Defence Science Journal, Vol. 60, No. 2, March 2010, pp. 164-168

Inconsistent Performance of a Tandem-shaped Charge Warhead

S. Harikrishnan and K.P.S. Murthy

Armament Research and Development Establishment, Pashan, Pune -411021

ABSTRACT

Tandem shaped charge warhead is one of the efficient methods to defeat the explosive reactive armour (ERA) protected main battle tanks (MBT). In this concept, two shaped charges mounted in the same missile are initiated one after the other with certain time delay. First shaped charge jet would remove the ERA and the second jet would penetrate the bare armour. Both these explosive charges are mounted close to each other most of the time due to severe space constraints in the system. It is necessary to protect the second charge from the blast effects of first charge, during the time delay between the initiations of two charges. Blast effect of precursor charge on main charge is understood to have detrimental effects on the performance of warhead system.This paper presents a case study of an investigation into the inconsistent performance of a tandem warhead for a third generation antitank missile. The warhead generated a crooked jet resulting in inconsistent penetration performance. Typical crater profiles were observed when the penetration performance deteriorated. Systematic analysis was carried out and simulations were performed using Autodyn-3D to reproduce the phenomenon. Experiments were conducted using Flash X-ray which substantiated the assumptions made for simulation studies.

Keywords: Tandem warhead, precursor blast, blast isolator, explosive reactive armour

1. INTRODUCTION

Introduction of explosive reactive armour (ERA) protection to main battle tanks (MBT) necessitates the use of tandem-shaped charge warheads for anti tank missiles to defeat the MBTs. The concept of tandem-shaped charge involves a precursor charge (PC) and a main charge (MC) set to initiate with a predetermined time delay.

This paper presents a case study of the investigation carried out to find out the reason for inconsistent penetration performance of a tandem warhead during static performance tests conducted. The system under consideration is a third generation anti tank missile which houses the precursor charge in front-section offset to the missile axis. Precursor charge consists of 250 g of HMX-based explosive. Main charge is housed at 200 mm to the rear of precursor charge. Space between PC and MC houses electronic systems consisting of printed circuit boards, connectors, cables, and their mounting frames. Precursor charge is initiated by a fuze, which has mass of 250 g. A general arrangement of warhead is shown in Fig. 1.

2. PENETRATION PERFORMANCE TEST OF WARHEAD

Penetration performance of tandem warhead is carried out against rolled homogenous armour (RHA) integrated with explosive reactive armour (ERA). The ERA is mounted on a stack of armour plate as shown in the test set up in Fig. 2. Each armour plate has dimension 600 mm × 300 mm × 80 mm. Warhead is positioned against the ERA-protected RHA at an angle of 30^0 to the horizontal plane in such a way that both precursor and main charge jets pass through the ERA panels. Main charge and precursor charge are initiated with a time delay using separate arming and detonating mechanism. This time delay is so adjusted

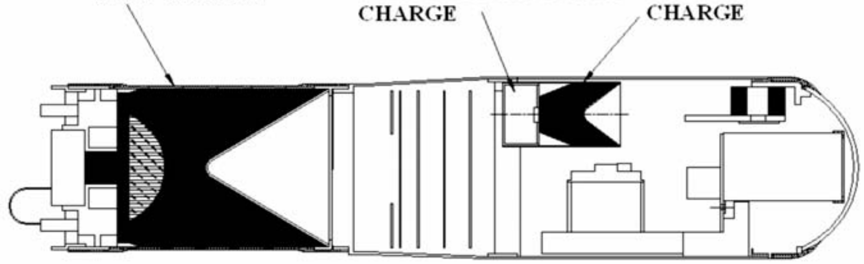


Figure 1. General arrangement of a tandem warhead system for a third generation antitank guided-missile.

