19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

ANALYSIS OF ACTIVE PROTECTION SYSTEMS: WHEN ATHENA MEETS ARENA

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The Russian system called ARENA is certainly the most successful active protection system that has been produced yet. ARENA is intended to protect tanks from antitank grenades and ATGMs.
ATHENA is a computer-based simulation program that provides the capability to explore the value of various hard-kill active protection systems. This paper illustrates how ATHENA can be used to analyze and optimize some features of ARENA. The analysis phase is focused on the parameters describing the intercept of an ATGM by means of a directed field of fragments generated by a protective ammunition. After examining two conflicting system designs, the optimization phase leads to reconsider the design of the protective ammunition.

INTRODUCTION

Active protection systems (APSs) are defensive systems designed to protect armored vehicles [1, 2, 3, 4]. The goal of an APS is to detect, intercept, destroy or confuse attacking enemy munitions. “Hard kill” systems engage and destroy incoming projectiles before they impact their intended target. These systems create a zone of protection at a safe distance around the vehicle. “Soft kill” systems confuse and divert incoming guided munitions with the use of obscurant munitions, jammers or signature reduction measures.

Active protection is one of the key technologies to improve the survivability of future armored vehicles. It is in fact the central point of the protection concept designated as “Don’t be hit” within the frame of the US Future Combat System program. An ideal APS should create an hemispheric zone of protection around the vehicle and be effective against the full range of anti-tank weapons. Thus, using APSs should allow to decrease the mass of passive and reactive armor while increasing the overall survivability of the vehicle.

As concerns NATO countries, most active protection systems are in research or developmental stages. Considering the complexity of such systems, computer-based simulation programs are required to explore and assess the effectiveness of various system designs. ATHENA is the name of such a program.

As concerns Russia, active protection systems have already been developed. The system called ARENA is certainly the most successful APS that have been yet produced.

Therefore, to some extent, ATHENA was bound to meet ARENA. This paper describes this very first meeting, i.e. the analysis of ARENA using ATHENA.

ATHENA

Designing active protection systems obviously requires computer simulation when considering the following issues:

- APSs must be effective in various operational conditions against the full range of current and future anti-tank weapons;
- Many technical solutions may be considered as regards the design of the system components,
- Assessing the overall system effectiveness cannot be achieved without taking into account the interdependence of the system components.

ATHENA is a computer-based simulation framework that has been developed by ISL in order to explore and analyze the design of various active protection systems [5].

The analysis scheme of a specific APS consists in the following steps: definition of the critical engagement sequences, assessment of the overall system effectiveness, sensitivity analysis (i.e. looking for the most significant parameters) and optimization. The ideal system should exhibit a maximal effectiveness factor and a minimal sensitivity factor. Furthermore, if the description of an APS is incomplete, ATHENA can be used to determine the parameters of the missing subsystems so that the overall effectiveness reaches a fixed level.

ATHENA is tailored to simulate the basic sequence of events of a hard kill system as defined in [5]: target[1] acquisition, launch of the protective elements and target intercept. ATHENA is a flexible library of models that are connected together to form the complete simulation (to some extent, this is similar to the MultiSIM-IDS architecture [6] that was developed for the US Army Tank-Automotive and Armament Command). These models are based on theoretical considerations and/or experimental results. They describe the physical parameters of each real-world object (target, sensor, launcher and protective element) as well as their interaction mechanisms. New models can easily be added to the framework in order to describe new concepts of APS or to provide higher fidelity simulation capabilities.

The system capability is the collective attribute of the performance of its subsystems. Given an engagement sequence, the overall effectiveness factor P_K is defined as follows: $P_K = P_D \, P_H \, P_{K/H}$ where P_D = probability of target detection, P_H = probability of hit and $P_{K/H}$ = degradation level of the target lethality.

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[1] As far as active protection systems are concerned, the term “target” obviously refers to the incoming anti-tank ammunition.

ARENA

ARENA is the latest generation of Russian APS [1, 2, 4]. It is intended to protect tanks from antitank grenades and ATGMs, including top-attack ATGMs. The system was revealed in 1992 at the Dubai exhibition. The Russians have successfully demonstrated the system to the Germans and French in 1994.

