

OME Assignment

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**Considerations of the functional
design of a mechanical, airburst nose
fuze for a medium-calibre (90mm-
130mm) fitted to a free-flight rocket
with an HE/Fragmentation warhead.**

ACDA 4019

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Contents

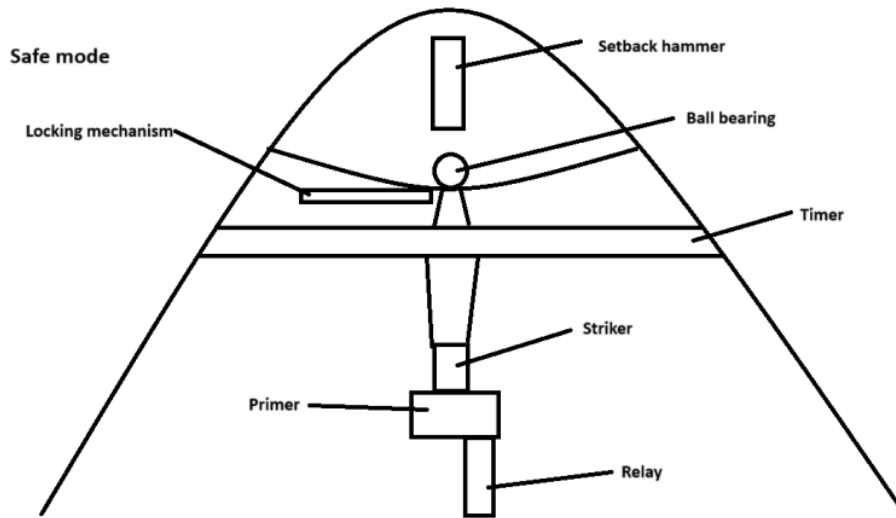
Introduction	3
Design	4
Considerations and Solutions.....	5
Essential purpose and components of an artillery fuze.....	5
The explosive train within the fuze.....	6
Safety in storage and transport.....	6
Handling and Human Factors	6
Forces experienced by fuzes	7
Achieving airburst	7
Forces and phenomena in flight and at Target.....	9
Potential Failure Modes	10
Summary	12
References	13

Introduction

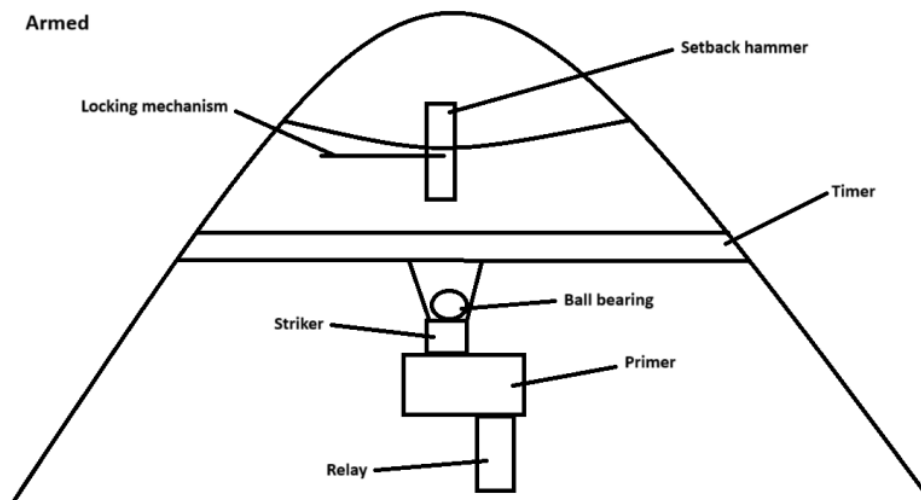
When prehistoric man first dropped his club on his toe, he realised his weapon could be dangerous to himself and the enemy. With today's sophisticated weapons, we must ensure a degree of safety so the weapon will not detonate until it has reached its intended target. [1]

This safety starts with the fuze. There are generally two categories, electronic or mechanical, with many subdivisions based on their functioning method or action to initiate the explosive train. In this essay, the focus will be on the mechanical air-burst nose fuze.

