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EXPLOSIVELY FORMED PENETRATORS (EFP) WITH CANTED FINS

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Recent improvements in sensor and electronic technologies enable smart munitions to detect and identify targets more than 200 meters away. Therefore, the next generation of smart munitions will require EFP designs with extended standoff capability. In the U.S., extensive work was focused on forming EFPs with canted fins, to induce spin-up. This spin-up will improve the EFP's aeroballistic characteristics and on target accuracy. This paper will present computer simulations of the EFP's canted fin formation and aeroballistic simulation of the EFP's flight characteristics. The formation studies were conducted using LS_DYNA and the aeroballistic studies were conducted using TRASTA. In addition, these computer simulations were verified with actual long-range tests using tactical warheads. These canted fin EFP warheads were also tested under dynamic spinning conditions.

BACKGROUND

The ultimate goal of smart munitions such as SADARM and WAM, and any future system employing an Explosively Formed Penetrator (EFP), is to defeat the most difficult target at the longest standoff. In order to do this, an EFP must be aerodynamically stable so as to strike the target with a small miss distance and a small angle of obliquity.

A common way of improving performance for any projectile is to avoid resonance and reduce dispersion by controlling the roll rate. This is accomplished by canting the control surfaces at the rear, causing the body to spin up, much like a pinwheel in a breeze. By forming canted fins on an EFP, the same improvements in aerodynamic stability can be realized.

Several techniques for forming EFPs with straight fins have been investigated and presented in past International Ballistic Symposiums[1,2,3]. These techniques include using waveshapers embedded in the explosive, and copper shims inserted between the liner and explosives. While straights fins will improve an EFPs aerodynamic stability over conventional EFPs with coned or flared tails, they do not increase the EFP's spin rate.

An indication of the benefits of increasing the EFP's spin rate can be seen in Figure 1, which shows the effect of various initial spin rates on the miss distance of an idealized EFP shape with a one-degree asymmetry in the tail. These results were obtained by feeding estimated aerodynamic coefficients into a six-degree of freedom simulation code. As can be seen from the graph, the case of lowest deviation from aim point occurred at the highest spin rate, with the worst case being that of no spin.

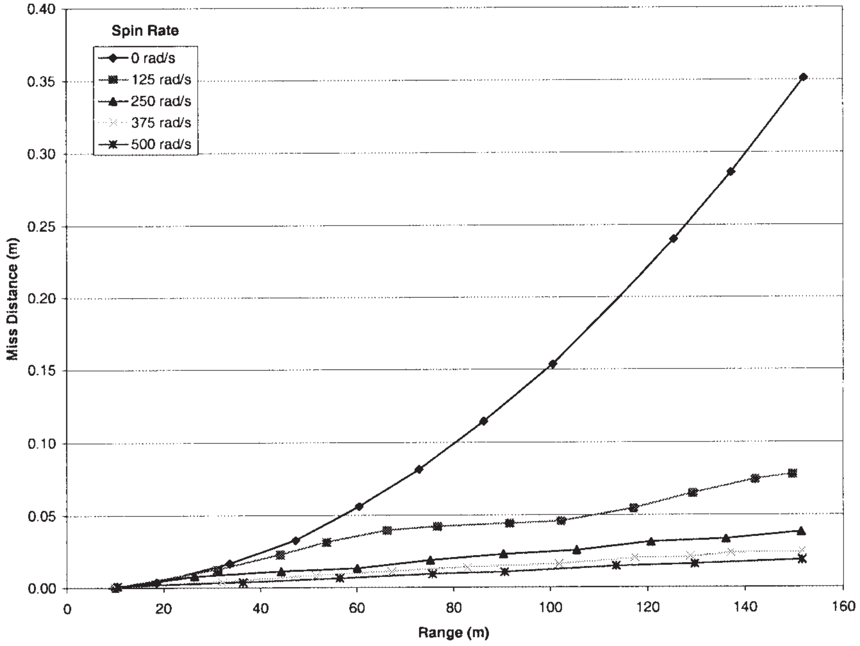

Figure 1: Spin effects on miss Distance simulations indicate that increasing an EFP's spin rate dramatically reduces its miss distance.