The system incorporates the following engineering solutions:

- Use of a multi-functional millimeter radar with "instant" scanning of all protected sector to detect and track antitank targets;
- Use of focused instant-effect protective ammunition for aimed destruction of incoming targets;
- Control equipment, represented by a specialized computer that provides automatic control over radar operation and system as a whole.

Fig. 1 describes the basic features of the system. Protective ammunitions are housed in silos arranged around the turret. The rack-mounted radar is fixed on the turret roof. In combat mode of operation, the radar constantly scans for approaching ATGMs and locates any target within 50 meters of the tank. Once the threat is detected, the radar switches to the target tracking mode, thereby obtaining data on the moving target. After processing this data, the computer selects one of the silos and fires a small projectile (similar to a Claymore mine) into the path of the approaching ATGM. At the determined moment, the computer generates command signals to the selected protective ammunition. The latter detonates a few meters from the target, generating a directed field of destructive elements which destroy or disable the target to levels which are no longer dangerous for the tank.

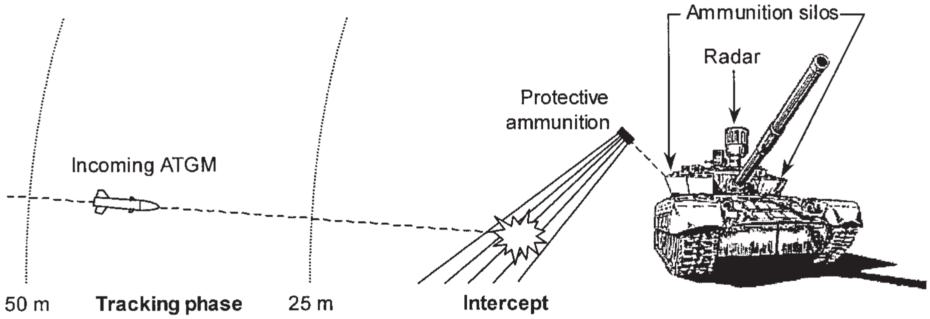

Figure 1 – Schema of ARENA operations.

Each ammunition covers a given azimuth sector. The protection zones of contiguous munitions overlap to a generous extent, which allows for multiple intercepts of targets coming from the same direction. In standard configuration, the total number of protective ammunitions mounted on the tank is 22–26. This is enough to create a zone of protection that covers both the front and the lateral surfaces of the tank.

ATHENA MEETS ARENA

Examining the full capabilities of the real ARENA system is beyond the scope of this paper. Since many features of the system cannot be accessed via public sources, we have set up a theoretical model of the system, making realistic assumptions for the missing parameters. This model is focused on the effectiveness of the target intercept by means of a directed stream of fragments. It does not take into account the detection and acquisition subsystems.

Simulation models

The protective ammunition is modeled as a circular fragmentation charge. The following parameters have been estimated: charge caliber = 150 mm, total number of fragments= 400, mass of each fragment = 2 g. According to this data, the pre-fragmented liner of the charge is about 6 mm thick. The field of fragments is represented as an axis-symmetric cone (Fig. 2). The fragment trajectories within the cone are supposed to be uniformly distributed.

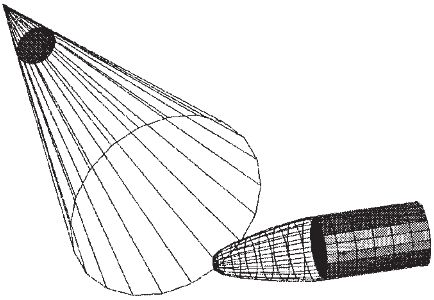

Figure 2 – Field of fragments and target.

The target is a 130 mm caliber ATGM. The estimation of the target performance degradation is only dependent on the number of fragments that achieve a direct hit on the shaped charge of the missile (no functional failure model is taken into account). Experiments conducted at ISL [7] have shown that the mean value of the degradation level of the shaped charge is about 70% for a single fragment hit. This result was observed under the following conditions:
shaped charge caliber = 65 mm, fragment mass = 0.5 g, fragment speed = 140 m/s. Extrapolating this result to a 130 mm caliber shaped charge requires to consider a fragment mass of 2 g and a fragment speed of 1800 m/s (the kinetic energy of the fragment must increase with the caliber cubed). Furthermore, it is assumed that the degradation level increases up to 90% for at least two fragment hits.

