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High-Capacity Artillery Projectile (HICAP) Fin Characteristics

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13. ABSTRACT (Maximum 200 words)

One of the key technologies being developed for the High-Capacity Artillery Projectile (HICAP) is an out of bore deployable fin assembly. The fin assembly must stabilize the projectile and maintain the reduced spin level imparted by the slip obturator. The design described herein uses a rearward opening, foldout fin. This fin has acceptable aerodynamic characteristics and deploys utilizing the projectile spin imparted from the obturator. The fin blades are concealed during launch in a base module that is easily obturated.

This report contains design factors, predicted aerodynamics, and results from the fin opening tests.

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1. INTRODUCTION

The High-Capacity Artillery Projectile (HICAP) project is a joint venture between the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, and the U.S. Army Armament Research, Development, and Engineering Center (ARDEC), Picatinny Arsenal, NJ. The goal of the HICAP program is to generate double the lethality of conventional artillery projectiles at equal or greater ranges. HICAP must also be compatible with the present inventory of 155-mm gun tubes.

In June 1993, representatives from ARL's Propulsion and Flight Division (PFD) rejected a square-based HICAP design proposed by Kayser (1992). The design offered several technological challenges in obturation and was considered too expensive to develop into a reliable projectile. This square-based projectile design was originated to accommodate Kayser's novel folding fins that were aerodynamically efficient and manufacturable. Unfortunately, the fin blade design was predicated on a square-based geometry, and the requirement of minimal case intrusion created the need for a simpler base module design that produces satisfactory obturation, provides acceptable aerodynamics, and meets artillery projectile safety requirements.

The HICAP is a two-piece projectile. It is fully assembled when the aft stage is rammed into the rear of the front stage and locks. The task of designing a base module (the rear portion of the aft stage) that houses the fin, supports the obturator, and is compatible with 155-mm projectile length and mass specifications was performed by PFD. This report focuses on both the fin design and the operation of the fin during a field test.

HICAP uses a six-blade fin configuration to stabilize a roughly 12 to 1 length-to-diameter (L/D) ratio projectile. As payload volume increases, a longer body is needed to deliver the payload (assuming the same caliber gun is used). The typical artillery projectile is spin stabilized. Large L/D spin-stabilized projectiles develop sizeable Magnus forces, which tend to cause the projectile to veer off course. The larger the L/D, the greater the Magnus effect. A HICAP program goal is to create a fin-stabilized, all-composite structure (to include the base module and fins) that can be fired from the rifled 155-mm M199 gun tube. The use of composites allows a larger fraction of the total weight to consist of payload. Figure 1 illustrates the rear module; the fore sections of the projectile have been simplified.
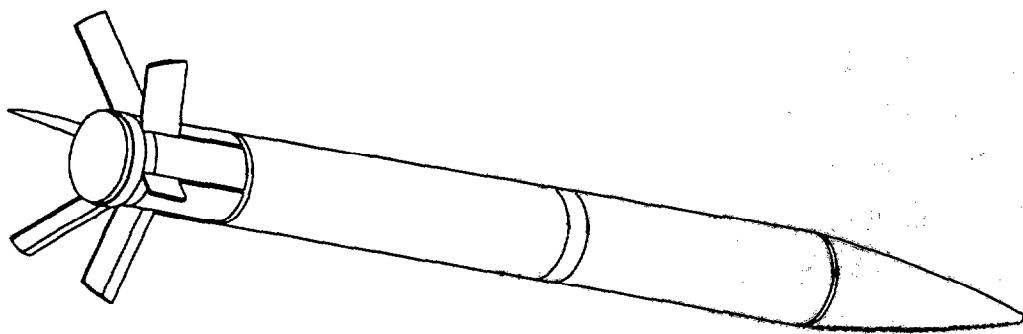
Figure 1. Simplified overall HICAP configuration.

2. BASE MODULE REQUIREMENTS

The HICAP base module had to meet several requirements to be considered acceptable. Some of the more pertinent requirements are as follows:

- Nothing can be discarded from the projectile before payload dispersal (i.e., no pusher plates [lightweight plastic rotating bands exempted]).
- The entire base module can be no longer than 11 in (based on front and rear module designs).
- The fins must give adequate stability from Mach (M) 2.2 to subsonic velocities and must have acceptable drag characteristics.
- The fin must be stowed while in the barrel and deploy upon muzzle exit.
- The fin must maintain sufficient spin for payload dispersal.

