

Principles of OME Assignment

by Jennifer Mungham

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Principles of OME

ACDA 5010

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Introduction

Energetic material fall into three categories; pyrotechnics, propellant and explosives. The energy is released most rapidly in an explosive, which detonates, producing blast waves of pressure as the reactants rapidly produce large volume of heated gases which then expand. Explosives can then be divided further into primary and secondary explosives; primaries are very sensitive to stimuli such as shock, heat and friction. Secondary explosives tend to be less sensitive and therefore safer to handle. Primaries are used in small quantities as detonators; the first part of an explosive train. The energy from the primary is then sufficient to detonate a booster charge; which in turn releases enough energy to detonate the insensitive main charge. Many bombs make use of explosive trains to reduce the risk of accidental detonations and take advantage of powerful insensitive charges.

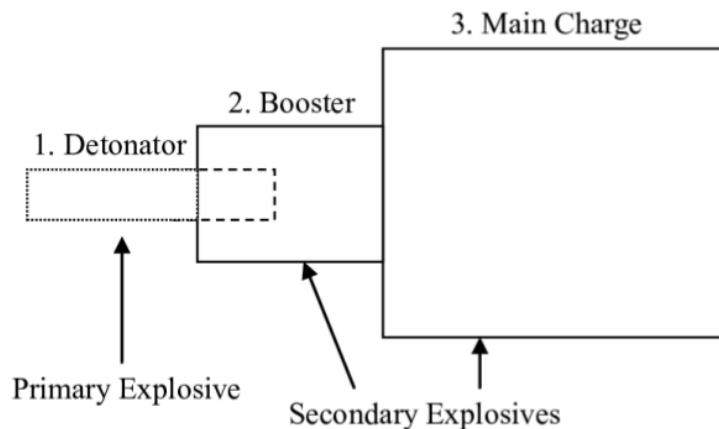


Figure 1 Example of a three-step explosive train [1]

When placed inside a casing, an explosive uses some of its detonation energy to disrupt the casing, breaking it apart into fragmentation. This fragmentation then carries away some of the energy which can be used to penetrate targets. Therefore the heavier the casing, the more energy it absorbs into the fragments and the less energy is available for blast damage. The denser the fragments the better penetrative effects they will have on the target as they deposit more energy on a smaller areas than less dense fragments. Fragment sizes can be altered from the natural break-up of the casing by altering the physical properties of the case; such as scoring the inside of the case. The density of material can also be varied throughout the case to change the effect of the fragmentation at different points.

The fragmentation penetrates targets through one of two mechanisms; ductile failure and plug failure. Ductile flow is where the local target material is heated and pushed aside, through plastic flow, by the fragment. Plug failure is where the fragment cuts out a hole through the target as it passes through. Fragmentation is very disruptive to

targets in the immediate vicinity, but as both the fragmentation and blast lose energy as they travel, their effects diminish quickly with distance from the target.

Both blast and fragmentation will damage infrastructure and people in their immediate vicinity after detonation. Blast can have a shattering effect on infrastructure but can also impart a high impulse to structures to destabilise them. As there is a trade-off between the two damage mechanism of blast and fragmentation, it is vital for success, to design the munition with the type of target in mind.

Table 1 Different Equations for describing the formation and behaviour of fragmentation

Mechanism	Equation Name	Equation
Penetration	Milne-de Marre	$\frac{mv^2}{d^3} \cos^2 \theta = c \left(\frac{t}{d} \right)^n$ Equation 1 Milne-de Marre Equation for fragment penetration [2]
Velocity	Gurney Equation (cylinder)	$v_m = \sqrt{2E} \left(\frac{M}{C} + \frac{1}{2} \right)^{-1/2}$ Equation 2 Gurney equation for the velocity of fragmentation from a cylinder [3]
Slowdown		$V_s = V_d e^{\left[\frac{-C_d \rho_a A s}{2m} \right]}$ Equation 3 Equation describing the slowdown of fragmentation [4]
Damage Volume		$DE = \text{Minimum}(12.36W_e)$ Equation 4 Damage volume estimation for non-shaped charge & cased warheads [5]
Effect of Case on Blast		$W_b = 1.19 \left[\frac{1 + M_r(1 - M_c)}{1 + M_r} \right] c$ Equation 5 US Army Equation for estimate of the blast of an equivalent bare charge [4]

Munitions such as bombs, which produce a combined blast and fragmentation effect are relatively cheap and simple to manufacture and have an omnidirectional effect. This omnidirectional functioning however can be disadvantageous as it can lead to collateral damage. As the blast wave and fragmentation both lose energy over distance, the effectiveness of the munitions are also very dependent upon distance to target which has led to many developments in fuze technology.

Almost as soon as there were aircraft in military conflicts, there were aircraft deployed explosive munitions. World War I saw the use of gravity powered unguided bombs from initially small load capacity quickly rising to over 500kg capacity [6].

During World War II the average accuracy for air dropped bombs was at best 1000 feet [7]. This was deemed unsuitable for modern warfare and both sides moved towards precision, guided munitions. Guidance precision munitions rely on a “feedback” loop in which the error of the relative position from current position and target is measured and a proportional course correction is applied [8].

The early guided Tarzon bomb could achieve an accuracy average 283 feet in the Korean War but ultimately was unreliable and unstable [7]. The 1960’s saw the development of heat-seeking missiles which became the first true precision-guide bomb in 1967. The first laser guided bombs, the pathway, could then achieve an accuracy of 20 feet using fins to make course corrections [7]. The system relied on two planes, one to hold the laser on target and the other to deliver the bomb. Later advances, allowed a single plan to provide the laser guidance and bomb deployment using a gimbal mounted laser pod on the wing of the aircraft.

