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User-Friendly Explosive Reactive Armour – a Long-Term Reality

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ABSTRACT

There is a strong need to develop explosive reactive armour (ERA) for protecting battle tanks against an emerging threat of kinetic and chemical energy missiles. In this context, global trends, principle and limitations of ERA and threat perception-based types of ERA have been dwelt upon. User-friendly ERA is a long-term reality. User-friendly ERA system is thus defined to be an efficient and protective system that not only provide full protection to the tank crew, but is also harmless to the supporting infantory. The indigenously-developed ERA system is close to be termed as a user-friendly ERA.

1. INTRODUCTION

For over 75 years, in any conventional ground action, a battle tank has been the key weapon due to its inherent characteristics of high mobility, fire power and crew protection. Accordingly, ever increasing quest for higher fire power, higher mobility and better protection, has led to the design of present day main battle tanks (MBTs), which fall in the category of heavy tanks. Threat by lethal kinetic as well as chemical energy projectiles further poses a formidable task of maintaining such a high power-to-weight ratio with increased protection. Seemingly, the development of gas turbine engine might appear to provide some relief to salvage mobility problem for the tank designers. However, unaffordable overall cost associated with the demand of high order logistic support due to heavy fuel consumption and frequent high standard maintenance support due to poor reliability in the dusty terrain puts the clock back. A natural question that arises in the minds of the designers is where to go from here ? Hit avoidance, wherein the incoming projectile is destroyed far away from the surface of the tank, would be a logical and straightforward answer to this problem. However, this concept of active armour remains in conceptual state only and it would be a matter of decades before it comes into operation. In the absence of any realistic solution, an intelligent application of the age-old explosive power may thus offer the desired results in the years to come.

This paper highlights the importance of ERA in view of the development of high penetration kinetic energy projectiles and shaped charge missiles. The principle of design, limitations, and global trends in the development of user-friendly explosive reactive armour (ERA) system for the protection of battle tanks have also been dealt with.

2. NEED FOR ERA

With the introduction of explosively formed projectiles (EFP) having striking velocity of more than 2000 m/s, tandem missiles, advanced antitank guided missiles capable of penetrating 1000-1200 mm of rolled homogeneous armour (RHA) steel and depleted uranium (DU) kinetic energy

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projectiles (KEP) have threatened the very existence of even MBTs of the world. Though depleted uranium penetrators may not find place in the tank due to obvious reasons, the tungsten(W) penetrator technology advancement also appears to be at its peak level. Present day tungsten (W) penetrators have very high penetration capability[1] as mentioned in Table 1. It should be appreciated that a maximum of 23-25 per cent of the total weight of the tank can only be reserved for the purpose of protection of the tank[2]. Whereas for protecting armoured fighting vehicles (AFVs) against present and futuristic ammunition, this figure can be as high as 30-40 per cent, thereby causing an imbalance in the design of AFVs.

Table 1. Latest ammunition development parameters

Country	Type of penetrator	Range (km)	Angle of attack (degree)	Penetration in RHA (mm)
USA	DU			560
	W			480
UK	W	2.0	Normal	500
	W	1.0	71	520 (path length)
ıny	W	2.0	Normal	560
	DU	2.0	Normal	640
Russia	DU	2.0	60	250
	W	2.0	60	230
	Steel	1.8	Normal	400
	W	2.0	61.5	220
	W	2.0	Normal	500

Against these impressive odds, passive armour may no longer be able to protect the crew of the tank in its present form. The ERA development thus assumes importance in providing protection to MBTs and old generation tanks held by various countries of the world. Some of the locations on the tank turrets may have slightly poor protection levels, especially in the case of old generation tanks. In these locations, bulging caused by ERA may not be of severe nature as part of the projectile energy is dissipated in bending and stretching of the plate material[3]

3. PRINCIPLE & WORKING OF ERA

Many investigators have expressed their views about the working of ERA[4-12]. However, there is no coherency in these expressions. Some explain that the projection of the metallic plates in the path of the jet adds to the thickness of the base armour. There are some who explain that it is the disruption of the jet caused by the detonation products thereby reducing the penetration capabilities of the jet of the shaped charge. Most of the investigators agree that the efficacy of ERA is drastically reduced at zero obliquity. They also confirm that basically the ERA system comprises explosive sheet sandwitched between two metallic plates.