Design



My design incorporates a setback hammer and timer function as the two types of safety mechanisms as set out in the NATO guidelines. Once the rocket has been fired, the setback hammer will be forced onto the ball bearing, which will be squeezed through a hole, and the locking mechanism will lock the setback hammer in place; the ball bearing will fall onto a setting lug to set the timer off, as the timer rotates it opens a hole up, once completed its rotation to desired time the hole will be big enough for the ball bearing to drop through to the striker thus starting the explosive train.



*** Pictures not accurate or to scale.

Considerations and Solutions

Essential purpose and components of an artillery fuze

The primary purpose of an artillery fuze is to ensure the projectile detonates at a precise moment after launch to achieve maximum effectiveness. The fuze's timing and arming mechanisms ensure safety and prevent accidental detonation during storage, handling, and transportation. Depending on the mission requirements, the fuze can support multiple modes of functionality, such as airburst, delay, or impact.

The components of an artillery fuze:

- A safety and arming mechanism is needed to ensure the fuze is safe to handle and only has arms after firing.
- Detonator to initiate the explosive charge.
- Booster ensures the main charge detonates
- Firing pin strikes the detonator to initiate the explosion
- Timing mechanism to control when the fuze activates based on time, impact, or proximity.
- A proximity sensor detects the distance to the target and triggers the explosive when required. [2]

The explosive train within the fuze

The explosive train comprises small explosives that lead to the primary warhead detonation. NATO sets out specific requirements to ensure the rocket's safety and prevent unintentional arming. This includes:

- At least two different safety features shall be used to prevent the unintentional arming of the fuze. They shall be independent of each other and designed to minimise the potential for common cause failure.
- The control and operation of these safety features shall be functionally and physically independent from other processes within the munition.
- Not capable of being armed manually.
- Only able to arm once it has gone through a series of events resulting from sensing environments that occur during or after launch. [3]

To ensure my design meets these requirements, it has two safety features: the setback hammer, which will not be initiated until the rocket is launched and subjected to G-force. The second feature is the timer, which is preset depending on the mission and length of flight; as the timer rotates, a hole appears in the middle, which allows the ball bearing to pass through to the striker. These features are not dependent on any other process within the munition and cannot be armed manually; the only way to start the arming process is by subjecting the munition to the G-force achieved in the launch.

Safety in storage and transport

To stay within the NATO safety guidelines while being stored, fuze systems need physical barriers such as pins or blocks to prevent accidental initiation. While in safe mode, my design cannot be initiated as the hole for the ball bearing to go through initially is too small. It can only be forced through by the strength of the setback hammer hitting it.

To ensure the ball bearing does not move while being handled or transported, it sits in a funnel the same diameter as the ball; this also ensures it goes exactly where it is meant to after being hit by the setback hammer.

The environment in which they are being stored must be monitored to prevent components from expanding, degrading, or corroding, causing mechanical failures and potential premature arming.

Handling and Human Factors

When designing systems that involve handling explosive devices such as fuzes, it is essential to incorporate considerations for human factors to enhance safety, reliability, and ease of use. Below are some of the key considerations:

- Ergonomics—Components should clearly indicate their function and correct orientation to reduce handling errors. The fuzes should be packed and clearly labelled according to hazard divisions and compatibility groupings.
- Labelling - All fuzes should be clearly marked with information such as arming status, orientation, and handling precautions.
- Instruction Manuals - Provide concise and easily understood handling instructions, ideally supplemented by visual aids.
- Inert States- Fuzes should remain inert during storage and handling, requiring specific launch conditions to transition to an armed state.
- Tamper Resistance - Prevent unauthorised or accidental activation through robust safety mechanisms.
- Shock Resistance - Design fuzes to withstand accidental drops or vibrations during handling without arming.
- Hands-on Training - Provide realistic training for personnel to familiarise them with the fuze's operation and safety features.
- Simulated Handling - Use inert training models to practice handling without risk.
- Stress Management - Teach operators to manage stress effectively in high-pressure scenarios to reduce errors.
- Redundancy - Use independent safety mechanisms to reduce reliance on flawless human handling, which is unrealistic.
- Error-Tolerant Design - Design systems to prevent or mitigate the consequences of mistakes, such as accidental drops.

