

Principles of OME coursework

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by Luke Brown

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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 a HE/ fragmentation warhead

ACDA 4019: Principles of OME

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Introduction:

Purpose of a fuze:

Fuzes are used in many military devices, such as bombs, shells, mines and rockets. As described by [1], a “fuze is a device that initiates an explosive function in a military weapons store, most commonly causing it to detonate or release contents.” They are required to ensure the explosive functions in a controlled and reliable manner, as well as provide a safety mechanism by staying in the SAFE mode until certain conditions are met.

Mechanical airburst rocket nose fuze example:

As explained in [2, p. 29-31] and [3, p. 38-39], a rocket fuze may be an:

- Impact fuze – Detonating upon contact with a target or surface.
- Time fuze – Detonates after a pre-set time delay.
- Proximity fuze – Detonating at a specific altitude utilising radio waves to measure distance.
- Multi-function fuze – Detonating at either impact, proximity or time, depending on the purpose.

As the requirement is an airburst, either a time, proximity or multi-function fuze may be used. However, given the necessity for a mechanical fuze, we can exclude the proximity fuze, which typically relies on an electronic system. Therefore, this essay will focus on a time fuze design, as illustrated in Figures 1 and 2, detailed in [4]. Alternative designs can be found in [5] and [6].

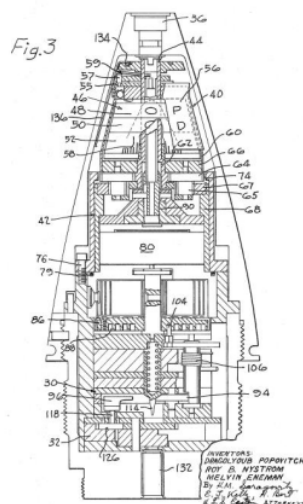


Figure 1 - Mechanical time fuze cross section

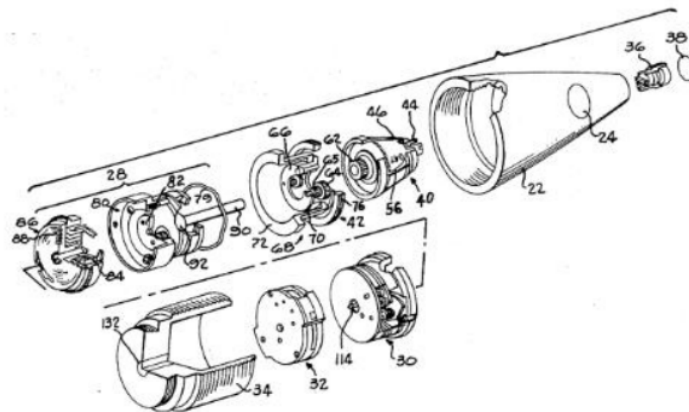


Figure 2 - Mechanical time fuze internal components

Main objectives:

A successful time fuze must have a reliable detonation at a predetermined time, ensuring optimal fragmentation dispersal over the target area. It must also be durable, adaptable, aerodynamic, compact and cost-effective to ensure the fuze is suitable for mass production and prepared for harsh environments. Furthermore, it also must remain SAFE during storage, transportation and launch to prevent accidental detonation. This is outlined in the NATO standards for the safety of fuzing systems [7], describing "Fuzing Systems shall include at least two safety features."

Time fuze components:

General components:

Typically, a mechanical time fuze will include a:

- Casing – To protect the internal components from damage, heat and pressure.
- Timing mechanism – To regulate the release of energy at a controlled time, a pendulum example can be seen in [8].
- Arming mechanism – Used to set the fuze to ARM. It also should include safety features.
- Timing adjustment interface – Allows the user to set a desired time delay.
- Detonator – Primer used to start the explosive train.
- Booster – Takes over from the detonator to initiate the main charge.