3. FIN DESIGN

Many factors were considered when creating the HICAP fin. Most of these are shown in Figure 2. The fin blade length and aspect ratio were chosen not only to satisfy stability and drag requirements, but also to survive aerodynamic bending forces as well. Perhaps the most critical part of the fin design is the placement of the blade pivot point and locking hole in relation to the fin center of gravity (Fcg). When

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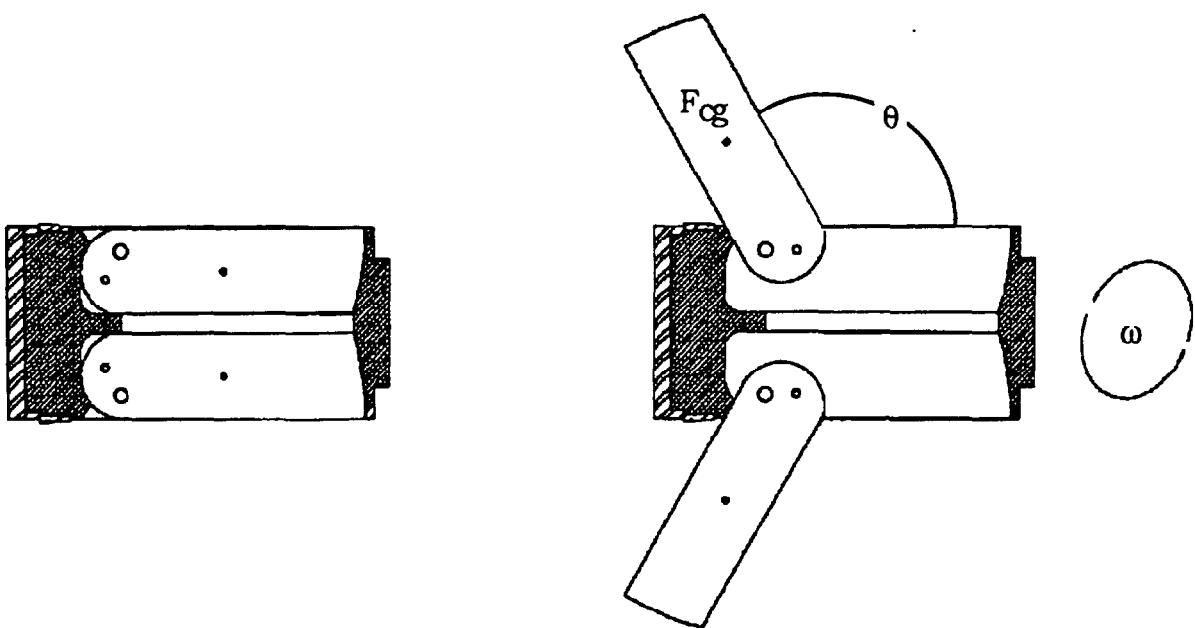
Figure 2. Stowed and open configurations of the HICAP base module.

in the stowed position, the Fcg is below the fin pivot point in relation to the projectile axis. This ensures that while the projectile accelerates, the fins will be subject to a moment that keeps them closed while in-bore. Once the projectile exits the gun, the acceleration force is substantially removed and the fins open under the centrifugal force created by the spin that results from the normal rifling process. The acceleration rate (which creates the fin closing moment) that balances the centrifugal opening moment is 750 g's (g = 9.81 m/s^2). This assumes a projectile spin rate of 5 Hz. The acceleration at muzzle exit is approximately 2,000 g's, so the fins should remain closed in-bore. The positioning of the fin blade pivot point can change the exposed blade area when the blade is extended in position. A lower pivot point (one closer to the projectile centerline) results in less exposed blade area. The exposed area can vary by as much as 20% based on the pivot point location. The fin blade rotates through an angle (theta) of 120° before locking into position at a 60° angle to the projectile body. The fin blade length and span are limited by physical dimensions of the base module and the bore.

The forces required to stop the fin blade at the locked position were also considered. A very rapid fin deployment might cause the blades to bounce off the stop and either fail to lock or damage the blade. A differential equation simulating the fin motion was created and solved with the boundary conditions

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(BCs): $\theta = 0$ at time $= 0$, and $\dot\theta = 0$ at time $= 0$. Based on these BCs, estimates of the fin velocity at the stop are shown in Figure 3 for a projectile spin rate of 5 Hz. Damage should not occur, assuming an aluminum fin, until a fin opening rate of 50 Hz occurs. Frictional forces were not modeled in the simulation equation. Composite fins and a composite base section may alter the allowable spin rate due to the fracture sensitivity of the materials and composite layups used. The following differential equation was used as a first estimate of the angular acceleration of the fin about its pivot (fin opening).

$$\ddot\theta = \frac{f_m\ \omega^2\ (r_p + f_{arm}\ \sin\theta)\ \cos\theta\ f_{arm} + D\ f_{arm}\ \sin\theta}{I_{fin}}$$

θ = the angle between the fin centerline and the projectile centerline.