Received 03 September 2009

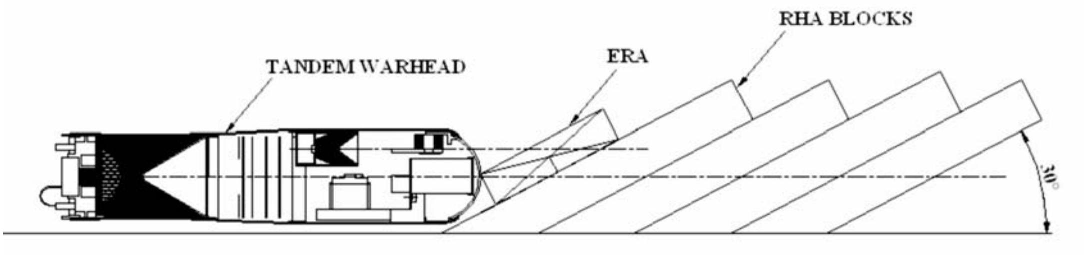


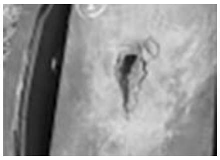
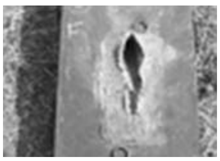
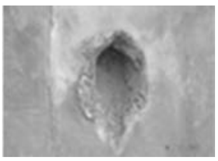
Figure 2. Warhead test set up.

that the main charge jet reaches RHA after the ERA detonation products are cleared from the main charge jet path.

3. INCONSISTENT PERFORMANCE OF TANDEM WARHEAD

Shaped-charge jet emanating from precursor charge initiates the ERA. Main charge is initiated after certain time delay when the debris of detonated ERA is cleared from the main charge jet path. As per one dimensional codes based on generalised PER theory, the expected penetration of warhead is 800 mm after defeating ERA. However, penetration recorded on the target was inconsistent varying from 260 mm to 750 mm. Crater formed at the entry of target was elongated. It was also noticed that when the warhead registers its intended penetration, elongated craters are not observed. Data from various tests are reported in Table 1.

Table 1. Penetration in RHA and crater profile

Test number	Penetration in RHA (mm)	Crater profile
1	260	
2	300	
3	378	
4	480	
5	750	

3.1 Problem Analysis

On studying the characteristics of main charge jet penetration crater observed on the target plate, it was observed that the main charge jet was shifting to the upper plane from the intended point of hit on the target as shown in Fig. 3.

Possible reasons for this observation on the crater geometry were broadly categorised into either warhead related (internal) or target setup related (external). Internal causes include factors related to warhead that lead to the generation of an improper (crooked) jet. External factors are those related to the target setup. Elongated craters are observed when the target or warhead has a transverse velocity with respect to jet. A cause and effect diagram was constructed to understand the factors causing this phenomenon as shown in Fig. 4.

Different factors causing the formation of a crooked jet is shown in the above cause and effect diagram. Detailed deliberations were undertaken to understand the effect of each of the above factors. All the external parameters were ruled out because target and warhead disturbances are much slower phenomena as compared to shaped-charge jet formation and its penetration. All parameters, as regards to the precision of manufacturing and assembly of warhead-were controlled thereby eliminating many of the warhead related factors. Moreover, the main charge in stand alone mode has recorded consistent performance in mild steel target blocks.