Hence, the effectiveness factor is defined as follows:

$$P_K = P_{H1}*0.7 + P_{H2+}*0.9 \quad (1)$$

where P_{H1} = probability of exactly one hit, P_{H2+} = probability of at least two hits. Note that e_q. (1) is a pessimistic estimation of the performance degradation.

The probabilistic terms are not computed according to a Monte-Carlo process. In fact, a geometrical construction of the solid angle that intercept the target is performed. This gives the average number of hits (m), assuming that fragments are uniformly distributed over the intercept surface. The probability P_{H_n} of exactly n hits (n = 0, 1, 2, 3, ...) is then estimated with the Poisson distribution function: $P_{H_n} = \frac{m^n}{n!}e^{-m}$.

This model assumes that hits are independent events and that m is small (less than 10% of the total number of fragments).

System configuration

Fig. 3 displays the vertical and horizontal views of the system configuration. The tank outline fits the LECLERC data.

The protective ammunition is located on the turret roof. The firing angle (θ) may vary from 30° to 60°. When detonating, the ammunition generates a field of fragments, the axis of which is supposed to be perpendicular to the ammunition flight path. The angular width (α) of the field may vary from 20° to 45°. Whatever the value of (3, the detonation point D is located so that the interception distance at the hull level is a constant (see Fig. 3). This fixed distance is arbitrarily set to 3 m.

Engagement sequences are considered at the tank turret and hull levels. The turret level is obviously critical in terms of azimuth coverage while the hull level is critical as regards the fragment density distribution.

Basic results

Considering α and θ as control variables, the analysis of the system leads to the following result: increasing the azimuth coverage requires to increase α and θ while increasing the fragment density distribution requires to decrease α and θ.

In order to illustrate these conflicting options, consider two system configurations that will be denoted by S 1 and S2. Both systems must provide a protection through 270° around the tank by means of 26 ammunitions.

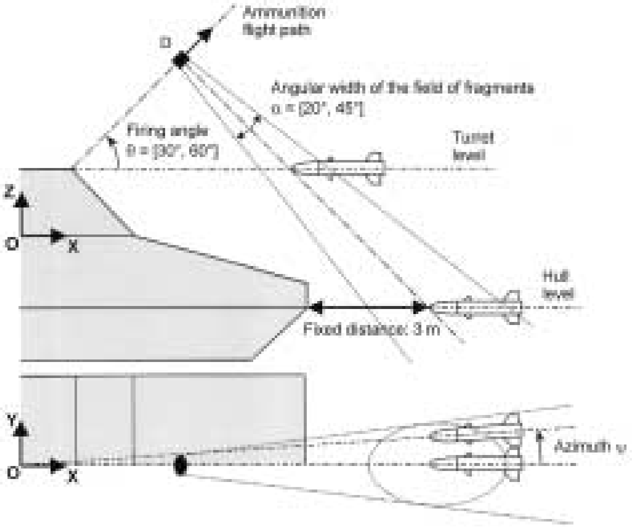

Figure 3 – System configuration.

Home
Table of Contents

As regards S1, each ammunition covers a 10° azimuth sector at the turret level (Fig. 4a). As regards S2, contiguous protection sectors must overlap: therefore each ammunition covers a 20° azimuth sector (Fig. 4b).

Given these constraints, the search for the optimal solution for each configuration yields the following data:

Horizontal cross section of the protection areas at the turret level

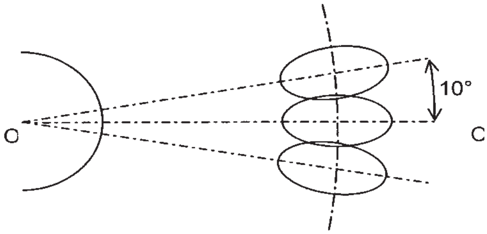

Figure 4a – S1: no overlapping.

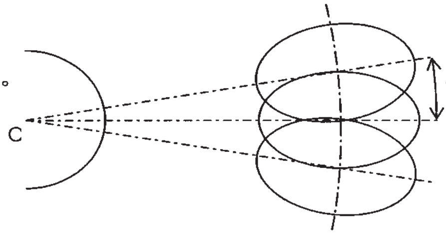

Figure 4b – S2: full overlapping.