Chemical properties and energetic material:

For a mechanical time fuze, both the detonator and booster contain energetic material. The detonator contains a small volume of primary explosive, which is highly sensitive and designed to initiate the booster. Examples of primary explosives used in detonators, as discussed in [9, p. 33], include lead azide and lead styphnate. In contrast, the booster contains a larger volume of secondary explosive, which is less sensitive and serves to initiate the main charge. Secondary explosives commonly used in boosters, as cited in [9, p. 34], include RDX and TNT. Furthermore, separate from the fuze, the main charge of the HE/ fragmentation warhead may also consist of secondary explosives. The difference being the booster provides a high detonation velocity while remaining relatively sensitive, whereas the main charge is used to provide a maximum blast and fragmentation effect and is rendered less sensitive. Examples for the main charge include TNT and Comp. B as found in [10, p. 72].

The explosive train:

The explosive train is a concept used to create an explosive chain reaction, as pictured in Figures 3 and 4, detailed respectively by [11] and [12, p. 2]. There are two main types of the explosive train being high and low. The low explosive train involves a sustained release of energy, e.g. deflagration. In contrast, the high explosive train involves a main explosive effect, e.g. detonation. For the fuze, a high explosive train is utilised. In this instance, the sensitive, low volume/ energy detonator initiates the more insensitive, higher volume/ energy booster, which, in turn, initiates the even more insensitive, higher volume/ energy main charge. The explosive train is integral to the fuze functional design because of its robustness in energy amplification and its capability to incorporate safety interlocks between different explosive stages.

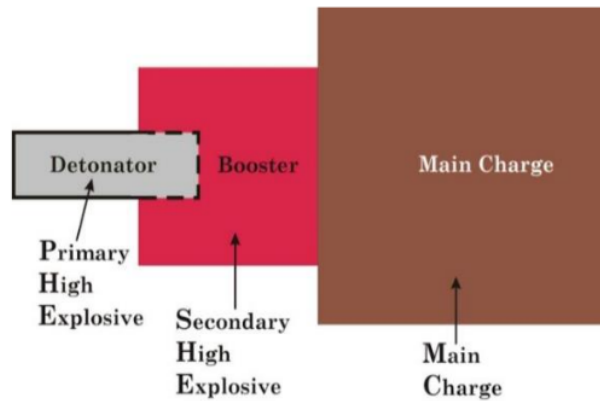


Figure 3 - The explosive train (1)

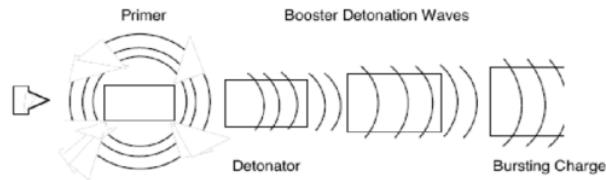


Figure 4 - The explosive train (2)

Safety design features:

Forces and phenomena in flight:

Rocket systems are subjected to a wide range of forces and phenomena during their in-flight phase. As detailed in [13, p. 1-13], these include thrust, inertia (setback), centrifugal force (spin), frictional forces, lift and drag, all of which are key factors influencing the rocket's flight performance. Additional factors, noted in [14], include weather effects, gravitational force, vibration, changes in atmospheric pressure and temperature. Figure 5, cited in [15], provides a visual interpretation of some of the forces acting on the rocket. While forces such as thrust and lift are essential for rocket performance, unwanted forces and phenomena like frictional forces and vibration can have detrimental effects. These adverse influences must be accounted for and mitigated in the fuze design to ensure reliability and functionality.

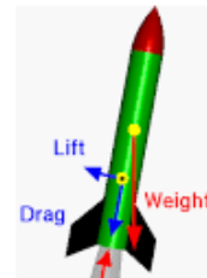


Figure 5 - Rocket aerodynamic forces

In addition, it is important to note that rockets typically experience significantly lower setback and spin compared to other explosive munitions, such as artillery shells. As noted in [16, p. 129-130], for rockets there is “smaller margins between the forces imposed by careless handling and those available for actuation of the arming mechanism.” For example, artillery shells can experience accelerations as high as “14000G,” whereas “CIT rockets” are “never more than 100G.” This difference arises because rocket propellant burns over a much longer period of time compared to the rapid and intense propulsion of artillery shells. Additionally, spin-stabilised rockets generate rotational forces gradually, using canted nozzles and helical fins, in contrast to the abrupt forces imparted by a driving band and rifled barrel arrangement in artillery systems.

