

A Review on Development of Fuse and Multimode Warhead for Short Range Tactical Missile

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Abstract -The development of fuse systems and multimode warheads plays a critical role in enhancing the effectiveness and versatility of short-range tactical missiles. This review paper presents a comprehensive analysis of recent advancements in fuse technologies and warhead design methodologies, focusing on their integration for improved target engagement and mission adaptability. Modern fuze systems, including proximity, impact, and programmable electronic fuzes, are evaluated in terms of sensitivity, reliability, and timing accuracy under varying operational conditions. Additionally, the concept of multimode warheads—capable of performing blast, fragmentation, and shaped charge functions—is examined with respect to design optimization, lethality, and structural constraints. The paper also discusses key design challenges such as fuze-warhead coordination, safety and arming mechanisms, environmental survivability, and miniaturization. Advances in materials, sensors, and embedded electronics have significantly contributed to the evolution of intelligent fuzing systems and adaptive warhead configurations. Furthermore, numerical simulation techniques, including computational fluid dynamics (CFD) and finite element analysis (FEA), are reviewed for their role in performance prediction and design validation. This review highlights current research trends, technological gaps, and future directions in the development of integrated fuze and multimode warhead systems, aiming to support the design of highly efficient and reliable short-range tactical missile platforms.

Key Words: Fuze System, Multimode Warhead, Short-Range Tactical Missile, Proximity Fuze, Warhead Design, Fragmentation

1. OVERVIEW OF THE PRESENT RESEARCH WORK

This chapter explains the principles and methodology of the current research on short-range tactical missiles are fundamental to modern warfare, as they provide targeted effects against time critical, mobile or distributed targets. The most important elements of a missile that determine how the delivered energy is translated into a tactical effect are the fuze and the warhead, although a multimode warhead provides flexibility in effect (e.g., blast, fragmentation, shaped charge, or a combination of one or more of these) to defeat various types of targets. It is important to integrate design and analysis of these subsystems to optimise mission performance and reduce collateral effects and ensure safety and reliability throughout the entire missile engagement envelope. This is a study of fuses design concepts and performance assessment in combination with multimode warheads on short-range tactical missiles. The introduction provides the background with the discussion of technical and operational drivers: the expansion of the target spectrum (armor, soft targets, urban structures), the necessity of selectable/adaptive effects to limit collateral damage, the need to use robust and small fuze sensors/algorithms to fit within the tight constraints of the missile form factors, and the need to have high reliability in extreme acceleration, vibration and temperature environments. Other important factors are the rules of engagement and legal/ethical considerations that favor controlled effects over uncontrolled damage.

2. INTRODUCTION

The evolution of fuze systems has significantly transformed the traditional mechanical fuze systems into modern day electronic and intelligent systems. The contemporary fuzes also include sensors, signal processing unit and adaptive control mechanisms in an effort to enhance accuracy and reliability as conditions

change [4]. Proximity fuzes are commonly used, among other fuzes, due to their ability to release a burst of fire, without direct contact, thereby causing maximum damage to aerial and mobile targets [5], [9]. Recent research has been on how to enhance performance of proximity fuzes through radar and laser-based sensing methodologies. Direction-finding capability coupled with radar proximity fuzes target detection accuracy and decreases false triggering [9]. Also, anti-jamming strategies have been established to enhance reliability in complicated electromagnetic environments [15]. Fuzes based on laser provide greater precision and resistant to electromagnetic interference, and thus, are suitable in short-range, tactical applications [14]. Fuze-warhead coordination is a very sensitive aspect that determines the effectiveness of missile systems. Conventional systems are based on a constant detonation time, which is not necessarily the best under different conditions. Dynamic methods with artificial intelligence, including neural networks, have been suggested to find optimal points of detonation, leading to increased lethality and efficiency [1]. There has also been a change in the design of the warhead, where the single-mode warhead has been replaced by multimode warheads that are capable of producing blast, fragmentation and shaped charges. Fragmentation warheads studies have indicated the significance of fragment size, distribution, and velocity in determining target damage [10], [11]. Moreover, multi-point initiation method has been demonstrated to better distribute directional energy and also improve the overall warhead performance.