On initially rotating submunitions, a dynamic instability caused by resonance has also been observed in the past as can be seen in Figure 2. Resonance is a condition where the penetrator spin rate equals its natural oscillation frequency. On this particular test, the EFP roll rate steadily decreased until it reached a natural frequency, causing the angle of obliquity (also referred to as attitude) to increase rapidly. The EFP tumbled, eventually striking the target sideways, achieving relatively little penetration.

Resonance can be avoided, however, by forcing the EFP to spin up using canted fins. Figure 3 shows the results of a similar test where an EFP, formed from the same liner design as in the previous figure, spun up purely by chance. In this case, the attitude remained bounded and the penetrator perforated its required target at full range. By intentionally canting the fins, this penetrator would spin up reliably, resulting in much better and more consistent performance.

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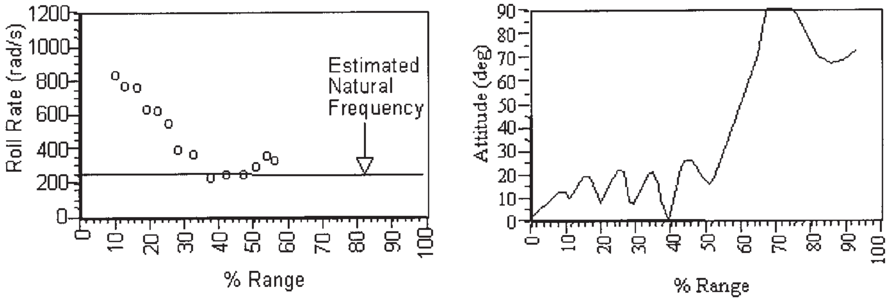

Figure 2: Resonance effects on aerostability. As an EFP spins down to its natural oscillation frequency, it can enter a resonance condition causing an unstable growth in attitude. A high impact angle at the target then causes greatly reduced penetration.

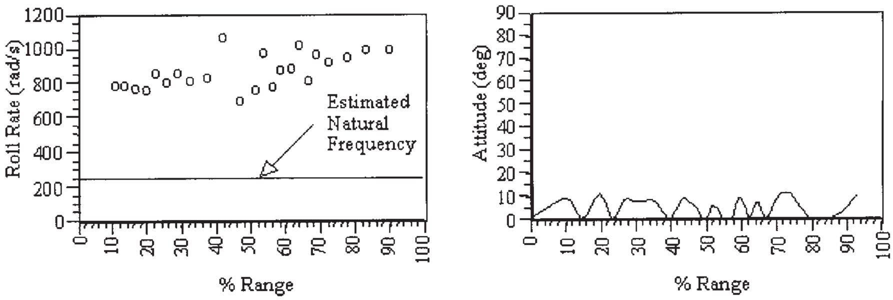

Figure 3: Avoidance of resonance. Test results of the same liner design as Figure 2, show that when the EFP spins up and avoids resonance, a stable flight results.

APPROACH

The best way to determine if an EFP formed canted fins is to soft recover it. Accurate measurement can then be made on fin length, fin height and cant angle. However, the success rate of recovering an EFP drops dramatically as the warhead size is increased. For this reason, this work was conducted in two separate phases; in the first phase, sub-scale warheads were tested with an EFP recovery system used to study different techniques of forming canted fins; in the second phase the most promising techniques were applied to larger warheads and fired at extended standoff (up to 210 m) to gather aerodynamic stability data.

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SUBSCALE TEST RESULTS

The test plan for the subscale program consisted of eighteen shots, which were divided into studying canted fin formation on two different EFP designs. It was anticipated that the finning techniques would need to be tailored for a particular EFP shape. This is the reason for testing two different EFP shapes, one with a relatively small length to flare diameter (L/D) ratio and another more solid penetrator with a larger L/D (see Figure 4). After the initial test series, it was observed that the solid EFP was less sensitive to the different techniques applied, while the shorter EFP yielded better canted fin formation with the techniques applied.

