THE EVOLUTION OF AIR TARGET WARHEADS

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Abstract

Warheads have evolved from simple designs that projected non-optimized size fragments in a symmetric pattern about the roll axis of the missile to those that aim optimized fragments in a concentrated beam in the target direction. Evolution has been driven by the changing target threat and is made possible by advances in warhead explosive initiation system and target detection (fuze) technology in conjunction with maturity of target vulnerability descriptions and methodology.

Introduction

Investments in warhead technology over the past few decades have resulted in transitions of advanced concepts that have increased the lethality of many anti-air missiles. The investments and the resultant transitions have produced an evolution of air target warheads driven by changes in the characteristics of the targets (size, speed, hardness) and interceptor missiles (speed, agility, fuzing) and by the ability to describe the vulnerability of the target with increasing fidelity.

A typical air target warhead consists of an explosive charge surrounded by a fragmenting metal case. The warhead is carried to the target by the intercept missile. There would be no need for a warhead if the interceptor could achieve a direct hit of the target. The interceptor's kinetic energy alone would cause target breakup (except perhaps for small shoulder launched missiles). Except for short range shoulder launched missiles, direct hits are rare. As range requirements increase, missile size increases and missile agility decreases. The result is a requirement for a warhead, an item that can eject high speed, lethal fragments at the target near the point of closest approach.

Air target intercepts can result in target/interceptor closing velocities of up to 9000 ft/sec for cruise missiles and even greater velocities for tactical ballistic missile targets. Existing target detecting devices (TDDs), sometimes referred to as fuzes; require that the warhead fragments be quickly accelerated to velocities similar to these closing velocities in order to hit the target. This magnitude of acceleration and final velocity can only be achieved through use of explosives. A typical pure explosive is a solid composed of molecules consisting of a carbon or carbon-nitrogen backbone with attached oxygen sources. These sources are either nitro groups (NO_2), nitrate ester groups ($-ONO_2$), or nitromine groups ($-NH-NO_2$). These explosives can be considered metastable materials that given the proper stimulus will decompose at the molecular level into gaseous H_2O, CO_2, CO, and N_2. Decomposition occurs so rapidly (reaction propagation rates up to 30,000 ft/sec) that the solid explosive mass can be considered to instantaneously convert to gas with an energy release of 1000 to 1500 cal/gm. The energy released heats the gases to 3000-4000°K with resulting pressures between 4 and

5 million psi! If the explosive has been encased in metal, the expansion of the gases will accelerate the casing to several thousand feet per second in a few microseconds.

Air Target Warheads of the 1950's

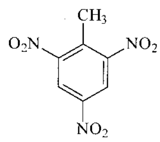
Examples of anti-air missile warheads in service during the 1950's are warheads employed on the air launched SIDEWINDER 1A and the ship launched RIM-2 TERRIER missiles. Both warheads produced a fragment pattern that was symmetric about the roll axis of the missile. The SIDEWINDER 1A warhead was a simple smooth steel tube filled with explosive. A plastic grid was placed between the case and explosive. The grid was designed in such a way that upon detonation of the explosive, the gases at the interface would be focused to score the case in a square pattern. As the case expanded it broke along these score lines. The TERRIER warhead was constructed of adjacent square wire rings that were notched to provide lines of fracture upon explosive detonation. The warhead was tapered at one end to produce a relatively wide polar spray pattern[*]. Both the SIDEWINDER and TERRIER warheads were designed to produce a large number of relatively small fragments.

Targets for these early missiles were relatively light fighter and bomber aircraft. Warhead design philosophy was to throw many small fragments at these targets to achieve a high probability of striking a vulnerable component. Unless detonated close to the target, these warheads would achieve a "K" type kill in which the damaged component/s would cause the aircraft to lose control within 30 sec of engagement.

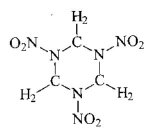
Explosives of the era were usually mixtures of TNT[†] and RDX[‡]. TNT, the first of the modern explosives, was developed prior to World War I. It is a relatively inexpensive melt-castable explosive, but by today's standards, it has relatively low performance. RDX was discovered in the early 1900's but was not used in military applications until WWII. It has 10 to 20% greater performance than TNT (performance related to power output - energy release rate).