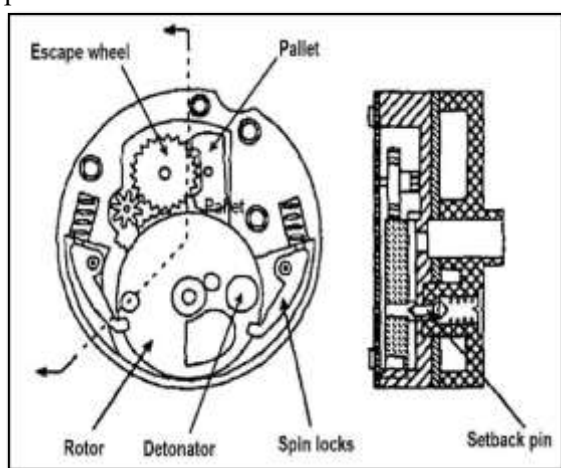


Figure 1. Internal component of fuse

These systems are critical to both the safety and effectiveness of weapon systems, and are a major area of research and development. Likewise, warhead technology has evolved from traditional blast and fragmentation warheads to multimode and directed

warheads, which can switch modes of operation depending on the target. Multimode warheads can operate in modes such as air burst, delayed detonation, and penetration, enhancing their versatility against various targets. Controlled and preformed fragmentation technologies have also improved the efficiency of damage through optimal fragment size, speed and pattern. Another key consideration in missile systems today is the fuze-warhead integration or fuze-warhead coordination.

3. LITERATURE REVIEW

This chapter has referred to the up-to-date literature review papers in my dissertation report research work. There are objectives, and based on the summary of the literature review, some work has been carried out.

The part that decides when and how a weapon will have its last effect, called the brain of ammunition, is a fuze. It is necessary to make sure that the warhead goes off at the best time so that it inflicts the greatest damage. With the increased sophistication of the weapon systems, and the need to be more accurate and effective, the importance of the fuze in the ability to operate with a wide range of conditions has increased in significance. Electromagnetic interference is experienced in fuzes nowadays. The type of such interference can be classified as energy interference and information interference. More specifically, information interference (primarily due to the contemporary jamming systems) is essential. These advanced jammers, which employ Digital Radio Frequency Memory (DRFM) technology, can generate very realistic and misleading signals, making them challenging to defeat. Thus, enhancing the anti-interference performance of fuzes has been a critical focus of advanced defense technologies around the world., it was explain in the following article of Jinwei Jia ,Review of anti-informational jamming techniques for radio proximity fuze (2025). The fuse has evolved tremendously since it was first introduced as a basic mechanical process to a highly advanced and sophisticated electronic and smart fuse. Initial fuze systems were mostly mechanical, using impact (percussion) or time fuzes. Impact fuzes Exploded when they hit the target, and time fuzes Exploded after a pre-programmed time delay. Although these were simple and strong, they had a number of weaknesses such as poor accuracy, incapability to be flexible to react to the changing operational environment, and limited effectiveness against fast moving or evasive targets (Cooper, 1996; Walters and Zukas, 1989).

3.1 Overview of Literature Review.

3.1.1 Fuze Technology Development

The Modern munitions have fuse systems that ensure that detonation happens at the most appropriate time and place and which ensures that storage and handling of modern munitions is safe. Early mechanical fuses were not very accurate, as compared to those systems that utilize advanced electronics and sensors to ensure reliable and adaptive operation. Fuzes are categorized as impact, time-delay, and proximity types with the proximity type being very effective as they detonate near the target and do not have to be in touch with the target. Recent trends are aimed at enhancing accuracy, reliability and resistance to countermeasures with integrated sensors, signal processing and intelligent control mechanisms.