While understanding the principle of working of ERA, it is to be noted that the mechanism of ERA functioning for a shaped charge differs from that of KEP. In the case of a high speed jet formed by a shaped charge, reduction in penetration can be achieved by:

(a) Plate cutting mechanism, or

(b) Disruption of jet, or

(c) Combined effect of (a) and (b)

The finding of this study is that both the flying-off of the metallic plates in the path of jet and the disruption of jet by the detonation product, play a rôle in reducing the penetration of the jet. However, a large number of experiments conducted in this area provide definite information that the major cause of reduction in penetration is due to the disruption of the jet and plate-flying plays a secondary role in the functioning of ERA. It should be, however, appreciated that in a microsecond phenomenon of detonation of the explosive, plates are very much required for providing confinement to the detonation products. It can thus be understood that apart from the projection of these plates in the path of the jet, indirect application of these plates is to assist the disruption of the jet by providing confinement for few microseconds. The very fact that the thickness of these top and bottom plates of ERA developed by various countries in the range of 2-12 mm is a point to ponder about their role in the penetration reduction. Plate thickness of the order of 4-12 jet diameter is predicted for initiation of explosive by a shaped charge jet having a velocity of 7 km/s and jet diameter as 1.5-3 mm[10,13,14]. Additionally, if plate cutting role is assumed to be a dominant factor, there is no reason as to why these plates should not be made out of a high density material like tungsten, which will offer drastic reduction in the penetration of the jet. The use of aluminium alloy, mild steel, armour grade material and even dense alumina (ceramic) as a plate material clearly points towards the fact that the disruption of jet is a major issue in the working of ERA.

With regard to the efficacy of ERA against long rod penetrator, information in the open literature is quite patchy. In a limited number of experiments conducted by us, it is evident that ERA can function against long rod penetrators, provided the sensitivity of the explosive is optimised to ensure its detonation at a very low striking velocity of these KEP (V = 1300-1500 m/s). Reduction in penetration of KEP is achieved by a combination of the deflection and fragmentation of KEP in the presence of the detonation product. Reduction in penetration by a KEP with low ratio of length to diameter of such projectiles, has been observed to be quite appreciable. For clear understanding of the working of ERA against long rod penetrators, a large number of experiments have to be conducted.

4. ADD-ON EFFECTS

ERA panels when mounted on the tank on its frontal arc, sides, nose plate and turret top will enhance its protection level against the missile threat. At the same time, these panels will have some overall adverse effects on the tactical functioning of the tank. Some of the important points are:

a) Add-on ERA system may change basic shape of the turret, which may not be acceptable to user from the tactical considerations point of view.

b) Panels have to be removed before the engine removal and the strip inspection of the gun.

c) Add-on ERA may cause blind zone in front of the driver, and the crossing of bridge layer tank may be difficult during night.

d) Gunner and commander sighting systems may have obstruction[15] in the vision.

e) Add-on ERA will create problems in the mounting of mine plough and tool boxes.

f) Relocation of IR lights, search light, smoke grenade and many more such items/equipment may have to be perforce taken up.

g) Loading/unloading from the tank transporters will be a difficult task for the tank driver.

h) Add-on ERA will pose maintenance restrictions at the unit and workshop levels.

Keeping in view, the gains achieved due to the employment of ERA on the battle tank, minor changes as indicated above have to be adopted. In any kind of add-on armour system adopted for enhancing the protection level of the tank, basically some kind of compromise in its tactical functioning has to be accepted by the tank crew. Add-on effects cannot be totally avoided while designing such armour.

5. LIMITATIONS OF ERA

ERA is a novel technique to protect battle tanks against the threat of high-calibre, shaped charge projectiles, without affecting the mobility of the tank. However, its use also results in a large number of functional restrictions imposed on the crew of the tank. Some of the most relevant limitations of ERA system are:

a) Due to localised heating and plastic deformation, there is a possibility of stress corrosion cracking, especially in the light alloy armours[16].

b) Weldments may develop cracking tendency near the explosion site on the tank surface.

c) Damage to the fittings on the tank, like the sighting system, mounting brackets, IR lights, periscopes, etc.

d) Burning of explosive due to penetration of high speed fragments of the highly explosive shells or from the body of the warhead.

e) Components of the ERA system might play havoc to infantry by hitting them in the close vicinity.

f) High chances of collateral damage.

g) Damage to radio antenna thus hampering communication links.

h) Fragments of ERA components may fall on the engine deck/the diesel tanks thus causing fire hazard.

i) ERA does not provide full protection to the tank as gaps are left in between the panels for avoiding sympathetic detonation.

j) If the angle of attack of a missile is so adjusted that it makes an angle of 0 to 30° with the normal of the panel, ERA will be rendered ineffective.

k) ERA can be easily countered with the deployment of tandem missile.

l) Major repairs are required to bring the tank to battleworthy condition, once it has been hit by the missile.

m) Large quantity of explosive used in ERA builds a psychological pressure in the mind of the tank crew. That is the reason why ERA has been rejected by some of the armies of the world.

n) Explosion of ERA panel gives out tank location to the enemy.

o) Performance of ERA is dependent on the location of the hit on the panel, by the impacting missile.