[*] The polar angle is the angle measured with respect to the longitudinal axis of the warhead, which usually corresponds to the longitudinal axis of the carrier missile. The azimuth angle measures the angle around the roll plane of the missile.

[*] Trinitrotoluene



[**] Cyclonite or Hexogen



The Continuous Rod Warhead Era

The Continuous Rod (CR) Warhead was conceived at New Mexico Institute of Mining and Technology (NMT), Soccoro, NM during the early 1950's. Its genesis was from early tests of discrete rods in which the rods were shown capable of slicing through aircraft skin and damaging internal structure. The CR concept was a means of producing a rod long enough to slice through the entire fuselage or wing to cause catastrophic breakup of the aircraft. The CR warhead consists of a double bundle of steel rods running lengthwise around the circumference of an explosively filled cylinder. The rods are welded together at alternate ends. Upon detonation of the central core of explosive, the rods are projected radially outward forming a lattice as illustrated in Figure 1. The rods continue to expand reaching what is called "full open radius," the stage at which the hoop is fully extended. As the hoop continues to expand, the rods fracture. After fracture, the rods are still capable of causing component damage, but not catastrophic structural damage.

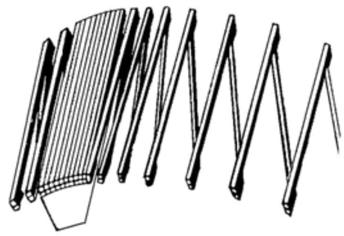


Figure 1. Section of Cylindrical CR Case Showing Initial Rod Bundle Configuration and Expansion

All Navy anti-air missiles employed the CR concept during the 1960's and into the 1970's. A SIDEWINDER version was developed at NAWC/China Lake, SPARROW, TERRIER, TARTER, TALOS, STANDARD and PHOENIX versions were developed at NSWCDD with contract support from the Applied Physics Laboratories, Johns Hopkins University. This novel concept however, became ineffective shortly after service introduction. Development testing had been conducted against 1950's type aircraft which could be effectively damaged by the CR kill mechanism. The target fighters and bombers in service during the 1960's were of heavier construction and more densely packed with components. It was difficult for the CR to achieve the desired structural kills against these targets. The rods could still inflict damage to components; however, the single narrow rod meant impact at only one location, and if there was not a vulnerable component at this location, the target would not be killed.

Air Target Warheads of the 1970's and 1980's

The 1970's and 1980's saw the return of fragmenting warheads with emphasis on higher velocity and improved fragment size control methods. Higher fragment velocity could be obtained by increasing the relative mass of explosive and by use of higher performing explosives containing RDX or HMX[§]. HMX has 10% greater performance compared to RDX. It was initially a by-product of RDX production and as such, its supply was limited. It soon could be separately synthesized and became the explosive ingredient of choice and remains so today.

The Navy's emphasis during this period was the defeat of Soviet cruise missiles. At the same time, cruise missile vulnerability descriptions and target vulnerability methodology reached a high level of advancement allowing optimization of fragment size. Two of the most popular size control methods were the Pearson notch and the opposed notch techniques. Both methods allowed use of a solid steel casing whose residual strength after notching could carry the missile flight loads, if required, and provide for case expansion before rupture to obtain high fragment velocity.

John Pearson at the Naval Air Weapons Center/ China Lake (NAWCWD) developed the Pearson notch, also referred to as the shear-control method, during the 1970's and 1980's[1]. The inside of the steel cylindrical case is notched in a diamond pattern as illustrated in Figures 2 and 3. Even though the notches are shallow, they are effective in initiating a fracture trajectory which travels to the outside of the case as the case begins to expand upon detonation of the core explosive. This method is effective for certain ratios of case thickness to notch spacing. For optimum ratios, 80% of the case mass can be controlled to the desired size.