3.1.2 Proximity Fuze Technologies and Sensor Integration

The development of proximity fuzes is an important addition to fuze technology, particularly in air-defense fuzes and in tactical missile systems. They employ electromagnetic, radar, laser or acoustic sensing to measure the targets and identify the best detonation point depending on the relative motion and location. Radar-fuzes have a long range and are robust, with further designs that enhance target detection and false alarms. Nevertheless, they are susceptible to problems like electronic interference and jamming which has prompted study on the anti-jamming method. Proximity fuzes based on lasers are highly precise and exhibit greater resistance to electromagnetic interference, thus being suitable to a short-range application.

3.1.3 Fuze-Warhead Coordination Mechanisms

Fuze-warhead coordination is crucial for maximizing missile effectiveness by ensuring detonation occurs at the optimal position relative to the target. Traditional methods use fixed distances or time delays but may be less effective in dynamic conditions. Recent approaches employ adaptive techniques using artificial intelligence, such as BP-ANN models, to predict optimal detonation parameters. Studies also show that optimizing detonation height and angle improves fragment distribution, increases effective fragment density, and enhances overall lethality.

3.1.4 Warhead Design and Multimode Capabilities

The design of the warhead is an important factor determining the destructive power of a missile. Traditional

warheads were single-mode (blast or fragmentation), whereas modern systems have used multimode warheads that are able to deliver more than one effect depending on the type of target. This enhances flexibility in attack on many targets. The latest developments are multi-point initiation systems, including exploding foil initiators (EFI), which to increase the directional energy and fragment velocity. Also, optimized fragment design taking into account size, distribution, and velocity are important factors in enhancing overall lethality.

Literature Review Distribution in Fuze and Warhead Research

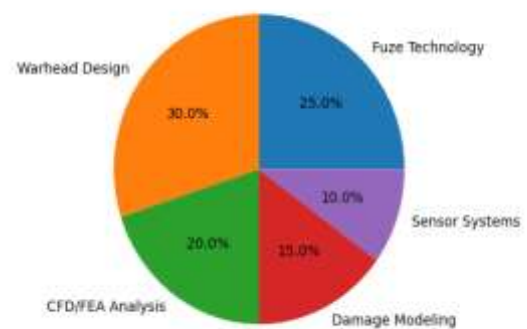


Figure 2. Review distribution on fuze and warhead

3.2 Research Gaps and Challenges

Although there has been significant progress, the development of fuze and multimode warhead systems has several challenges: Adaptive Detonation Control: The current systems usually rely on a predefined set of parameters, which limits the flexibility in dynamically changing environments. Miniaturization: This involves incorporating sophisticated sensors and electronics into miniature missile systems has been a challenge. Anti-Jamming Capability: Providing a trusted operation in electronic contested environments is still a topic of active research. Precise Damage Prediction: The existing models are limited because the distribution of fragments and target interactions are uncertain. Complexity of Integration: To have a seamless coordination among the fuze, warhead and guidance systems, requires advanced control strategies.

3.3 Literature Review Summary

Studies have found the fuze to be a major factor that led to the explosion and the performance of the missile. Alternative types of fuzes have been explored such as proximity, time and impact fuzes, although proximity fuzes are preferred because they are more efficient than the other types of fuzes. Recent reports focus on the use of fuzes that are smart, i.e. that integrate sensors, signal

processing and control components so as to be able to flexibly operate under varying conditions. The integration of fuze and warhead is very crucial and some factors such as fuze delay time, relative velocity and miss distance influence how the fragments will interact with the target and its effectiveness. Fragmentation, fragmentation dispersion and damage models are also paid attention to. Multimode and directional warheads enhance the flexibility through energy shaping and multi-initiators. However, miniaturization, integration of sensors, jamming and real-time processing has problems. To conclude, the future will see smarter, responsive and accurate systems being assisted by new simulation and modeling.

3.4 Research Gap

The following gaps are suggested by the current state of research of fuze systems and multimode warhead design. Most work is premised on the still detonation approaches with minimal consideration given to adaptive systems. The available designs are also not integrated with fuze-warhead and little attention is paid to factors such as miss distance, dispersion and movement of the target. The designs of multimode fuze give priority to a particular mode, and do not involve target-driven switching between fuze modes. Other challenges are multi-point initiation, sensor fusion, anti-jamming, and miniaturization, integration and reliability. Overall, in order to enhance the performance and accuracy, a holistic approach, integrating smart control, simulation and real-time systems, are needed.