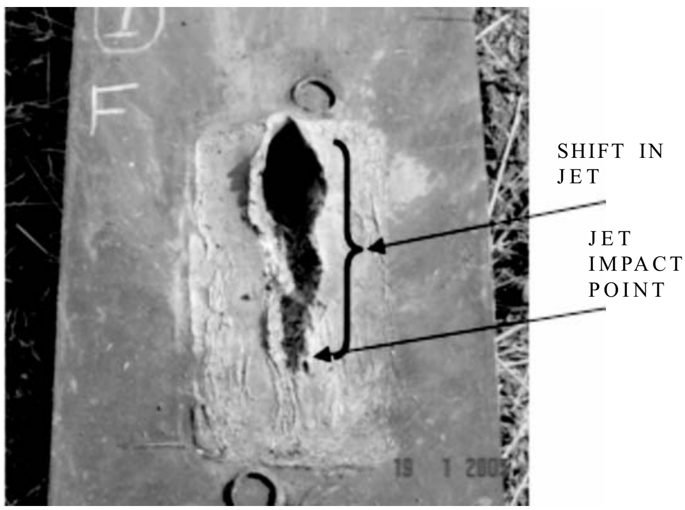


Figure 3. Penetration crater geometry.

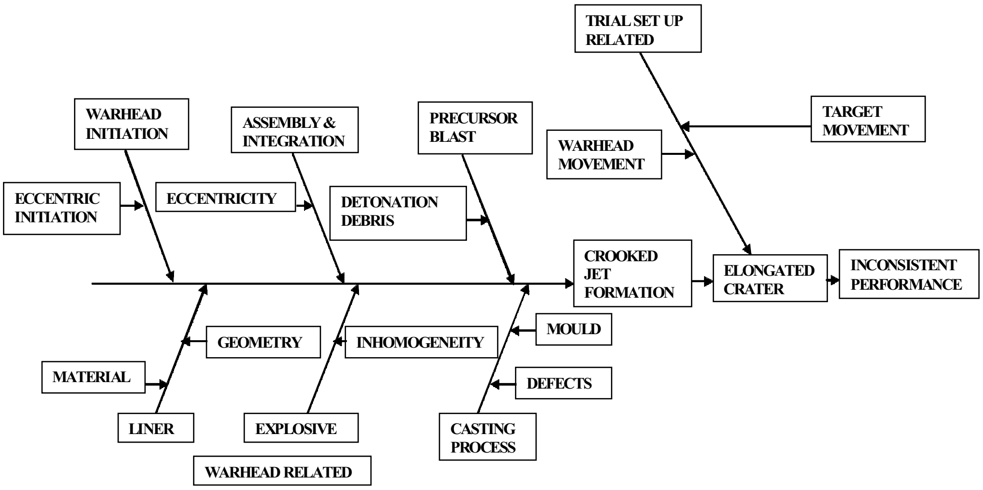


Figure 4. Cause and effect diagram.

Next step was to analyse the effect of precursor blast on main charge. Effects of precursor charge blast on main charge functioning would mainly be in two ways; (a) direct blast effect, and (b) disturbance in the collapse process of main charge liner due to the flying components of missile system housed in the space between PC and MC during the time delay[1,2]. Shift in the jet penetration towards the upper plane can be explained by assuming an asymmetric collapse of the liner elements. If collapse of liner elements above the liner axis is perturbed, jet flow will tend to shift towards the upper plane to conserve momentum[3]. Asymmetric collapse would set in radial velocity in the jet. Perturbation of collapse can be caused by the debris of precursor detonation entering into the collapse volume.

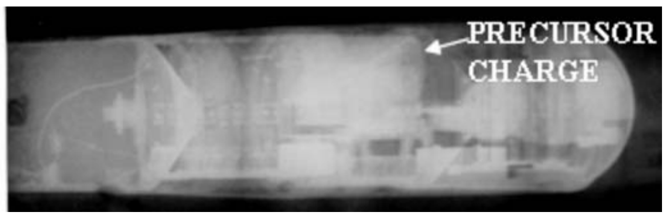
3.2 Experimentation

Experiments were carried out to study the precursor debris movement. Test on tandem warhead was carried out where an inert main charge was used and the precursor charge was detonated. Flash X-ray photographs were taken at different intervals as given in Fig. 5. Flash X-ray image at 350µs show that debris from the precursor charge is entering main charge collapse volume. Main warhead and precursor warhead are configured to initiate with a predetermined time delay which results in the collapse of main warhead liner between 320-380 µs after precursor charge initiation, to effectively counter various ERA in use world over. Since the precursor charge is positioned offset to the main missile axis, the debris from detonation of precursor charge enters the collapse volume in the upper plane of the missile axis.