6. DESIGN PRINCIPLE

The ERA system has three basic components, namely, two metallic plates, thin sheet of explosive and a container with an appropriate mode of mounting the same.[1] Before understanding the design and development of an ERA system, it would be essential to know the following:

(a) Likely threat perception and missile characteristics,

(b) Existing protection levels of a system which needs enhanced protection levels and type of armour system,

(c) Angle of attack and thickness of base armour at zero obliquity,

(d) Existing blind zones and permissible blind zone in front of the driver and the gunner, and

(e) Allowable weight penalty and performance characteristics of the gun control system.

Having gained information on the above parameters, it is desirable to ascertain the performance of the ERA system used for enhancing the protection levels of the tank. Since explosive forms the heart of the ERA system, the constituents of explosive are to be optimised first. The optimisation of many more technical parameters is totally dependent on the explosive quality. The change of explosive leads to changes in many other design parameters. It is thus important to understand that ERA design revolves around the type of explosive being utilised in the ERA system. The speed of the shaped charge jet, its diameter and the velocity of detonation (VOD) of the explosive in relation to the mass (thickness) of the flying plates are the critical design parameters for the success of the ERA system. Mass of the flying plates and the mass of explosive used will play a deciding role in the design of such armour system. Like a fire triangle, ERA design can be summarised in the form of a speed-based triangle as shown in Fig. 1. Matching of these three speeds is the prime concern of an ERA designer. Since the optimisation of explosive depends on the level of technology developed by any country, it is seen that design philosophy of different countries is different. Such a difference in explosive technology will lead to different types of ERA products being available in the market. It is for this reason that the ERA panels offered by different countries are available in different shapes and sizes. The thickness of top and bottom plates and their material also differ in these ERA systems. In addition, the tank protection philosophies pursued by various countries will also be reflected in these varying ERA products.

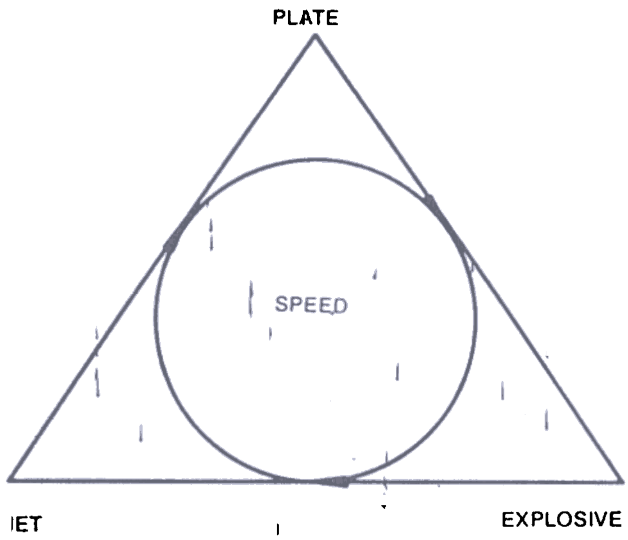


Figure 1. Speed-based ERA design triangle

While designing an ERA system, development work will include optimisation of the following parameters:

