

Explosive Train Assignment Final - 2011912

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Considerations of Explosive Trains in Artillery Rounds During Service Life and Use

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Executive Summary

Explosive trains ensure munitions remain safe throughout their service life and reliably initiate when they hit their target. This report outlines the stages of the explosive train and gives examples of designs and materials used for the propellant charge and the high explosive main charge of a 155 mm artillery shell. The case study contained TNT as its main charge, a common secondary explosive in military applications. However, historical evidence supports that TNT is unsafe if stored incorrectly or used in hot climates. Several arguments for its replacement and other safety considerations that could be applied in the explosive train design have been discussed.

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1. Introduction

This paper explores the roles of explosive trains in ensuring the safety and reliability of munitions throughout their service life, focusing on the 155 mm artillery shell containing Trinitrotoluene (TNT) as its main charge fill. It examines the selection of appropriate energetic materials in each stage of the explosive train and evaluates potential alternatives to TNT for enhancing safety and reliability.

TNT is a powerful secondary explosive that has been extensively used as the main charge in weapon systems for many years. TNT has proven to be an effective explosive in main charges and is regarded as the benchmark for comparing other explosive materials (known as TNT equivalence [1]). However, despite its wide utilisation, several problems are associated with its use. These include safety and environmental concerns. This paper discusses these issues in the context of the explosive train of a 155mm artillery shell and proposes changes to enhance the weapon's safety.

2. Background

The 155 mm artillery shell (seen in Figure 1) is a cost-effective munition [2] for delaying, disrupting, or destroying enemy forces and supplies. Numerous examples of artillery shells are used worldwide, such as the L15A1, L21A2, and M795. The M795 consists of a 10.8 kg TNT high explosive main charge [3] and can be configured with different fuzes (e.g. impact, delay, or proximity) depending on the target and purpose. The shell also requires a bagged propellant charge system that propels the projectile from the launcher's barrel towards the target.



Figure 1 - M795 projectiles during Desert Fire Exercise, 2013 [4]

3. Explosive Train

The explosive train refers to the series of components that make up an explosive device. Taking the 155 mm artillery shell, for example, the first explosive train triggered is the propellant charge, which can either be a fitted cartridge charge containing granular propellant, or a separate propelling charge like a bag charge (seen in Figure 2) or a more modern design, the modular charge system (Figure 3). The cartridge system delivers a standardised propelling force to a round, while the incremental systems allow the propellant grains to be adjusted depending on the target's distance.

This type of explosive train is called an igniferous chain because it is not designed to produce detonative effects [5]. On the other hand, the second explosive train in an artillery shell *is* designed to detonate the warhead. Known as a disruptive train [5], these start with initiation and transition to detonation at a stage of the explosive train.

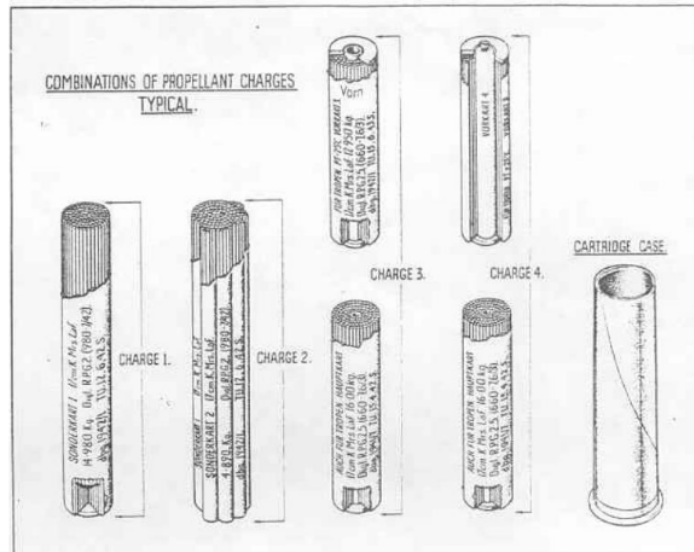


Figure 2 - Propellant bag charge design [6]



Figure 3 - Modular Artillery Charge System (MACS) for 155mm artillery rounds [7]

3.1. Initiator

The initiator is the first stage of the explosive train. To ensure its successful operation, a sensitive primary explosive material is selected. For safety, initiators require an external stimulus to trigger, which can come from a chemical, electrical, or mechanical effect caused by the weapon's design. For instance, an electrical firing pulse from the launcher could trigger a conducting composition cap to initiate the propellant cartridge for an artillery shell.

To prevent accidental firing during a munition's service life, initiators require at least two safety modes to be activated before the initiator can function. An example safety mode is a firing pin which

is removed before firing. Another example would be when the weapon requires a setback force to move the initiator into line, which minimises the chance of unintentional initiation during storage and handling.

