

Silas Blevins L4 OME Assignment

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Considerations of explosive trains in artillery rounds during service life and use.

PRINCIPLES OF OME L4 ASSIGNMENT

Silas Blevins | OME Degree Apprenticeship | May 2023

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1 Introduction

1.1 Overview

In warfare, it is often necessary to deliver munitions onto targets at a range greater than that which is achievable by infantry. This was initially achieved through mechanical systems such as catapults, which were superseded by early gunpowder-based systems in the medieval and renaissance eras which themselves were eventually developed into the modern rifled artillery seen in service around the world today. The figures below show various examples of systems which could be considered artillery.



Figure 1: A Replica Trebuchet - A precursor to artillery [9]



Figure 2: The Dardanelles Gun - A 15th Century Siege Gun



Figure 3: A Modern Artillery System - The 105mm Light Gun [10]

Modern artillery can be used to fire a range of payloads including High-Explosive, Smoke and Illumination rounds. This report will discuss the explosive components of a typical high-explosive shell and the propelling charges. The explosive trains involved in the initiation of these components will be evaluated and potential improvements or replacements for components of these trains will be considered.

1.2 A Typical Artillery Shell

This report will consider the explosive components of a typical High-Explosive shell and its propelling charge. The explosive components of the shell are the Main Charge, which for the purpose of this report is considered to be made of Cast TNT¹, and the Fuze which uses a detonator considered to contain a primary explosive – there may also be a booster made of another secondary such as PETN². In order to propel this shell down the barrel, a propelling charge is needed. This consists of double based propellant and a priming composition.



Figure 4: 155mm Artillery Shells [11]

¹ Trinitrotoluene

² Pentaerythritol tetranitrate

1.3 A Brief Discussion of Explosive Trains

The main charge of the shell is made of a secondary explosive. A secondary explosive is defined as being 'more difficult to initiate' (than primary explosives) [1]. This means that a primary explosive is the preferred method of initiation for a secondary explosive as it can be initiated by a very small stimulus whilst providing the significant activation energy required to initiate a secondary explosive. This decreasing sensitivity allows sequential initiation of an explosive system in a so-called Explosive Train. If a booster is used, it falls between the primary explosive and the main charge and is typically made of a secondary explosive of higher sensitivity than the main charge.

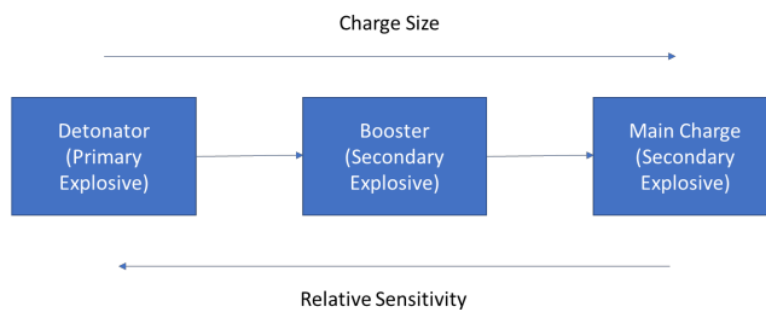


Figure 5: A diagram of an explosive train for a high explosive warhead

1.4 Operational Climates

Modern warfare requires that troops are deployed to locations around the globe at all times of year and as such the ammunition used by these troops will be exposed to a range of temperatures from the cold winters of Eastern Europe to the dry summers of the middle east. Therefore, when considering the choice of explosive to form the explosive trains in a munition, the response of the explosives to temperature should be considered.

2 The Main Charge

2.1 In-Service Round

This report considers an artillery round filled with melt-cast TNT. Some properties of TNT are given below.

Property	Value	Notes
Temperature of Ignition	240°C [2]	Assumes heating at 5°C/min – slower heating can reduce the value
Melting Point	80°C [3]	None
TNT Equivalence	1.0 [3]	None
Figure of Insensitivity (Rotter)	150 [3]	None
Detonation Pressure at Theoretical Max. Density	16GPa [3]	None

Table 1: Some Explosive and Material Properties of TNT

From this table it can be seen that TNT will melt before igniting if heated at a steady rate and is relatively insensitive when compared to other secondary explosives such as PETN with an FoI of 50 [3]. However, the properties and behaviors of the explosive pose a number of safety issues. Foremost amongst these is the formation of cracks in the solid charge as the melt-cast composition cools and solidifies. When the round is fired from the gun, the high-g acceleration experienced by the round can cause the filling to collapse around the cracks, leading to adiabatic compression within the explosive which can result in detonation of the round within the gun barrel [4]. An example of this was the 'Cumbrian Pie' incident where a round detonated in the barrel of an AS90 self-propelled howitzer during a test firing [5]. From this it can be seen that an explosive which can be manufactured using a technique other than melt-casting would be a beneficial replacement for TNT as a main filling for a charge.

Another manufacture-related issue of TNT is the exudation of the explosive into the threads of the fuze pocket of a shell which can lead to a detonation owing to compression of the crystals when the fuze is inserted.