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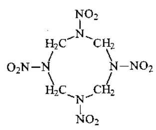
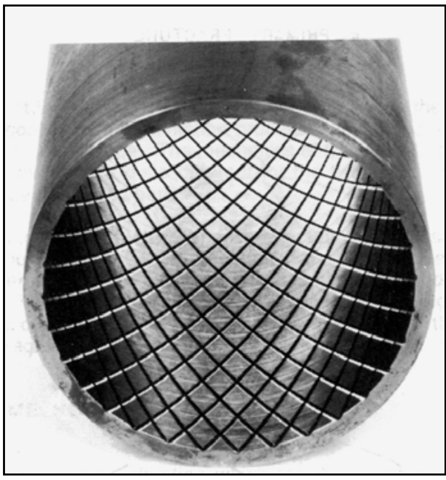
§ HMX (Octogen) 



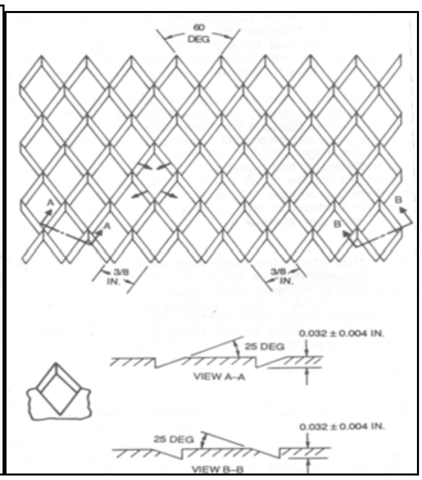


Figure 2. Steel Cylinder Showing Inner-Surface, Diamond-Pattern Grid (figure 1 from reference 1)

Figure 3. Diamond Grid Design With Nonsymmetrical Profiles (figure 6 from reference 1)

The opposed groove method was developed at NSWCDD during the 1970's and is still being refined to this day. As the name implies, it consists of narrow tapered or straight grooves cut on the inside and outside of the case directly opposite one another. The grooves are cut to a depth and the radius at the bottom of the groove chosen so that the thickness remaining between the grooves provides the required case strength and rigidity while also assuring that the case will break cleanly between opposing grooves upon explosive detonation. The opposed groove technique allows for a wider choice of fragment size but the case is weaker compared to the Pearson notch technique. The opposed groove technique can yield 90% or more of the case mass into the desired fragment size. Figure 4 shows recovered fragments from a warhead using this control method.

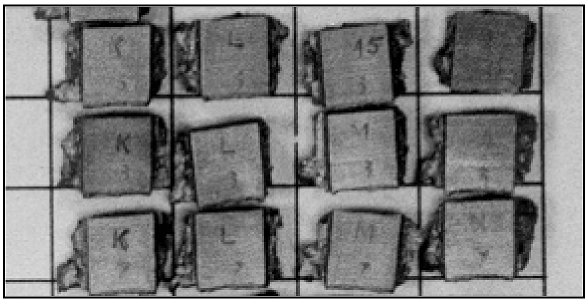


Figure 4. Fragments Formed By the Opposed Notch Method

The Aimable Warhead Era

During the late 1980's and into the 1990's, Advanced Development began on aimable warheads. Up until this time, deployed air target warheads were axisymmetric; i.e., they produced a fragment pattern that was the same in all azimuth directions. The first generation aimable warhead is the Asymmetric Initiated (AI) Warhead. An AI warhead is a cylindrical warhead in which initiation occurs on a line or lines at the explosive/case interface opposite the direction of aim as shown in Figure 5. Asymmetric initiation produces an asymmetrical fragment pattern with a 20 to 30% higher velocity in the direction of aim compared to the same warhead initiated along the central axis. Figure 6 shows the fragment pattern resulting from this type of initiation scheme. In practice, the aiming of such a warhead can be accomplished by initiation of 1, 2, or 3 lines of initiators from a warhead containing 4 to 16 equally spaced lines of initiators. An azimuthal sensing TDD would be used to signal the choice of initiator lines to direct the maximum kill mechanism on the target. This type of aiming system requires no physical orientation of the warhead prior to detonation. Therefore, the time between determination of the required aim direction and warhead detonation can be zero.

AI technology had been around for several years, having undergone exploratory development by the Air Force at Eglin Air Force Base, Florida, during the 1970's and intermittently at NSWCDD from the late 1960's to the late 1980's. These efforts explored the effects on fragment velocity versus central cylindrical explosive voids, single, multiple and sequential multiple line initiation and number of initiation points along each line. AI technology was implemented at NSWCDD during the early 1990's when the warhead was integrated with an advanced initiation system and azimuthal sensing TDD. The impetus for this development was a need for higher fragment velocities than could realistically be achieved from axially initiated warheads.