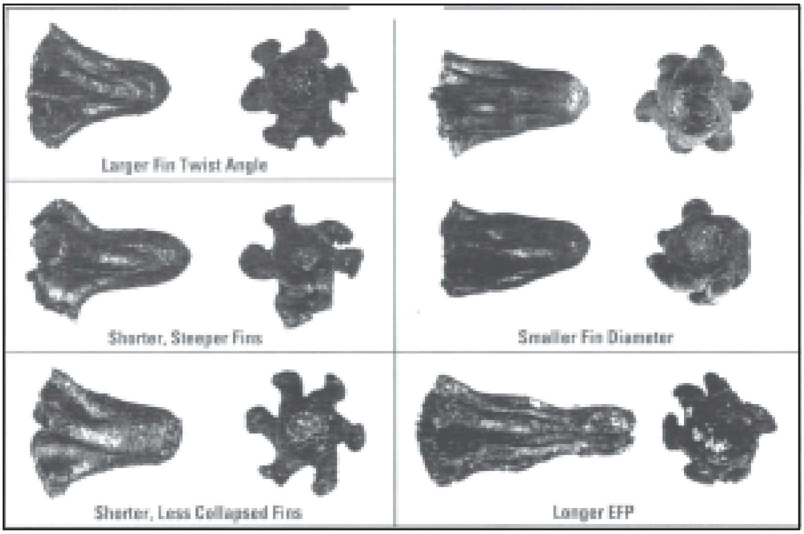

Figure 4: Subscale test results.

A baseline design, based on the short EFP with canted fin angle measurements of 60 degrees, was selected for additional testing. When viewed from the side, the fin length was 80% of the total body length (Figure 5). A long standoff test was conducted using the baseline EFP design to gather aerodynamic data. The EFP formed similarly to that in Figure 5 and flew very straight and stable all the way to the target. Figure 6 shows a graph of EFP spin rate vs. range and the final yaw screen image prior to target impact. Indications are that the penetrator initially began to spin in the negative direction (right hand rule) due to a torque caused by fin twisting during formation. However, air acting on the fins then reversed the rotation and spun the EFP up to a rate of 750 rad/s at the target (Figure 6).

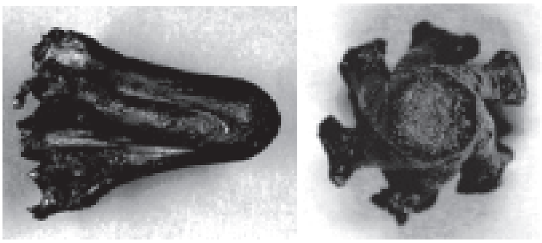

Figure 5: Baseline subscale EFP design soft recovered.

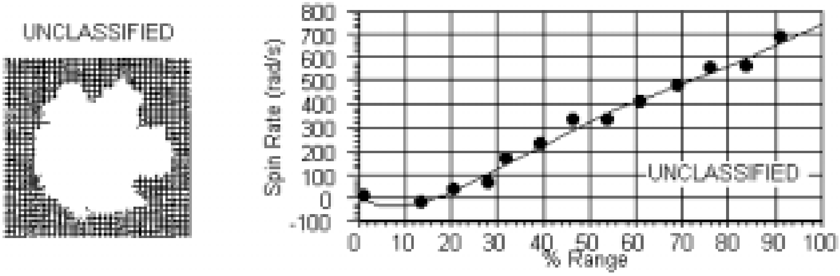

Figure 6: Test data for baseline subscale EFP design.