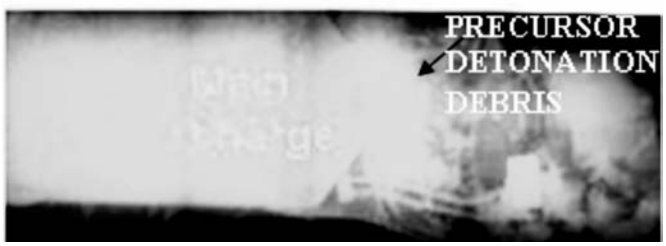
3.3 Simulation

Shaped-charge problems have been simulated using hydrocodes by many researchers[4,5]. Autodyn is a commercially available hydrocode based on classical continuum mechanics, which is used to describe the dynamics of a continuous media with the set of a differential equations established through the application of the principles of mass, momentum, and energy from a macroscopic point of view. Simulation of the present problem was performed using Autodyn–2D and 3D. The simulation contains four materials namely copper, explosive, aluminium and RHA. Material for precursor fuze is aluminium and is described by Johnson-Cook model for its strength behaviour. Material for liner is copper. Since the explosive loading on liner is quite high strength behaviour of copper is neglected in the analysis. Target is described by RHA steel with shock equation of state and von Mises strength model. For modeling the shaped charge problem in 3D, multi material Eulerian space was considered. High explosive was modeled with JWL equation of state. Built-in functions of Autodyn were used for modelling the geometry.

Autodyn 2D analysis was carried out to assess the time at which the blast product from precursor charge enters the collapse volume of main charge. An axi-symmetric



(a) T = 0 µs



(b) T = 350 µs

Figure 5. Flash X-ray radiographs at different intervals from the initiation of precursor charge.

model of the precursor charge and blast barrier was considered for simplicity. Fuze for precursor charge was modeled as equivalent thickness of aluminium. It has been observed in the simulation, the back blast from the precursor charge arrives in the main charge collapse volume close to the time at which main charge is set to initiate. It has been observed the pressure wave deteriorates considerably since large amount of energy is absorbed by the deformation of the fuze and venting through the rupture of missile casing. Different events of the blast phenomenon of precursor charge is shown in Fig. 6.

Scaled down hydrocode model of main charge was generated in Autodyn-3D. When the precursor charge detonates, the heavy fuze located at the rear of the precursor charge gets projected towards the main charge liner. Precursor fuze consists of number of small components and weighing about 250 g and diameter of 60 mm and contributes to the major debris of precursor detonation. This interacts with the collapsing liner wall of main charge and prevents the collapse of certain main charge liner elements from plane above the charge axis because the precursor charge is placed at an offset from the main charge axis. This phenomenon was simulated by removing certain liner portion from the upper plane in the model where the liner wall is prevented from collapsing by the precursor debris. Simulation showed that the jet shifts upwards due to setting up of radial velocity in the jet leading to the formation of crooked jet. This results in an elongated cut on the target plate as observed during static trials. Simulation results are shown in Fig. 7.

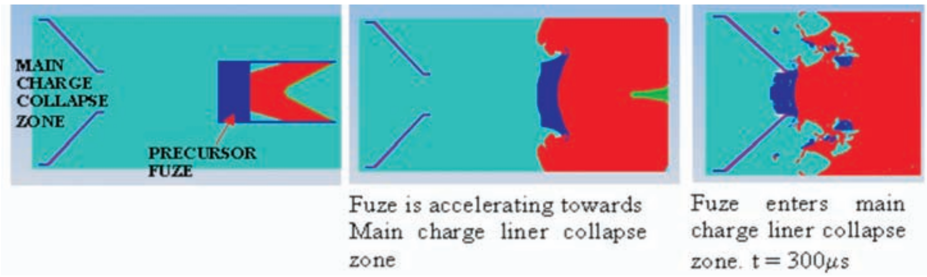


Figure 6. Hydrocode simulation of precursor blast.