Forces experienced by fuzes

During launch, the fuze experiences several forces that can be harnessed for beneficial use to remove safety features and arm the fuze. These forces ensure the fuze transitions from safe to armed only when it has undergone certain conditions at launch:

The rocket's rapid acceleration (setback) causes internal components to move rearward, initiating the arming sequence.

The spinning motion of the rocket generates centrifugal force, which can move locking balls outward to release safeties.

The tendency of components to resist changes in motion can be used to align the explosive train during deceleration. [4]

Achieving airburst

Achieving airburst at a predictable time and position is a key requirement for enhancing the effectiveness of a rocket. This is achieved by designing the fuze and its triggering mechanism to control the timing or spatial parameters for detonation precisely. Below are some of the principles and methods used:

- Timer-Based Airburst Fuze

A mechanical or electronic timer is preset during rocket launch or flight to detonate the warhead after a specific time has elapsed. This method is effective when the time-to-target is known or can be estimated during pre-launch planning.

How It Works:

- At launch, the setback force or acceleration activates a clockwork mechanism or electronic timer within the fuze.
- The timer counts down from a preset delay, calculated based on the rocket's velocity and distance to the target.
- Once the timer completes, the explosive train is triggered, initiating the airburst.

It is highly predictable and not affected by environmental factors like wind or altitude variations.

- Barometric or altitude sensing

A barometric sensor detects the rocket's altitude and triggers detonation at a pre-determined height above the ground.

How It Works:

- A barometric chamber in the fuze measures air pressure changes as the rocket ascends and descends.
- At a predefined pressure (corresponding to a target altitude), the sensor initiates the detonation sequence.

It is reliable for operations requiring detonation at a specific height above the ground, such as clearing obstacles or maximizing fragmentation dispersion. However, it is limited to use cases where altitude is the primary factor for detonation.

- Spin- or Aerodynamic-Based Timing

It relies on the rocket's spin or airflow to measure the time or distance traveled during flight.

How It Works:

- Spin-stabilized rockets use rotational movement to engage gears or timers in the fuze mechanism.
- Alternatively, aerodynamic forces on vanes or impellers can measure the rocket's velocity and flight duration.

- Once the calculated flight time or distance is reached, the fuze triggers detonation.

It works without complex electronics and can function reliably in mechanical systems. However, it requires precise calibration to account for variations in rocket speed or environmental conditions. [1]

Forces and phenomena in flight and at Target

Several forces and phenomena can be used to initiate the fuze at the desired time and place to ensure that the fuze functions reliably under various operational conditions.

During Flight:

The setback and centrifugal forces have been covered above.

Aerodynamic Forces:

- Caused by the airflow over fins or vanes as the rocket travels.
- Can be used to activate mechanical timers or dynamic pressure sensors.
- Ensures the fuze's arming sequence aligns with the rocket's velocity and trajectory.

Gravitational and Inertial Forces:

- Affect the rocket's trajectory and stability.
- Influence the timing mechanisms that measure distance or flight time to predict detonation at a specific position.

Phenomena Influencing Detonation at the Target

Proximity to the Target:

- Proximity-based sensors (radar, optical, or magnetic) detect when the rocket is near the target, triggering the fuze.
- Ensures detonation at the optimal distance for maximum effectiveness, especially for fragmentation warheads.

Impact Forces:

- When detonation by impact is required, the fuze must sense the sudden deceleration or deformation on contact with the target.
- Mechanical impact sensors or piezoelectric crystals can be used for this purpose.

Altitude and Pressure Changes:

- The fuze's barometric sensors can detect altitude changes, triggering detonation at a pre-set height above the ground.

Environmental Factors:

- Wind, temperature, and humidity during flight can slightly alter the rocket's trajectory or velocity, necessitating robust and adaptable fuze designs.