FULL SIZE WARHEAD DESIGNS

In phase two, four Candidate EFPs were formulated utilizing the design data from the subscale tests (Figure 7). An aerodynamic analysis was conducted on each shape with TRASTA, a 6 degree of freedom code at Alliant Techsystems. TRASTA uses a modified Newtonian impact theory to predict the flight behavior of high-speed projectiles such as EFPs. Surface elements and mass properties from the LS-DYNA simulations were converted directly into TRASTA format. Initial conditions, such as angular and translational velocity components, were applied and the free body motion of each shape was simulated out to a range of 210 meters.

Preliminary predictions showed design 2.0 was the most statically stable but it produced the lowest spin torque. Design 3.0 was the least stable, but had the highest spin torque (Figure 8). Design 2.0 produced a monolithic penetrator as shown by the flash x-ray and Cordin photo (Figure 9). As predicted, it had the lowest spin torque of the three designs, actually decreasing from 650 rad/s to 300 rad/s over the entire range. However, thirty yaw screens confirmed that the penetrator was stable. The EFP struck the target at 210 meters with an extremely low radial miss distance. Design 3.0 produced a penetrator that broke at the tail fin as shown by the flash X-ray and Cordin photo (Figure 10). Fortunately, the tailpiece rotated enough to clearly show twisted/canted fin formation on the photograph (Figure 10).

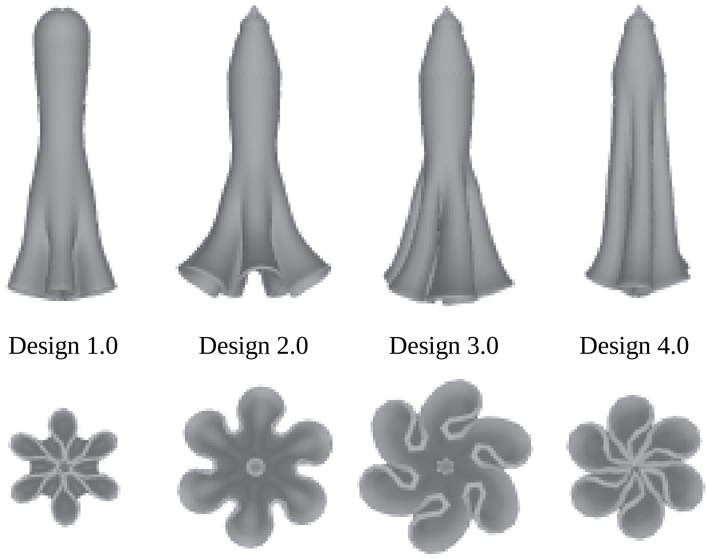

Figure 7: Candidate full scale EFP designs generated with Dyna3D.

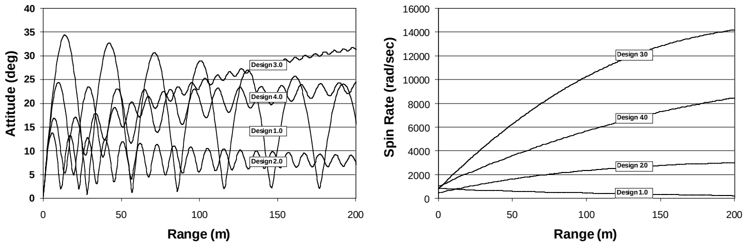

Figure 8: TRASTA prediction of EFP stability & spin up rate.

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Figure 9: Design 2.0 test results (X-rays and Cordin).

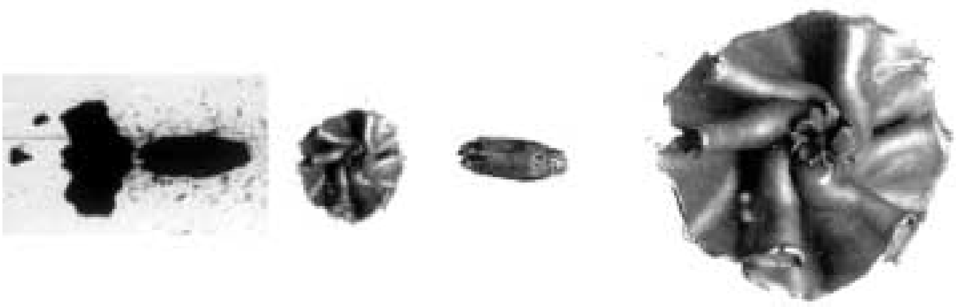

Figure 10: Design 3.0 test results (X-rays and Cordin).