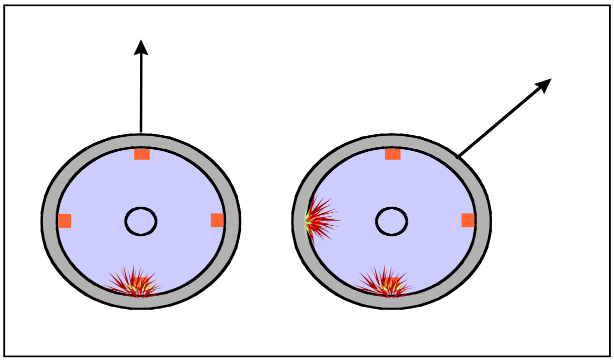


Figure 5. Operation of the AI Warhead

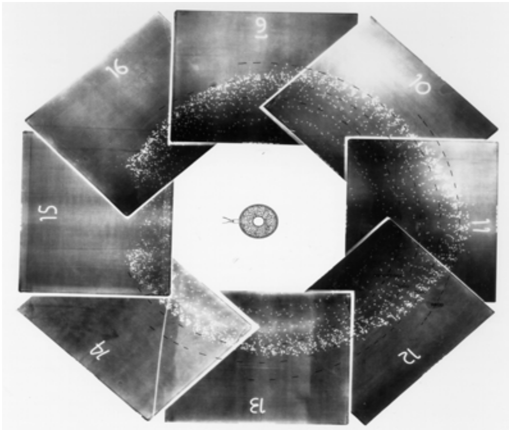


Figure 6. Radiograph of Fragment Pattern from an AI Device Showing Enhanced Velocity in Aim Direction (Directly To the Right of the Original Charge Position)

The enhancement through asymmetric initiation can be measured by two methods: (1) fragments can be ejected in the direction of aim at velocities 20 to 30% higher than normally possible; or (2) a fixed weight warhead system can devote more relative weight for the case and less for explosive and project more fragment mass in the direction of the target at a velocity equal to that produced by an axially initiated warhead. It is this latter measure that is the most useful.

Fragment velocities from an axially initiated cylindrical warhead can be estimated from the well known Gurney formula[2]:

$$V = A\left(\frac{1}{2} + \frac{M}{C}\right)^{-\frac{1}{2}}$$

where V is fragment velocity, A is a constant depending on the type of explosive used, M is the case mass, and C is the explosive mass. This equation becomes:

$$V = (1.25)A\left(\frac{M}{C} + \frac{1}{2}\right)^{-\frac{1}{2}}$$

in the direction of aim for the AI warhead. A typical value for A is 8500 ft/sec. Figure 7 is a graph plotting relative mass that can be projected at a target as a function of desired initial fragment velocity (AI relative to an axially initiated warhead of equal weight). Relative mass is found by determining the M/C ratio which gives the desired fragment velocity for each of the two type warheads. For a fixed weight system, the fraction of weight that can be devoted to the case for this desired fragment velocity is:

$$M = 1/\left(1 + C/M\right).$$

The relative values of M for the AI compared to the axially initiated warhead are found along the ordinate in Figure 7. It can be seen that the advantage of employing the AI warhead is when the required fragment velocity is high. This occurs when the miss distance is large, closing velocities are high and/or when the target is short.

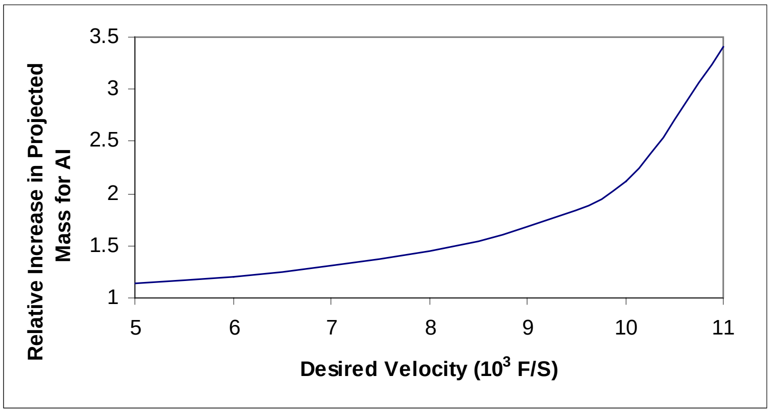


Figure 7. Relative Fragment Mass Projected in Aim Direction By AI Compared to Axially Initiated Warhead of Equal Total Weight