I_{fin} = the moment of inertia of the fin.

ω = the angular rate of the projectile.

f_{arm} = the horizontal distance from the fin pivot to the F_{cg} at $\theta = 0$.

f_m = the fin mass.

r_p = the distance from the projectile centerline to pivot.

D = drag force on fin.

A form of the equation was used without the drag term and matched to the results of a spin test at the Transonic Range (TR). The spin test did not simulate aerodynamic effects. This was considered a reasonable approximation, since the drag term on the right side of the equation is considerably smaller than the centrifugal force based first term. Tests were conducted to estimate how quickly the fins deployed under the expected spin conditions and to detect any resulting damage. This modified equation was verified as the opening rate, $\dot\theta$, and the times required to open measured in the TR test were very close to the computed values. Figure 3 shows the results obtained from the computed values.

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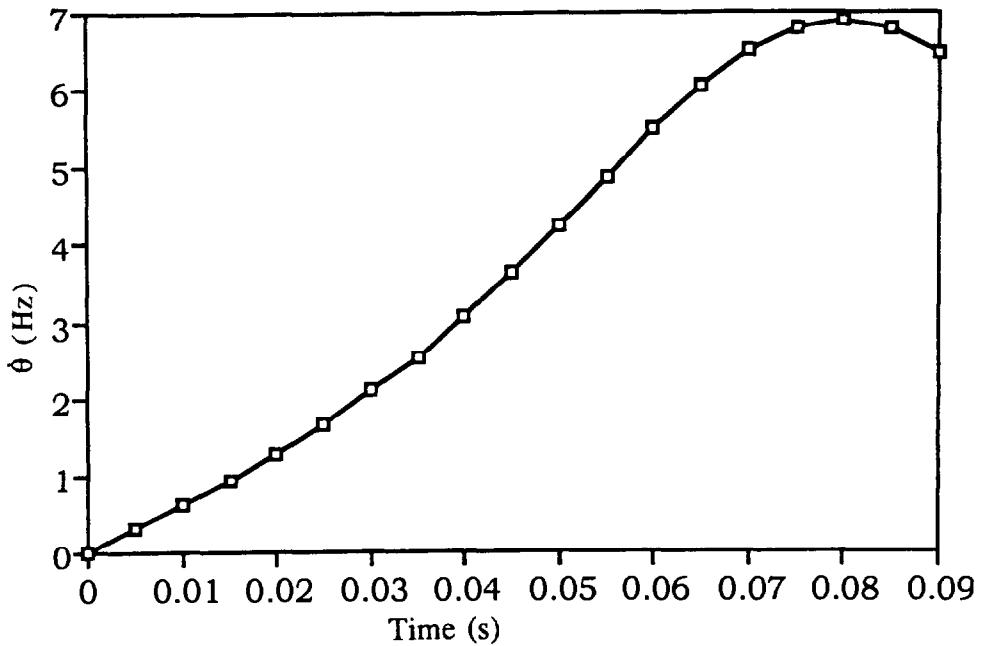
Figure 3. Fin opening rate $(\dot{\theta})$ vs. time.

The fin blade lock mechanism must function for the fin blade to perform as intended. A 0.67-cm-diameter hole perpendicular to the fin contains a detent pin. The locking mechanism is composed of a spring-loaded dowel (detent pin) and a set screw. The dowel engages, as the smaller hole (shown in Figure 2) on the fin blade rotates in front of the pin. The dowel is tapered, and the fin blade hole is counterbored to aid in the locking process. The spring force can be changed by adjusting the set screw.

4. AERODYNAMICS

The drag characteristics of the projectile significantly impact total range. Figure 4 shows the drag coefficient vs. Mach number. This plot shows the typical peak at Mach 1 and a more gradual decline with increasing Mach number. The potential exists to reduce the fin drag of the HICAP by using fewer fin blades.