Conclusion

In the case of air defence missiles, impact is not usually achieved, and the missile is designed to explode at a given distance of the target, by using a fuze. A laser fuze produces laser pulses, the signals that are reflected off the target, and the warhead is activated to detonate, sending fragments off to damage critical parts of the target. The main difficulty, called fuze warhead coordination, is to choose the appropriate delay time to maximise the fragmentation damage. This can be done with fixed-delay laser fuzes, in which various delay components are chosen according to the engagement scenario and relative motion. Given the high-speed interactions, the process needs to be fast and efficient, thereby simple and robust delay systems are ideal for MANPADS. The fuze system (typically mounted near the warhead) consists of safety, arming and target-sensing components, and two types of fuzes are commonly used in missiles.

REFERENCES

1. P. Hou, Y. Pei, and Y. Ge, "Adaptive fuze-warhead coordination method based on BP artificial neural network," *Defence Technology*, vol. 19, no. 2, pp. 456–468, 2023.
2. H. L. Nguyen, T. V. Nguyen, and M. T. Pham, "Fixed-time delay calculation method based on fuze-warhead coordination," *Journal of Aerospace Technology and Management*, vol. 17, pp. 1–12, 2025.
3. C. Hong, Z. Wang, and L. Zhang, "Optimal damage model for directional detonation control of aimable warhead," *Aerospace Science and Engineering*, vol. 12, no. 4, pp. 103722, 2025.
4. P. Liu, J. Sun, and H. Zhao, "Innovation of control technology for smart fuzes," *Frontiers in Physics*, vol. 11, pp. 1309373, 2024.
5. Z. Tian and C. Liu, "Research and design of proximity fuze scheme based on 24 GHz radar sensor," *IOP Conference Series: Materials Science and Engineering*, vol. 569, no. 3, pp. 032007, 2019.
6. H. Li and X. Zhang, "Numerical simulation of fragment dispersion and damage assessment," *Mathematics*, vol. 10, no. 10, pp. 1688, 2022.
7. X. Zhang, H. Li, and Y. Chen, "Target damage effectiveness model for fragmentation warheads," *Mathematics*, vol. 10, no. 17, pp. 3101, 2022.
8. M. Khalil, A. M. Z. Ahmed, and S. K. Gupta, "Multidisciplinary design optimization of tactical missile systems," *Aerospace Science and Technology*, vol. 78, pp. 314–326, 2018.
9. J. H. Choi, K. W. Lee, and S. H. Kim, "Direction-finding radar proximity fuze sensor design," *IEEE Sensors Journal*, vol. 13, no. 12, pp. 4565–4572, 2013.
10. Y. Zhao, X. Li, and J. Wang, "Fragmentation characteristics of preformed fragment warheads," *International Journal of Impact Engineering*, vol. 134, pp. 103356, 2019.
11. J. Wang, Y. Liu, and H. Sun, "Dynamic modeling of fragment dispersion and lethality analysis," *Defence Technology*, vol. 16, no. 5, pp. 1023–1032, 2020.
12. L. Chen, Z. Huang, and X. Wu, "Design optimization of shaped charge warheads," *Propellants, Explosives, Pyrotechnics*, vol. 43, no. 6, pp. 567–575, 2018.
13. B. Sun, Y. Zhang, and K. Li, "Multi-point initiation system for directional warhead performance enhancement," *Defence Technology*, vol. 18, no. 3, pp. 789–798, 2022.
14. Y. Li, J. Chen, and Q. Zhao, "Laser proximity fuze detection and signal processing techniques," *Optics & Laser Technology*, vol. 140, pp. 107012, 2021.

15. H. Zhang, X. Liu, and Y. Wang, “Anti-jamming techniques for radar proximity fuzes,” IEEE Transactions on Aerospace and Electronic Systems, vol. 56, no. 4, pp. 3120–3132, 2020.