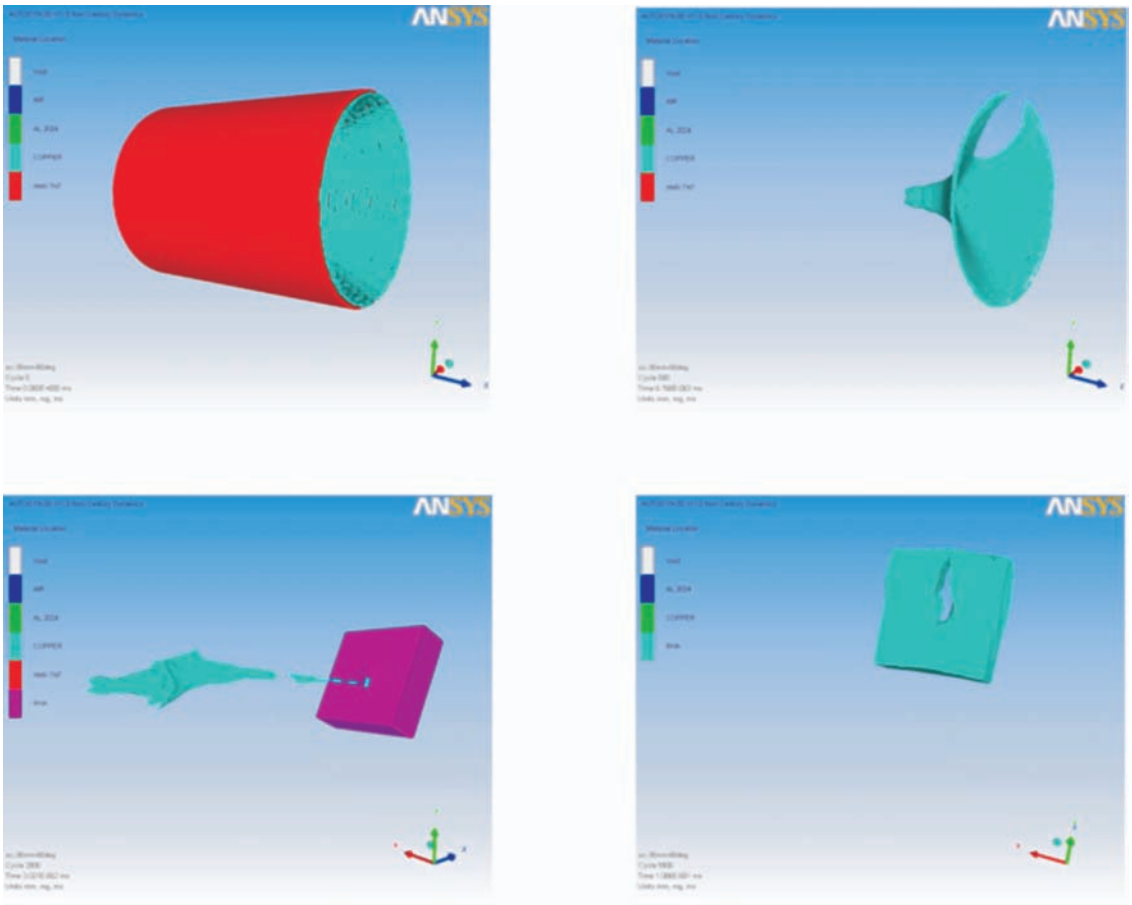


Figure 7. Simulation showing asymmetric collapse of MC liner resulting in an elongated crater on target.