A typical material for initiators in an igniferous train would be a sensitive primary explosive that deflagrates rather than detonates. An example that could be applied to a conducting composition cap would be lead styphnate mixed with a conducting component like carbon black or graphite [8].

The initiator for the disruptive train in an artillery shell would likely be triggered by mechanical effect rather than electrical. For instance, a stab detonator (Figure 4) could be used so that when the weapon impacts the target, the detonator fires. L mixture – a composition of Lead dinitroresorcinate (LDNR), barium nitrate and tetrazene – is the most common filling in British service stab-sensitive initiators [5].

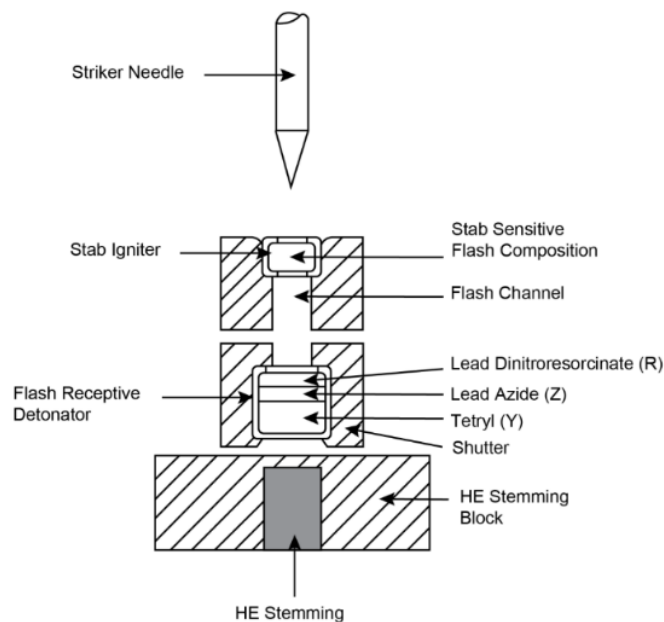


Figure 4 - Example of a stab igniter - flash receptive detonator system [5]

3.2. Stemming

Stemming is only applied to disruptive trains, not igniferous ones, and it is used to transfer the detonation energy from the initiator to the booster. In addition, stemming uses a secondary explosive such as RDX, as a primary explosive here would be too sensitive to use and could trigger the booster and, in turn, the warhead.

3.3. Booster

The booster (Figure 5) is an intermediary for amplifying the energy the initiator/stemming releases to trigger the main charge. Therefore, the explosive must be sensitive enough to accept the stimulus generated by the initiator/stemming whilst also generating the required energy to trigger the main charge either through deflagration to detonation transition or shock to detonation [5].

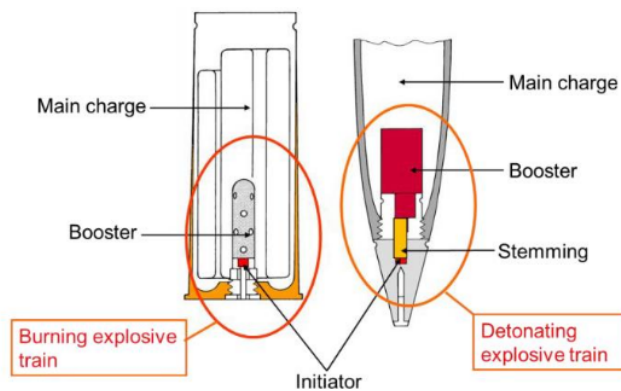


Figure 5 - Examples of a booster design in a burning explosive train and a detonating explosive train [5]

In the propellant cartridge pictured on the left of Figure 5, the booster contains vents for the hot particles and gases to emit a more uniform heating effect on the propellant grains of the main charge, creating numerous hot spots in the main propellant charge to ensure the required activation energy is exceeded and a burn front can be initiated.

The booster in the disruptive explosive train (seen on the right of Figure 5) is designed to initiate the high explosive main charge by progressing the shock front caused by the stemming stage so that the speed of sound for the main charge material (not to be confused with the speed of sound in air) is exceeded. The pressure caused by the shock front generates hot spots within the material, causing a thermal explosion of the main charge. A common material used for boosters in disruptive explosive trains is pressed RDX.

The composition selected for the booster of an igniferous firing train must generate a high flame temperature that efficiently radiates thermal energy to the surrounding propellant to produce a uniform initiation of the main charge [9]. Typical materials used are black powder or nitrocellulose mixed with other energetic materials to enhance its ignition properties.

3.4. Main Charge

The main charge is the final stage of the explosive. In a disruptive explosive train, the main charge provides the destructive force of the artillery shell. Secondary explosives are typically used as they are less sensitive, providing safety during transportation, storage, and handling. TNT is a common choice for the main charge due to its low manufacturing cost, low sensitivity to impact and friction, and good performance.