2.2 Proposals

An ideal replacement for TNT would ideally have

- A similar or greater TNT Equivalence.
- The ability to be manufactured with the little to no formation of voids.

- The ability to be manufactured without exudation into fuze pockets.
- A higher FoI than TNT and compliance with IM³ regulations

An example of an explosive that would fill these requirements is 2,4-Dinitroanisole (DNAN), which was first used during the Second World War. This is an explosive which can be melt-cast like TNT, meaning that it could be manufactured without significant modifications to the process when compared to a candidate explosive that can not be melt-casted. Of particular note is the lower impact sensitivity when compared to TNT, with a value given by the Insensitive Munitions European Manufacturer's Group (IMEMG) as FoI > 220 [6]. This value is significantly higher than that of TNT indicating reduced sensitivity to impact. The Temperature of Ignition is also given in [6] as 340°C – higher than that of TNT which suggests the explosive would be less vulnerable to ignition whilst being stored in a warm climate. Despite these positive aspects, the friction sensitivity is given as 160N – indicating a higher relative sensitivity than TNT's 216N [6]. JSP333 discusses DNAN and highlights that it has a higher melting point than TNT which can be mitigated through the use of additives such as N-methyl-4-nitroaniline (MNA). The JSP also discusses the oxygen deficiency of DNAN and points out that it is even more oxygen-deficient than TNT. This oxygen deficiency results in relatively poor explosive performance and as such DADN is typically combined with other explosives such as NTO – in US service this combination forms IMX-101 which is used to fill artillery shells [7].

3 The Fuze

3.1 In-Service Round

In the current round, a small amount of primary explosive is initiated when the shell impacts the target. In order to ensure safety in transit and use, at least two safety features must be present to ensure the main charge is not initiated until the correct conditions are met. Examples of such features are keeping the primary explosive out of alignment with the secondary so that a flame front cannot propagate in the event of accidental initiation of the primary or requiring that a component of the fuze be manually removed or inserted before firing. A replacement for this system would have a number of integrated safety features and minimize the amount of primary explosive used owing to its high sensitivity.

3.2 Proposals

This report proposes the adoption of the Slapper Detonator as the initiation mechanism for artillery shells. A Slapper Detonator, or Exploding Foil Initiator, eliminates primary explosives from the ignition train, instead relying on direct shock initiation of a secondary explosive such as PETN through introduction of a high voltage. [8] This would allow the fuze to be adapted to a range of targets as the voltage supply could be triggered by a piezoelectric system on contact with a target or by a

³ Insensitive Munitions

radar proximity system if an airburst detonation was required. Below is a simplified diagram of a Slapper Detonator.

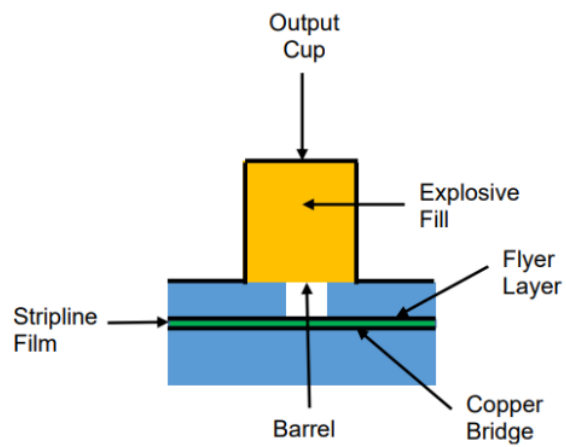


Figure 6: A Slapper Detonator [8].

4 Conclusions

This report concludes that the high-explosive components of an artillery shell can be replaced in service through the introduction of new explosive compositions and the elimination of primary explosives in the initiator. The main TNT charge could be replaced by a DNAN-Based composition – either pure DNAN or a mixed composition with NTO as seen in US service [7]. The initiation system would do away with all primary explosive-based detonators, instead opting for the use of secondary explosive-based Slapper Detonators. These modifications would increase the safety of the shell throughout manufacture, frontline service and disposal.

References

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- [9] L. Viatour, *Counterweight Trebuchets*, 2005.
- [10] UK MOD (Via defenceimagery.mod.uk), *Ex Ascari Storm Kenya*, 2020.
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GRADEMARK REPORT

FINAL GRADE

74/100

GENERAL COMMENTS

Instructor

A novel introduction, which introduced the task really well. Your knowledge of the artillery system and the components/sub-components was spot on. You also described, precisely, the issues with TNT during storage and the implications of voids on firing - well done. Some observations from the submission:

'Whilst providing sufficient explosive energy' would be a better term in para 1.3. You could have considered a definition for an explosive train, but the diagram in Figure 5 is useful.

1.4 response to temperature and environment - hot/humid, cold/wet, cold/dry, hot/dry, temperate etc.

2.2 Yes, a composition comprising DNA/NTO would induce safety. Dependent upon composition, it would be possible to determine performance. Do you have an idea of composition and performance? Literature?

3.2 The introduction of a slapper detonator would require some precise engineering considerations. Not sure about cost etc but its concept is safer than the use of a primary explosive. There would have to be discharge of voltage/current from a capacitor of some description to provide the energy to generate the plasma.

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