(a) Size and shape of the ERA plate,

(b) Plate thickness and its material,

(e) Plate strength and its density,

(d) Weldability of material used for the containers,

(e) Sensitivity of the explosive used,

(f) Speed of detonation of explosive,

(g) Density of explosive,

(h) Vulnerability of the containers to small arms fire,

(i) Immunity against fragments of different types of warheads,

(j) Angle of attack of the incoming missile,

(k) Fragmentless plate material to reduce danger to own troops,

(l) Zero sympathetic detonation to ensure multi-hit capability,

(m) Use of shock absorbing barriers between the panels,

(n) Mounting arrangements to ensure quick replaceability of panels,

(o) Non-burning of explosive due to penetration of the fragments,

(p) Effect of flat/curved plates on ERA functioning,

(q) Stand-off distance for maximum gain,

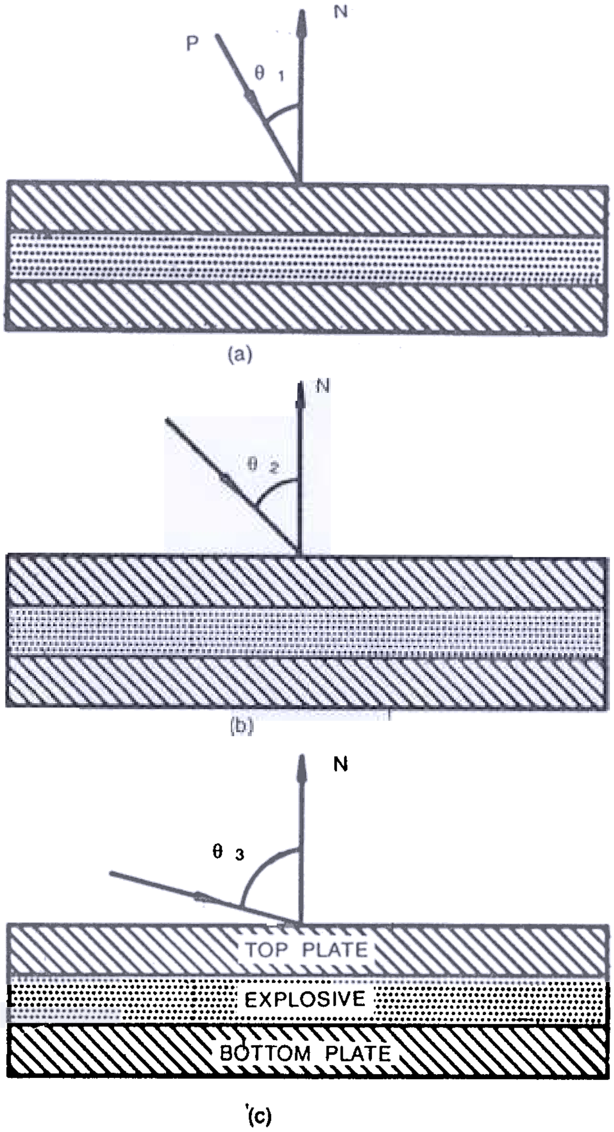
(r) Least weight penalty from mobility point of view, and

(s) Least height of ERA panel to reduce the problem of blind zone.

The above design parameters can be classified into vital, essential and desirable categories. Perfection in optimising the vital parameters cannot be neglected at any cost, and maximum development efforts are to be expended in it. However, optimisation of desirable parameters at times poses serious challenges, leading to overall changes even in the design of the vital parameters. In our development work, many years got wasted in just finalising the mounting mode of the ERA system, which otherwise appeared to be a simple task.

7. GLOBAL TRENDS

Information available suggests that the idea of protecting tanks with the application of ERA is quite old. Dr Held[4] invented ERA and his basic patent was accepted in 1970. Some of the advanced countries have an experience of more than four decades in the design and development of ERA. In fact, most of the NATO countries have gone for ERA development and they appear to be engaged in joint collaborative research work leading to the development of ERA and its countermeasures[5]. Merits, demerits and progress made by various countries in this area are available to a limited extent in open literature. Countries like Russia[17,18], Poland[19] and Israel[20] have provided details of ERA development work in open literature. However, NATO countries are maintaining silence over ERA development and its application on battle tanks. The USA appears to have not released any information about using ERA on battle tanks, though it has been put on MICV



P = INCOMING PROJECTILE / JET

N = NORMAL TO ERA PLATE

(a) POOR ERA PERFORMANCE

(b) SATISFACTORY ERA PERFORMANCE

(c) GOOD ERA PERFORMANCE

Figure 2. Angle of attack and ERA performance

Bradley along with honeycomb structure[14]. Truly speaking, silence of some of the countries by no chance should be construed as lack of interest either on the part of the army or the designers. On the other hand, it would be quite reasonable to assume that the so called mark I models of ERA have been developed by most of the countries for emergency situations. These mark I models may be light in weight, indicating that they are primarily meant to counter the antitank guided missiles of eighties. All the countries might have conducted elaborate field testing of Mark I models and scientists may now be engaged in minimising the serious limitations that may have been noticed during these trials. It is therefore wise to appreciate that the basic aim of total silence by these countries may be striving towards excellence.

