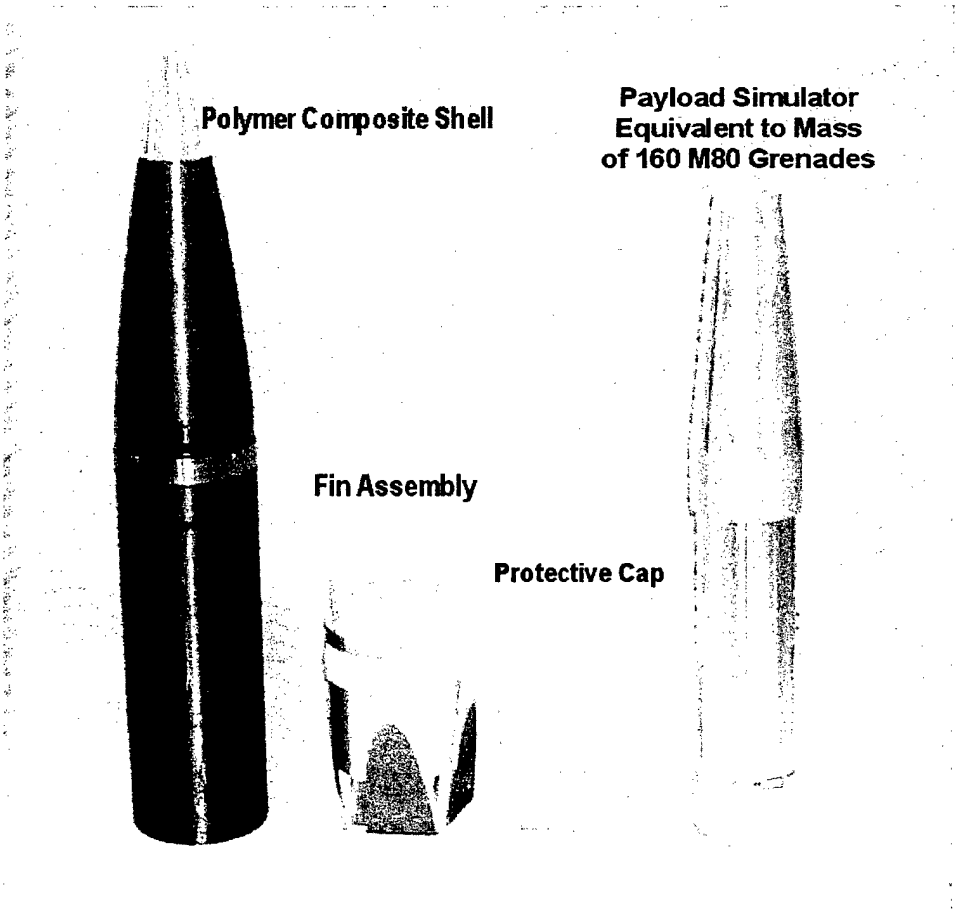

Figure 10. Lightweight artillery shell prototype before assembly.

cup is made from S-glass weave and an epoxy resin. Its function is to seal the fin assembly from gun gasses during launch, then shatter at muzzle exit allowing the fins to deploy. It is relatively flexible to allow it to conform to the shape of the fin assembly under pressure. The voids existing under the cup at the fin hinges are filled with a silicone gel. Under pressure, the gel responds hydrostatically to oppose the pressure from the gun gasses, preventing gas jetting and damage.

This projectile's fin assembly is relatively long (but not necessarily so) and renders it incompatible with the zone 8S charge due to interference. However, sufficient muzzle velocity is achieved with the zone 7 charge since the projectile is so much lighter. Figure 11 is a high-speed photo of the projectile just after muzzle exit. Two of the four fins have locked in place. The other two have not fully deployed and locked. It has been determined that these fins may have been pushed back to the folded position due to initial yaw of the projectile. The forces from airflow on these two fins would tend to close them back up before locking. It was also determined that the spring stiffness on the locking pin was insufficient to force the pin into place quickly enough.