		S1	S2
Control variables		$\alpha = 20°, \theta = 40°$	$\alpha = 30°, \theta = 60°$
Ammunition flight distance		2.9 m	1.1 m
Fragments flight distance	Turret level	2.6 m	2.1 m
	Hull level	4.8 m	5.5 m
Number of hits	Turret level	10	6
	Hull level	4	1
Effectiveness (P_K)	Turret level	90%	90%
	Hull level	85%	50%

Fig. 5a and 5b display the number of hits at the turret level as a function of the azimuth angle of the incoming target. One can observe that the requirements concerning the azimuth coverage are satisfied. As regards S2 (Fig. 5b), the angular sector protected by the mid-ammunition (A_0) is also protected by the contiguous ammunitions (A_1 and A_{-1}).

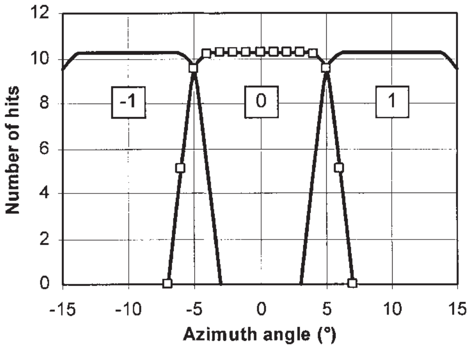

Figure 5a – Azimuth coverage (S1) .

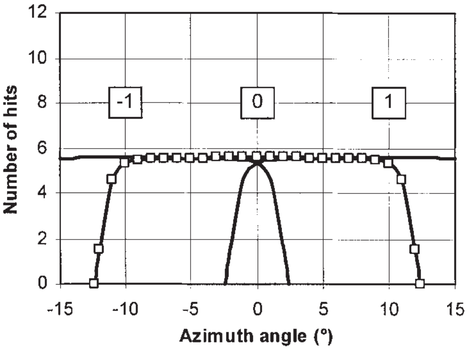

Figure 5b – Azimuth coverage (S2).

In conclusion, on one hand, S1 provides a very good level of protection around the tank, from the turret level to the hull level. However, it cannot protect the same azimuth sector twice. On the other hand, S2 provides a "double" protection of each sector, but it fails to protect the tank hull.

Optimization

The goal of the optimization process consists in changing some parameters of S2 in order to increase the protection performance at the hull level.

Changing the number of fragments contained in the protective ammunition would be an unrealistic solution. As a matter of fact, the ammunition should contain 1000 fragments to increase P_K up to 80% at the hull level. Decreasing the interception distance at the hull level (Fig. 3) has only a second-order effect on P_K.

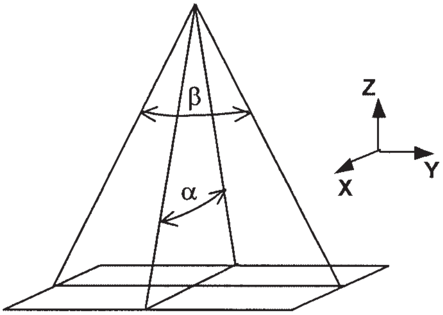

Figure 6 – Rectangular ammunition.

The solution consists in changing the shape of the protective ammunition. Consider a rectangular ammunition, the area of which is equivalent to the circular 150 mm-caliber ammunition. The field of fragments is represented by a four-sided pyramid. The angular width of the field is defined by two angles, α and β (Fig. 6). This modification introduces a new control variable (β).

Thus, a new solution can be computed, which gives the following results: interception distance at hull level = 2 m, ammo length= 175 mm, ammo width = 100 mm, $\theta = 45°$, $\alpha = 20°$, $\beta = 35°$ → the "double-protection" criteria is satisfied, P_K (turret) = 90% and P_K (hull) = 75% .

Influence of the position errors

Last but not least, ATHENA provides the capability to examine the influence of the errors related to the position of the target and the protective ammunition. Given the previous data and assuming that the errors are normally distributed, the limits of the standard deviations (σ_{max}) can be computed so that $P_K \geq 80\%$ at the turret level:

- 1-D ammunition position error (along the flight path): $\sigma_{max} = 20$ cm,
- 3-D target position error: $\sigma_{max} = 10$ cm.

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