The second generation aimable warhead underwent Advanced Development at NSWCDD. This warhead is referred to as the Deformable warhead, it is part of an integrated Directional Ordnance System (DOS) which includes a safe and arm device and an initiation system that was developed at NAWCWD.

The warhead concept is illustrated in Figure 8. It consists of an explosively filled fragmenting cylinder that may contain an explosive void. The fragmentation cylinder is surrounded with a layer of explosive that is divided radially and buffered so that the resulting strips can be initiated independently. Upon determining the desired direction of aim, a number of the outer explosive strips, called deforming charges, are initiated (3 out of 12 shown in the figure). Detonation of the strips causes deformation of the fragmenting case so that at some later time a large portion of the case is flattened, and at the same time, the void that may have been present in the main charge explosive is collapsed. This ensures that the explosive is in compression, at which time the main charge is initiated by a line initiator on the side opposite case deformation. The flattened portion of the case is projected at the target at high velocity. As a first order approximation, fragments are ejected in a direction normal to their outer surface, thus the fragments originating from the flattened portion of the case can be projected in a tight beam at the target. The beam tightness can be controlled and is optimized to the azimuthal resolution of the TDD. The beam typically contains three to five times the fragment mass compared to an ordinary warhead. This allows the warhead to achieve kills at double the miss distance or to achieve a higher quality of kill (catastrophic vs. slow kill) at the same miss distance compared to an ordinary warhead.

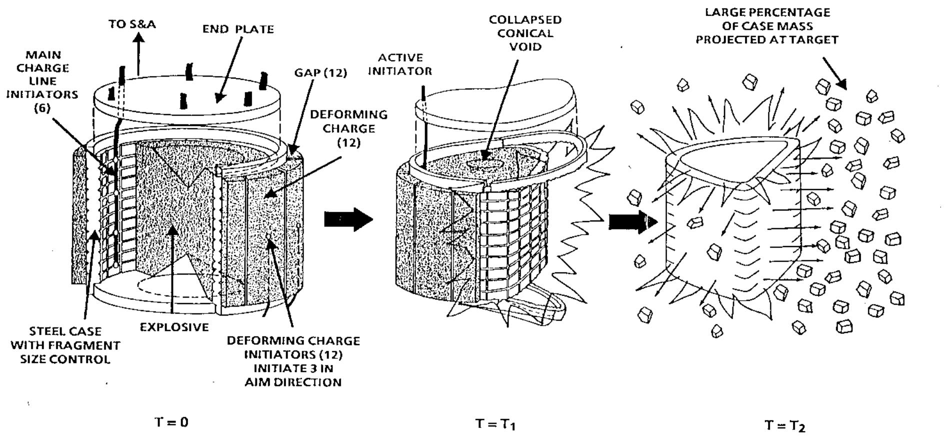


Figure 6. Sequential Operations of a Deformable Warhead

Summary

Air target warheads have evolved through the years in response to the changing target threat, increases in explosive output, advancements in associated ordnance components, and refinements in target vulnerability descriptions and methodology. Warheads have changed from designs using simple fragment size control techniques, whose size was chosen with little basis, and which produced roll symmetric fragment patterns to those incorporating sophisticated optimized fragment size control and that can bias fragment velocity or fragment mass at the target. Warhead technology transitions will continue to evolve into devices which direct narrow concentrated fragment beams at a specified area on the target. These warheads will be part of a unified system which will consist of a precision forward looking TDD integrated with the guidance and air frame control components.

References

1. Pearson, John "*A Fragmentation Model Applied to Shear-Control Warheads,*" Naval Weapons Center, China Lake, NWC TP 7146, May 1991
2. R. W. Gurney, *The Initial Velocities of Fragments from Bombs, Shells, and Grenades,* BRL Report 405, Sept 1943