Types of safeties:

There are two primary types of safety mechanisms in mechanical time nose fuzes: mechanical safety features and environmental safety features. Some examples of these mechanisms are outlined below, as referenced from [2, p. 69], [4], [5], [6, p. 4-6], [16, p. 129-131], [17] and [18].

Mechanical – Dependent on physical and mechanical inputs:

- Shear pin or spring-loaded detent – These components block or secure the detonator in a safe position. Setback forces typically shear or release these safety mechanisms, allowing the fuze to arm.
- Rotating weight or slider – A rotating weight or slider holds critical fuze components in place. Centrifugal force generated by the munition’s spin causes the weight or slider to move, releasing the components and arming the fuze.
- Clockwork timing gears – These gears remain locked until a specific speed or distance is reached. Once the pre-set delay has passed, the gears release a firing pin, which then activates the detonator.
- Physical safety pin – Similar to a hand grenade, a physical pin holds the fuze components in place. Only after the pin is physically removed does the fuze become functional.

Environmental – Dependent on external environmental conditions:

- Propeller or turbine – A small propeller or turbine located at the end of the nose fuze is connected to a locking pin or threaded shaft. The airstream (wind resistance) drives the propeller, which then gradually releases the locking mechanism, allowing the fuze to arm.
- Bellows or diaphragm – this component locks the fuze system in place. As the bellows or diaphragm expands or contracts (due to pressure changes), it compresses a spring or moves a lever, triggering the fuze to arm.

Figures 6, 7 and 8, cited in [18], picture some of the types of safeties as described prior.

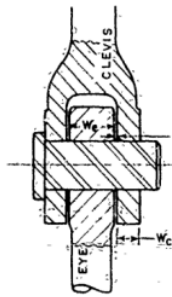


Figure 6 - Shear pin assembly

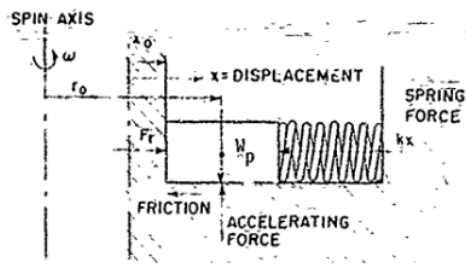


Figure 7 - Mass and spring under acceleration

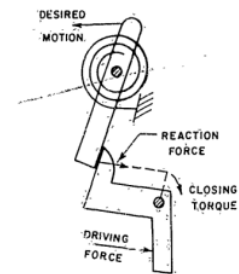


Figure 8 - Lever assembly

As highlighted in the safety features, various forces and phenomena can be taken advantage of in the transition from the SAFE to ARMED state. This typically involves a block of the explosive train. In rockets, the relatively low setback and spin forces may make it seem advantageous to incorporate alternate safety mechanisms, such as a physical safety pin or propeller/ turbine-based arming system. Nevertheless, many modern rocket systems continue to rely on setback and centrifugal based mechanisms, though these systems often use more sensitive components to function effectively under low forces.

Transition from SAFE to ARMED:

Figures 9 and 10 in [16, p. 130] illustrate an example of an MK 149 (AIR) mechanical nose fuze. This fuze utilizes “acceleration retracting a setback block, thus unlocking a propeller which, driven by the airstream, turns a shaft in threads to free the firing pin and complete the arming.” This example demonstrates how two safety features can work together to provide both reliability and safety, ensuring proper detonation under the right conditions.