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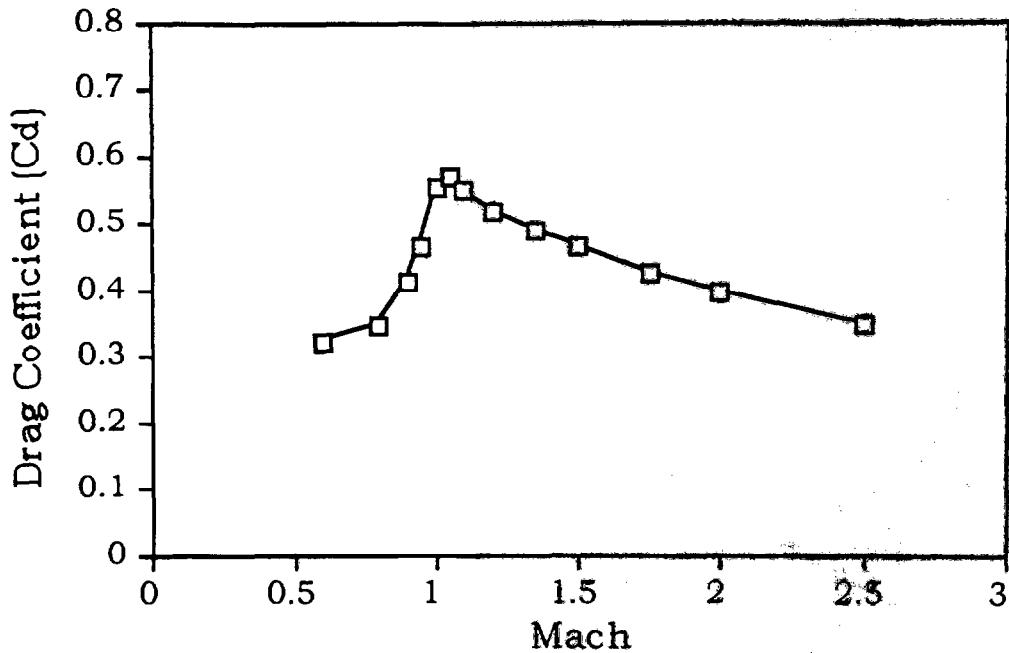
Figure 4. Drag coefficient vs. Mach number.

Of course this decreases the stability of the projectile at higher Mach numbers and can result in larger average projectile yaws. Large yaw magnitudes increase drag and decrease range. Clearly, a tradeoff exists between required stability, drag, and range. Minimizing the fin thickness also reduces drag. Very thin fins bend too much under aerodynamic loads, which is unacceptable. Ultra stiff composite fins offer drag reduction, but their use is uncertain due to their fracture properties. The present HICAP fin blades are aluminum and relatively uncomplicated. The maximum projected range attainable with this fin is about 18 km. The blades are beveled to reduce drag and produce a 10–15-Hz projectile spin rate. A HICAP composite fin of the same planform is scheduled for testing at a later date.

Figure 5 compares the maximum projected HICAP range using the fin suggested by Kayser vs. those of the present design. The fin area of the present design is 90% of the Kayser fin. The Kayser design achieves a lower drag through the use of a smaller projectile base area coupled with an effective fin scheme. Although this option is difficult to obturate and spin at 10–20 Hz simultaneously, future improvements could make it more viable.

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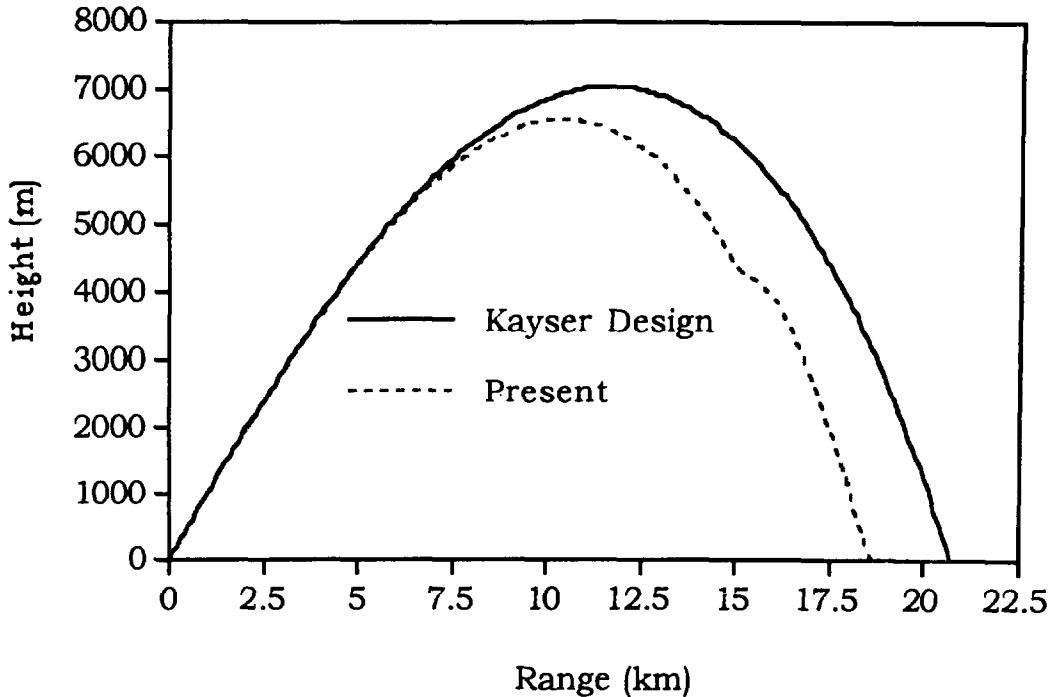
Figure 5. HICAP trajectory height vs. range.