Nitrocellulose (NC) is commonly used as a propellant main charge for gun systems. It is known as a single-base propellant, or it can be combined with nitroglycerine and nitroguanidine to make double- or triple-base propellants.

4. Discussion

4.1. TNT in Munitions

TNT has many advantages as a military explosive which is why it has been widely used since before World War 1. One of these advantages is its low melting temperature (81.7°C) which enables it to be cast very easily [10], but this also gives rise to hazards when operating in hot climates.

TNT is a eutectic, and so it can exude isomers of dinitrotoluenes (melting temperature of -10°C [11]) and trinitrotoluenes (melting temperature of 16°C) when they are inappropriately stored at the wrong temperatures. Exudation can cause the formation of cavities and cracks in the explosive fill leading to partial detonation during use or, worse, premature detonation. The exudated isomers can also leak into screw threads, including the weapon's fuze, which can lead to accidental initiation. Exudation is suspected of having been the cause of the Cumbrian Pie incident in 2006, when during an AS90 test firing, one of the artillery shells prematurely detonated whilst it was still in the barrel.

Moreover, when TNT continuously melts and sets during day and night cycles, its crystalline structure changes to form large crystals (noticeable in Figure 6 towards the centre of the article), making the explosive fill brittle and prone to cracking. When these crystals crack, they can produce the energy threshold necessary to cause unintentional detonation.



Figure 6 - A cross-section of cast TNT displaying an irregular crystalline structure

The low melting temperature of TNT can be mitigated by combining it with other energetic materials with higher melting points, such as hexanitrostilbene (HNS) or RDX. Although the TNT component in these mixtures will still melt at around 80°C, an intimate mix of another energetic material plus other additives will reduce the migration and exudation of TNT in the munition. A less sensitive material in the munition will also improve safety against heat, friction, and shock.

Despite TNT's wide usage in munitions, its performance can be found lacking compared with other modern secondary explosives, mainly due to its products of reaction upon detonation. It has a low oxygen balance of -73.9%, corresponding with a low heat of explosion of around 3,600 kJ/kg [11]. For comparison, RDX and HMX, also common secondary explosives, have an oxygen balance of -21.6% and heat of explosion of around 5,200 kJ/kg.

IMX-101 is a potential replacement explosive for TNT and has already been applied in 155 mm artillery shells in the US [12]. The IMX stands for Insensitive Munition eXplosive, but describing these

as relatively less sensitive is more suitable, as these new IMX formulations can detonate if provided with the right stimulus. BAE Systems developed IMX-101, which is less sensitive to heat, shock, and friction than TNT. It also has very similar detonation properties to TNT, making it a suitable replacement [13].

4.2. Other Safety Considerations

In addition to the safety improvements that could be applied to TNT in the main charge, another change that would improve the safety of a 155 mm artillery shell would be the substitution of any primary explosives in the initiator stage of the explosive train for a less-sensitive secondary explosive such as RDX. RDX is less friction, shock, and static sensitive and would minimise accidental initiation during handling and storage. Substituting a primary for a secondary in the initiator stage would require extensive design changes to the munition. The standard initiation methods used with primary explosives would not be suitable for reliably initiating a secondary explosive. The firing mechanism needed for a secondary explosive in the initiator stage would be a slapper detonator capable of storing large amounts of electricity and discharging it at high voltage and current to detonate the explosive.

5. Conclusion

In conclusion, this paper has discussed the critical role of explosive trains in ensuring safety and reliability in munitions throughout their service life, focusing on the 155 mm artillery shell. While TNT has been a widely used explosive for main charge fills, its safety and environmental concerns have led to a search for alternatives. This paper has outlined IMX-101 as a potential replacement for TNT, as it is already being deployed as an alternative in artillery shells. Other safety considerations have also been highlighted, such as the use of secondary explosives in the initiator stage of the explosive train. Improving safety in munitions is an iterative process, and it is vital to continue exploring new materials and designs to ensure the safety of those handling and deploying munitions.

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GRADEMARK REPORT

FINAL GRADE

83/100

GENERAL COMMENTS

Instructor

This is an exceptionally well written assignment, with good use of explanation, imagery and references. I enjoyed reading it as a well researched technical report.

The journey through the igniferous and detonative (disruptive is not doctrinal) trains was well structured, with appropriate examples from literature.

Exudation in Cumbrian Pie possible, but likely would have been seen. More likely to have been setback forces causing adiabatic heating of larger voids due to diurnal cycling?

Discussion on performance good, including the alternatives on offer. TNT toxicology?

Well done indeed Josh. A great piece of work.

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