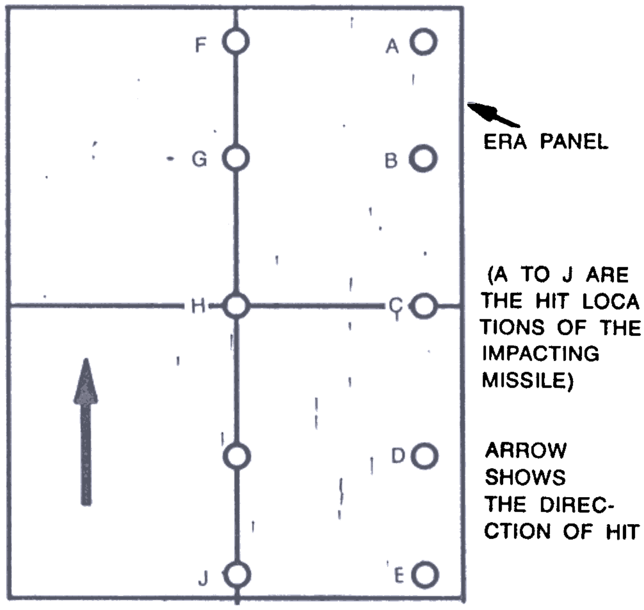


Figure 3. Impact locations of missile on ERA system

It appears to be an accepted and well-known fact that ERA is less effective at normal inclination, i.e. when path of the jet coincides with the normal of the ERA panel[4]. Thehigher the obliquity the better is the performance (Fig. 2). Some of the countries appear to have achieved appreciable degree of competence in this direction[19]. Figure 3 provides probability-based hit locations on ERA panel. The selection of overall design parameters based on the worst situation is observed to be satisfactory.

8. TYPES OF ERA

The need for and long-term gains of ERA have been understood by the world. The most confusing aspect of present day ERA development lies in knowing as to what type of ERA one has to design. There is no straightforward answer to this question. The choice of the type of ERA, i.e. light weight, heavy weight or medium weight will be governed by the tactical considerations, as dictated by threat perception. This clearly brings out the fact that ERA panels developed by one country may not be optimally suitable for another country. Design of the type of ERA is thus linked with the threat being visualised on the ground and on the existing protection level of the tanks. Thus, it is obvious that ERA panels designed for main battle tanks of the world may not provide satisfactory protection levels to the old generation tanks. The evolution of the type of ERA gets restricted to the total weight penalty as given in Table 2. Weight penalties expressed as percentage of total weight of the tank have indirect relation with the mobility of the tank turret. The option of heavy weight ERA would appear to be attractive; however, it may cause some degradation in the speed of rotation of the turret, especially beyond a slope of 25°. This aspect will have to be examined in depth, before designing heavy weight ERA panels.

Table 2. Expected weight penalties and protection gains

Type of ERA	Threat perception	Weight penalty (% of tank weight)	Remarks
Light weight ERA	Missiles only	1.5-1.8	a) Very good for world MBTs and medium tank b) One-round protection
Medium weight ERA	a) Missiles b) Long rod Penetrators	2.5-3.5	a) Two-round protection b) Optimum protection for medium tanks
Heavy weight ERA	a) Advanced missiles b) Advanced long rod penetrators c) EFPs	4.0-5.0	a) Reasonable multi-round protection b) Integrated design c) Turret mobility needs to be examined d) Very good for MBTs

9. USER-FRIENDLY ERA

In a broader sense, user-friendly ERA system is imagined to be a kind of efficient protection system which would not only provide full protection to the tank crew without any psychological barrier but also be harmless to the supporting infantry. In other words, any ERA system with the least number of limitations, qualifies to be termed as user-friendly ERA. Such a user-friendly ERA developed by any country is bound to stay for a long period, unless scientists lay their hands on a wonder material which can do the job of ERA while being totally insensitive. Thus the scientific community of the world is faced today with the task of converting 'explosive power' into 'friendly power'. Some of the logically desirable features of user-friendly ERA can be summarised as:

(a) It should work efficiently at normal or near normal angles of attack,

(b) Its effectiveness should be location- independent,

(c) It should not detonate with varieties of fragments,

(d) Should offer reasonable multihit capability,

(e) Should work against kinetic as well as chemical energy projectiles,

(f) Should produce only fine fragments to avoid danger to supporting infantry,

(g) Should be light in weight and easily replaceable by the crew, and

(h) Size of the panel should be as small as possible without compromising on its wavering, non-coherency, particulation and surface disturbance aspects[21-25]

While ERA offers unimaginable weight and space advantages in protecting world tanks against serious threat caused by missiles and KEP having much superior penetration capabilities, designers have to make ERA a user-friendly armour, at least to a reasonable extent. As per the open literature, so far, no country appears to have developed a user-friendly ERA fulfilling all the above requirements. The limitations of ERA system are quite noticeable; perhaps that is the reason why some of the armies of the world have not yet accepted introduction of ERA in the Services, though such armour is developed by them. Development work on indigenous ERA system suggests that we are very close to offer a user-friendly ERA system.

10. CONCLUSION

Development of User-friendly ERA system is a long-term reality for the protection of battle tanks against the threat of high penetration KEP and shaped charge jets. Indigenous development work suggests that we are close to offer such a system in due course.

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