Based on these test results, two additional designs (6A and 6B) were generated as shown in Figure 11. Aero simulations predicted design 6A would be stable and would have the greatest spin torque. Design 6B, which has the same finning technique as 6A but a different liner design, would also be stable. However, its spin torque was predicted to be less than the 6A design (Figure 12).

The first design, 6A formed a monolithic penetrator that spun up from 1000 to 6000 rad/s, similar to predictions. It hit the target at 210 meters with a low radial miss distance. The second design, 6B spun up from 700 to 2000 rad/s, again matching the predicted trend. It hit the target at 210 meters with an even lower radial miss distance. Based on initial testing, both designs show promise of meeting the requirements.

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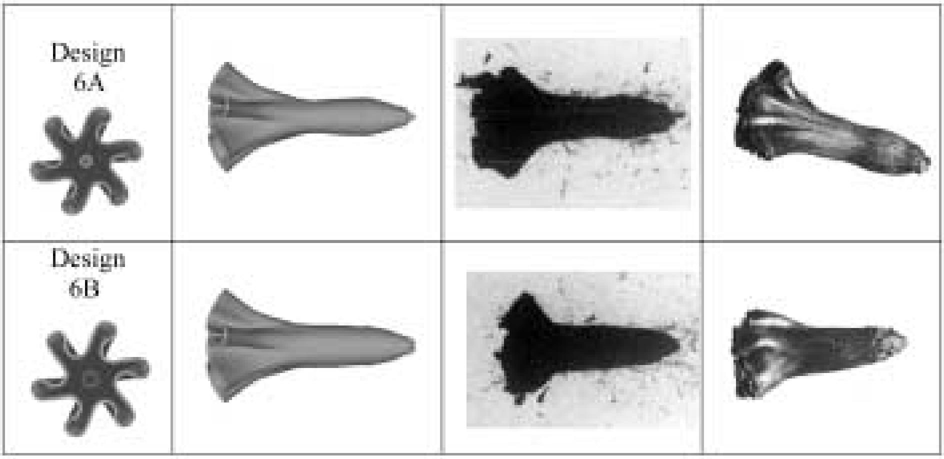

Figure 11: Design 6A and 6B follow-on design, simulations, test results (X-rays and Cordin).

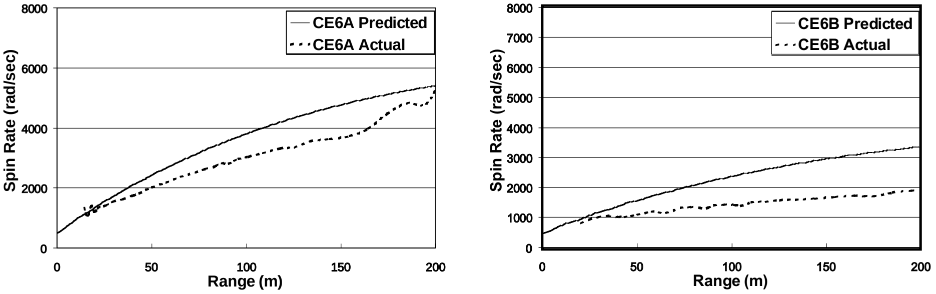

Figure 12: Design 6A and 6B aerodynamic data comparison (TRASTA-Test).

CONCLUSIONS

Computer simulations and test results conducted to date have shown that an EFP can be formed with canted fins for increased spin, stability and accuracy at extended ranges. By utilizing computer simulation codes, like Dyna3D for EFP formation and TRASTA for aerodynamic analyses, it is possible to generate a Canted Fin EFP which meets extended standoff and accuracy requirements in only a few design iterations.

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