Figure 9 – Mk 149 (AIR) mechanical nose fuze outer casing

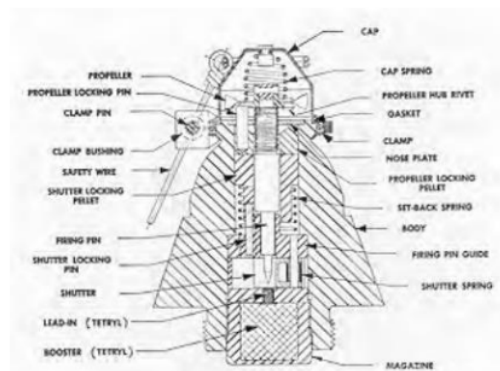


Figure 10 - Mk 149 (AIR) mechanical nose fuze cross section

A similar example can be seen in Figures 11, 12, 13 and 14, referenced from [19]. This TM-24A/ TM-24B mechanical time fuze has effectively a reversed arming method than seen in the MK 149 (AIR) mechanical nose fuze. “Airflow causes the Arming Vane and Fuze cap assembly to rotate and unscrew from the fuze body this allows the locking ball to fall out allowing upward movement of the detent pin which releases the timing hand.” Furthermore, the safety devices include an “Arming pin and safety fork locking the Arming Vane and Fuze cap assembly in place. Arming Vane and Fuze cap assembly holding Locking ball which in turn holds locking detent pin downwards. Detent pin locks timing hand.” This example again denotes how safety features are integrated into a functioning fuze system and how in-flight forces and phenomena can be utilised to move from the SAFE to ARMED phase.

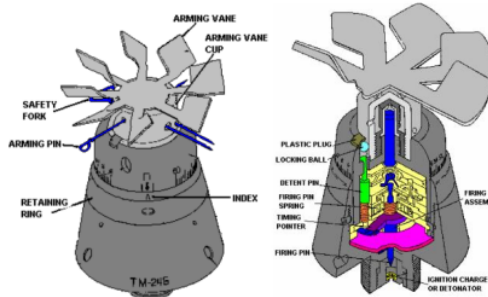


Figure 11 - TM-24A and TM-24B mechanical time fuze outer casing

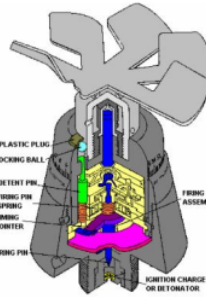


Figure 12 - TM-24A and TM-24B mechanical time fuze cross section



Figure 13 - TM-24B unarmed



Figure 14 - TM-24B armed

Storage, transportation and in-field considerations:

The UK Defence Standard 00-035 (Parts 01-06): Environmental Handbook for Defence Materiel [20], the U.S Military Standard 810: Environmental Engineering Considerations and Laboratory Tests [21] and the QinetiQ Shoeburyness Environmental Test Centre services list [22] can be used to characterize the environmental phenomena acting upon explosive assets during storage, transportation and in-field action.

This includes, but is not limited to:

- Vibration.
- Shock.
- Impact.
- Icing.
- High/ low temperature.
- High/ low pressure.
- Water: mist, rain, immersion.
- Salt mist.
- Solar radiation.
- Sand and dust.
- Fungus.
- Acidic atmosphere.

This short list describes some of the potential causes of failure in the mechanical time fuze. To ensure these effects will not prevent the fuze from being safe and serviceable, environmental testing is to be carried out, replicating these conditions in an attempt to uncover any issues with the fuze. For example, testing may reveal vulnerabilities such as water ingress through the casing during immersion or rotation of timing gears during vibration.

Achieving a predictable airburst:

Fuze burst mechanism:

Timing mechanisms are crucial for ensuring munitions detonate at a “specified time and place,” as noted in [23, p. 138]. This can be achieved through various types of timing mechanisms, the most common being the clockwork gear timer, as illustrated in Figure 15, cited in [24]. This mechanism incorporates a gear train and a runaway escapement to control detonation timing. “On firing, acceleration moves the setback weight rearward and releases the unbalanced rotor which, responding to sustained acceleration, rotates to the armed position delayed by the runaway escapement.” The runaway escapement releases energy stored by a wound mainspring, allowing the gears to advance incrementally. Once the countdown completes, the gear train triggers the release of the firing pin, striking the detonator, initiating the explosive train.

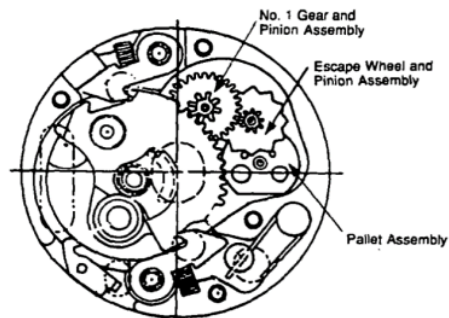


Figure 15 - Safety and Arming mechanism with gears

Time alteration:

The typical process of altering the timing delay in a mechanical time fuze involves adjusting the timer dial or ring. This adjustment changes the position of the gear train or escapement mechanism, modifying the delay duration. This is useful for engaging targets at various distances.