The graph of the present fin design trajectory height vs. range in Figure 5 shows a "bump" at between 15 and 17.5 km. The trajectory program used to create this plot relies on aerodynamic code predictions and/or range data. HICAP has only code predictions for aerodynamics thus far. Plans exist to obtain empirical HICAP aerodynamic data through testing at the TR. When working with aerodynamic predictive codes, various schemes are used to obtain projectile characteristics at different Mach numbers. This bump is likely due to the transition between two schemes. The overall effect on the range is minimal.

Figure 6 shows the moment coefficient $\left(C_{m\alpha}\right)$ vs. Mach number variation for the proposed fin configuration. The primary purpose of the fin blade is to provide stability over the Mach number range that the projectile encounters in flight. Moment coefficients $\left(C_{m\alpha}\text{'s}\right)$ of -10 to -15 are common for fin-stabilized, aerodynamically well-behaved projectiles. Figure 6 indicates that HICAP has good stability at M = 2.2 and further shows acceptable stability up to M = 2.5. This allows for future moderate increases in launch velocity without a fin redesign. These increases in launch velocity are likely, considering technologies such as liquid propulsion and electromagnetic launch.

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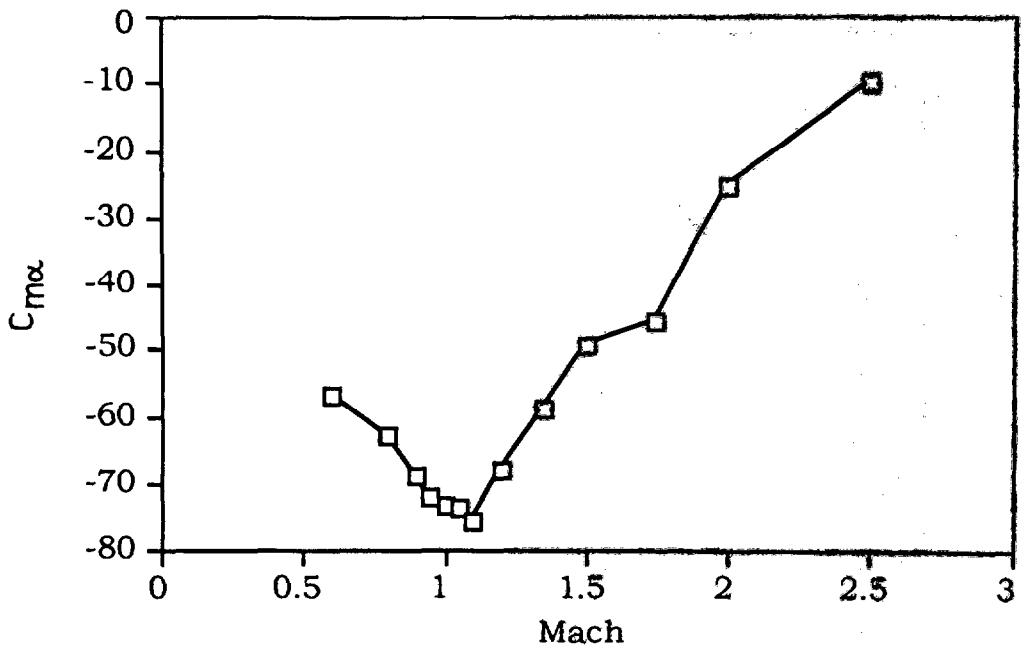
Figure 6. Moment coefficient vs. Mach number.

5. CONCLUSIONS

The latest HICAP design is obturatable, mechanically simple, and has acceptable drag characteristics. Its design allows the fin blades to remain closed while in-bore and open and lock once the projectile exits the muzzle. Furthermore, the design meets the artillery discard criteria and safety concerns. Currently, efforts exist to substitute composites for aluminum in the basic design and improve stability and lighten the projectile. The HICAP projectile design represents a significant step forward in the use of composites in the artillery regime. A practical stabilizing base module is essential.

6. REFERENCES

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