4. CONCLUSIONS

Investigation into the inconsistency in penetration performance of a tandem warhead has been carried out systematically and cause has been identified. Precursor detonation debris accelerating to the main charge collapse volume disturbs the collapse of the main charge liner. Moreover, the present design of tandem warhead incorporates a precursor charge, positioned offset to the missile axis. Detonation debris of this precursor charge cause asymmetric collapse resulting into the formation of crooked jet. The simulation studies with weight simulated aluminum block representing precursor fuze revealed that the debris of the precursor charge will reach the collapse volume of main charge within 350 μs. However, it may be appreciated that the actual precursor fuze consists of several small components and generates large number of fragments with wide dispersion. Hence, it is pertinent to assume that some of the debris would be reaching the collapse volume in random locations. It may be noted that any debris/fragment in the collapse volume of the shaped-charge would result in asymmetric collapse on the axis, thereby resulting in crooked jet formation. Thus, it is concluded that the randomness of debris locations has resulted in wide variation in penetration performance.

The above described problem can be solved by incorporating a blast isolator between precursor and main charge[6]. Design of a blast isolator is critical. A number of factors will govern the design. Position, shape and material of isolator are the most important factors[7]. Various simulation tools and instrumented experimentations are necessary to arrive at an optimum design of isolator for any tandem warhead.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Shri A.M. Datar, Director, ARDE; Dr Satish Kumar, Director, TBRL; and Shri S.S. Mishra, Project Director-NAG, for the support provided during the development of tandem warhead system and various diagnostic tests.

REFERENCES

1. Riggers, E.; Diekmann, R. & Scholles, H. Investigations for mutual effect reduction of shaped charges in Tandem warheads. *In* Proceedings of the 12th International Symposium of Ballistics, San Antonio, 1990. pp. 486-95.
2. Ling, Chen Mei; Dong, Yang Li; Jun, Shen Xiao & Qing, Ma Xiao. Design of small caliber tandem warhead against tank with explosive reactive armour. *In* Proceedings of the 19th International Symposium of Ballistics, Switzerland, 2001. pp. 691-95.
3. Walters, W.P. & Zukas, J.A. Fundamentals of shaped charges. Wiley Interscience Publication, 1989.
4. Heider, N. & Heimaier, S. Numerical simulations of the performance of tandem warheads. *In* Proceedings of the 19th International Symposium of Ballistics, Switzerland, 2001. pp. 1493-499.
5. Hayhurst, C.J.; Glanville, J.P.; Fairlie, G.E.; Clegg, R.A.; Lenselink, H; Cowler, M. & Quan, C.X. Integrated modeling of tandem warhead system. *In* Proceedings of the 21st International Symposium of Ballistics, Adelaide, 2004.
6. Meier, M.; VonAh, P.; Sorensen, J. & Ouye, N. Solutions to some design constraints in tandem warheads, *In* Proceedings of the 20th International Symposium of Ballistics, Sept 2002. pp. 663-68.
7. Harikrishnan, S. & Murthy, K.P.S. Design and evaluation of a light weight blast barrier for third generation anti tank missile with tandem warhead. *In* Proceedings of the National Conference on Advances in Armament Technology (NCAAT-2008), ARDE, Pune, November 2008, pp. S2.51-S2.58.

Contributors

Mr S. Harikrishnan obtained his MTech (Mechanical Engineering) from IIT, Madras. Presently, he is working as Head, Warhead Technology Division, Armament Research and Development Establishment (ARDE), Pune. He has been associated with various warhead development activities of integrated guided missile development programme (IGMDP). His current research area is shaped-charge-based warheads.

Mr K.P.S. Murthy, joined DRDO in 1988. He has been working on design and development of several warhead systems including safety arming mechanisms for various missile and rocket systems. He has published several papers in national and international forums. He is a recipient of *Dr Biren Roy Trust Award* in 2007, Technology Group Award in 2006 and *Agni Award for Excellence in Self Reliance* in 2005. Presently, he is working as Group Director for Warhead Technology, ARDE.