6. Recommendations

In an effort to assure full fin deployment, two modifications will be incorporated into the design. First, the slip obturator will be modified to slightly increase the initial spin rate. This would impart more angular momentum to the fins and deploy them more quickly. It would also alleviate some of the initial yaw observed in Figure 11. Second, a locking pin with a much higher spring constant will replace the current one. The high-speed down-bore movies indicated that the fins fully opened but did not lock. Employing a stiffer spring will help ensure the fins lock in place quicker. The current design uses a spring with a constant of less than 1 lb/in (1.8 N/cm). The new locking pin spring constant is 52 lb/in (91.8 kg/cm).

Figure 11. Muzzle exit photograph of the lightweight artillery projectile.

The current base (fin housing) is fabricated from high-strength aluminum that is hollowed out to reduce mass. A study is currently underway to investigate the use of composite materials for the base. This would remove sufficient mass to allow the addition of a rocket motor for increased range without a weight penalty or reducing the payload. One challenge of using polymer composites is the very high and localized stresses generated when deploying fins are stopped suddenly as they lock into position. This may shear the composite at the point of attachment of the hinge pin. A metal plate will be added onto the bottom as shown in Figure 12 (dark red) to mitigate this problem and serve as a more solid point of attachment for the hinge pins. Additional support rods would run the length of the structure and attach to a threaded metal ring at the top for ease of attachment to the shell adapter, which is a double-male threaded metallic ring.

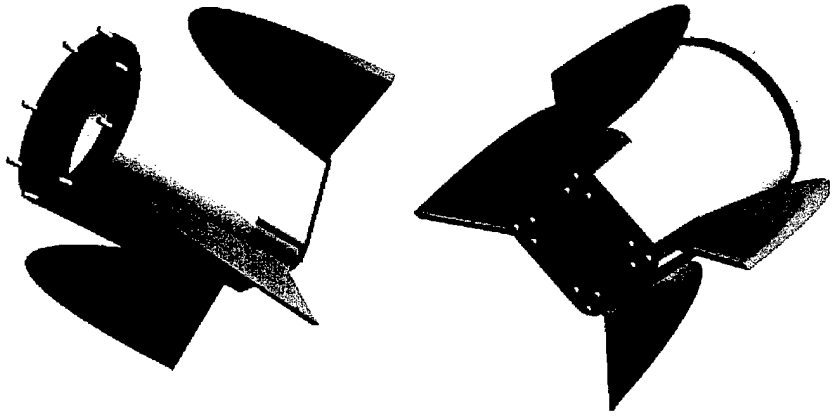

Figure 12. Composite material version of Kayser fin assembly.

7. Conclusions

The reduction of aerodynamic drag to increase range by the use of Kayser fins is a critical technology for a lightweight artillery shell. The technology has been proven using aluminum and further investigations into the use of composite materials are planned. The weapon platform is only part of the logistical equation in an effort to "Lighten the Force." Ammunition that is equal in lethality and range and weighs 25% less than current ammunition reduces the logistical burden without reducing effectiveness. Simply, this means that the Light Forces can emplace more firepower per logistical ton.

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REPORT DOCUMENTATION PAGE

Form Approved
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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final, January 1999–March 2001

4. TITLE AND SUBTITLE
The Lightweight Artillery Projectile

5. FUNDING NUMBERS
622618.H80

6. AUTHOR(S)
James M. Bender

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2573

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT*(Maximum 200 words)*

This report discusses the logistical advantages of using composite materials as a substitute for steel in 155-mm cargo-carrying artillery shells. A weight savings of 25–30% per projectile can be realized. Combined with the weight savings offered by the XM777 lightweight howitzer, Light and Rapid Deployment Forces can be equipped with the firepower of the 155-mm cannon utilizing projectiles with a four-to-one lethality advantage over their 105-mm counterpart, while weighing approximately twice as much. The system of lightweight howitzers and projectiles offers these forces a substantial increase in lethality as measured by kills per logistical ton.

14. SUBJECT TERMS	15. NUMBER OF PAGES
composite materials, artillery, logistics	35
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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