Failure modes:

Potential failure modes and mitigation:

Below details a short list of potential failure modes incurred on a mechanical time fuze. It also includes examples of mitigation features.

<u>Function</u>	<u>Failure mode</u>	<u>System effect</u>	<u>Cause</u>	<u>Mitigation</u>
<u>Fuze casing:</u> Contain fuze components.	Casing cracking/ failure.	Compromised fuze integrity, unintended detonation.	Material defect, impact damage, thermal stress.	Use of impact resistant material, casing reinforcement, better storage/ transportation.
<u>Energetic material:</u> Undertake explosive train reaction.	Failure of explosive train.	No detonation, little detonation with limited effect.	Chemical instability, contamination, improper storage conditions.	Use of stable high quality explosives, store in controlled conditions.
<u>Safety mechanism:</u> Ensure safety prior to use.	Safety mechanism failure (premature/ late).	Early detonation, detonation prior to firing/ collateral damage, no detonation.	Faulty safety mechanism, operator error.	Adherence to safety standards, additional personnel training, better storage/ transportation.
<u>Firing pin mechanism:</u> Initiate explosive train.	Firing pin misalignment or wear.	Failure to strike detonator, no detonation.	Mechanical wear, corrosion, misalignment.	Use of a higher quality resistant firing pin.
<u>Timing mechanism:</u> Cause detonation at a specific time.	Incorrect timing (premature/late).	Early or delayed detonation, failure to achieve optimal fragmentation.	Gear train, escapement malfunction, misadjusted timer.	Use of higher precision components, regular calibration, additional personnel training.

Table 1 - Fuze FMEA

Conclusion:

Key design considerations:

In conclusion, the mechanical time fuze must balance functionality, reliability and safety to ensure it is best suited for in-service use. Functionally, the fuze should be easy to use and effective in maximising fragmentation dispersal. This requires careful consideration of its components, accessibility and the quality and quantity of energetic material. From a reliability standpoint, the fuze must exhibit a low failure rate to maintain operational efficiency. This can be achieved by incorporating high-quality components, particularly in the timing and safety mechanisms. Finally, safety is paramount during storage, transportation and operational use to prevent injury and collateral damage. To achieve this, stringent standards and safety devices must be implemented effectively.

These three topics must be deeply considered and intertwined to ensure the well-rounded design of a mechanical time airburst nose fuze for a HE/ fragmentation rocket.

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Principles of OME coursework LB

GRADEMARK REPORT

FINAL GRADE

74/100

GENERAL COMMENTS

Dear Luke,

An excellent piece of work.

Engagement with Literature Skills

Exceptional engagement with an extensive range of relevant and credible literature. High-level referencing skills consistently applied.

Knowledge and Understanding Skills

Excellent knowledge and understanding of the basic underlying concepts and principles of the subject. However, would like to see more critical understanding of the mechanisms demonstrated for further marks. For example, would like to see more critical assessment of the strength and weakness of each of the design elements.

Cognitive and Intellectual Skills

Sound evaluation of the underlying concepts and principles. However, too reliant on describing or referencing existing designs. In order to demonstrate understanding of the mechanisms, they should be described in a simple, clear way with more a fundamental view through use of simple drawings and descriptions. Need to also more clearly articulate the sequence of events of the safety features.

Practical Application Skills

Very good uses of diagrams and figures, and tables to support the information. More marks would be given for better describing these diagrams or using simpler versions to convey a

better understanding of the underlying principles.

Transferable Skills for Life and Professional Practice

Work is accurate, coherent, fluent, and generally well-structured and organised.

Arguments and analyses were effectively communicated.

However, some deviation from an academic format, namely, text formatting and layout aspects could be improved upon. For example arrangement of diagrams relative to text (shouldn't be text next to diagrams) and text and line spacing should be consistent.

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