Target Interaction

- Fragmentation Spread: Airburst detonation ensures the warhead fragments are dispersed effectively over the target area.
- Shockwave Creation: Detonation at the optimal point generates shockwaves that maximize destructive effects on soft or unarmoured targets. [5]

Potential Failure Modes

The functional design of a fuze is complex and subject to various potential failure modes. These failures can impact the fuze's ability to perform its primary functions: safety during storage and handling, correct arming during flight, and precise detonation at the desired location. Below are some of the possible failure modes and the mitigation strategies for each:

Failure to arm

Possible Causes:

- Insufficient or incorrect activation of setback forces mechanisms during launch.
- Malfunctioning of mechanical timers.
- Environmental conditions (temperature, humidity) affecting sensitive components.

Mitigation:

- Incorporate redundancy in arming mechanisms (e.g., combining setback and spin-based activation).
- Use robust materials and design components to withstand various environmental conditions.
- Conduct rigorous quality assurance and testing under simulated operational conditions.

Premature Detonation

Possible Causes:

- Accidental arming during handling due to shocks or vibrations.
- Faulty safety mechanisms include failure of setback pins or centrifugal locks.
- Sensor errors in proximity or altitude triggers.

Mitigation:

- Design multiple, independent safety mechanisms requiring sequential activation (e.g., setback force and spin).
- Use shock-absorbing materials and secure mechanical components to withstand accidental impacts.
- Include a failsafe that prevents detonation if arming occurs outside prescribed conditions. [6]

Summary

Modern weapon systems, such as mechanical airburst fuzes, must adhere to NATO standards and include features that prevent accidental detonation in storage while being handled or transported. They must also ensure activation only at the intended time and place.

My design uses two independent safety mechanisms to prevent accidental detonation. The setback hammer will only be activated on launch, while the timer will only activate when the ball bearing has been dropped.

References

- [1] US Department of Defence, "Fundamentals of Naval Weapons Systems," [Online]. Available: <https://man.fas.org/dod-101/navy/docs/fun/part14.htm>. [Accessed 12 12 2024].
- [2] Unknown, "Wikipedia," [Online]. Available: https://en.wikipedia.org/wiki/Artillery_fuze#Terminology. [Accessed 12 12 2024].
- [3] NATO, *NATO STANDARD AOP-4187 Fuzing systems - Safety Design Requirements. Edition A, Version 1*, NATO, 2022.
- [4] Jack Brothers, "Propagation test of the proposed explosive train for fuze. MT. XM563," 1964.
- [5] Unknown, "Wikipedia," [Online]. Available: https://en.wikipedia.org/wiki/Artillery_fuze. [Accessed 13 12 2024].
- [6] Unknown, "Bombs, Fuzes and associated components," unknown.

OME Assignment

GRADEMARK REPORT

FINAL GRADE

58/100

GENERAL COMMENTS

Engagement with Literature Skills

The student has shown engagement with a limited range of sources throughout the paper. For further marks, I would expect to see engagement with a much wider range of sources. Additionally, whilst Wikipedia is a good source of knowledge, I would advise not to use it as a reference and instead find the source text. Similarly, citing a source as 'unknown' as in Reference [6] is not acceptable.

Knowledge and Understanding Skills

The student has shown they have a competent knowledge and understanding of the failure modes that result in unintended detonation and how these are prevented during storage, handling and launching. For further marks, I would expect to see a greater level of detail provided.

Cognitive and Intellectual Skills

The student has shown they have a sound evaluation of the basic underlying principles, describing how the safety features in their fuze would be removed in sequence in order to reach the armed state. It is not clear, however, how the timing mechanism is locked/unlocked; the reader must assume that it is a clockwork mechanism that is 'wound up' by the action of setting the time. For further marks, I would expect to see a greater level of detail provided.

Practical Application Skills

The student has shown a clear appreciation for the context of the fuzes through the use of diagrams. The diagrams clearly show the action due to setback forces, but they do not show the locking mechanisms of the timer in the SAFE condition, not the subsequent ARMING of the timer. For further marks, the student could provide step-by-step diagrams to aid their description of the order of removal of parts in the fuze that lead to the armed state.

Transferable Skills for Life and Professional Practice

The student's work was mostly coherent, organised, and accurate. The structure was suitable in the most part. For further marks, I would expect the student to have labelled the figures provided. In future, consider the flow of the document for the reader.

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8