Laser illumination was still susceptible to poor visibility which would block the laser as well as the target operator’s view, so electro-optical guided bombs were kept in service, such as the Walleye and Hobo even though they were more expensive and less reliable. In 1999 the joint direct attack munition (JDAM) was introduced which was a bolted on guidance package which used GPS. The JDAM had an accuracy of 33 feet but could be fires in any weather or visibility [7].

This increase in technology led to a change in the definition of precision guidance; the munition must have an accuracy of less than 10 feet. Older systems, such as the JDAM, which didn’t meet this criteria were re classified as near-precision [7].

Modern guided bombs are typically designed using a holistic systems engineering approach, where each part is considered individually and as a part of the whole. The manufacturing processes, storage, use and end of life cycle are all also considered during the design phase. Some of the generic, common parts of a guided munition can be seen in Table 2.

Table 2 Summary of main components of a guided blast/fragmentation munition

Component	Function	Examples
Fuze	Provides timing mechanism for detonation	
Primary Explosive	Detonator	Lead azide
Booster	Carries on explosive chain from detonator to main charge	RDX Tetryl
Main Charge	Explosive fill Fragments shell	RDX HMX

	Blast effects	
Liner	Provides good contact between main charge and shell	Bitumen
Shell	Encases charges Fragmentation	Steel
Guidance	Guides munition onto target	Radio Laser Electro-optic GPS

All explosive munitions will have a set of requirements in common, mainly relating to performance, safety and manufacture. Some examples of these can be seen in Table 3, these are likely to be some of the first requirements identified when designing a munition before moving onto the customer and target specific ones. The choice for liner materials will be affected by the requirement of fragmentation or blast to be the priority. The choice of explosive materials will depend on other factors such as availability as well as suitability for target disruption

Table 3 Examples of general requirements for energetic munitions

Design Area	Requirement
Safety	Energy release only on demand
	Remains safe throughout lifecycle
	Not emitting harmful gases during storage
	Not producing environmentally unacceptable products on functioning
	Minimal primary explosive
	Main charge doesn't undergo reactions with other components
Performance	Main charge to undergo no significant changes in uniformity of composition/density/explosive properties throughout life
	Performance remains constant under defined storage conditions
	Main charge sufficiently sensitive to be reliably set off from booster

	Energy release on demand
	Rapid growth to detonation
Manufacture	Main charge to have mechanical properties to allow it to be filled at high density into munition in a method suitable for industrial processes

Just because these requirements are common to most munitions doesn't reduce their importance in the design of a munition. They also do not provide a comprehensive list which will need to be found through talks with customers, users and target identification.

Method

A military requirement was raised for a Guided bomb unit (GBU) to be carried and delivered from a specified aircraft and provide blast and fragmentation damage to a specified type of building.

Outlining Requirements

The initial stage of design was to ensure there was a full list of requirements which would have come in part from the customer.

Likely requirements from the user will fall into different categories. There will be safety requirements such as using an insensitive munition for the main charge.

A list of the requirements can be seen in Table 4.

Table 4 User generated requirements

Design Area	Requirement
Safety	Energy release only on demand
	Remains safe throughout lifecycle
	Not emitting harmful gases during storage
	Not producing environmentally unacceptable products on functioning
	Minimal primary explosive
	Main charge doesn't undergo reactions with other components
	Remain stable through repeated heating/cooling cycle
	Be stable in storage temperatures of 0°C – 50°C
	Have a lifetime of at least 10 years
	Be unaffected by heating from supersonic airflow
	Use an insensitive main charge explosive
	Use components that won't be toxic for users to handle
Performance	Main charge to undergo no significant changes in uniformity of composition/density/explosive properties throughout life
	Performance remains constant under defined storage conditions
	Main charge sufficiently sensitive to be reliably set off from booster
	Energy release reliably on demand

	Supply required output on target
	Rapid growth to detonation
	Have a suitable effective range
	Accuracy of less than 10 feet to target
Manufacture	Main charge to have mechanical properties to allow it to be filled at high density into munition in a method suitable for industrial processes
	Use existing manufacturing processes and infrastructure
	Be made of ready available parts and ingredients
Compatibility with Aircraft	Must be light enough for aircraft to carry multiple munitions
	Have suitable geometry to sit existing munition holds on aircraft
Miscellaneous	Cost less than a specified amount per unit

Meeting Requirements

To have the best chance of meeting all the requirements, the designer may need to improve upon the specificity of the customer requirements. This may mean returning to the customer to add quantitative criteria to some of the given requirements or to expand upon the given list and add new requirements. More research can be done to further define the requirements. National and international legislature such as the UK's JSP rules for MOD must be obeyed for the design of a munition. Research can also be done to look at current systems and identify what aspects of different designs are worth thinking about incorporating or learning from unsuccessful designs. Furthermore, as a particular aircraft and target building type have been specified these will have to be researched to ensure that the munition is compatible with the platform and identify the weakness to exploit in the target.

If the requirements cannot be met there could be financial, reputational, legal and safety consequences. Failure to meet the operational requirements means the weapon will not be effective on target this could mean significant collateral damage or multiple weapons being used for the same target. If safety requirements are not met there could be significant damage to personnel and infrastructure from inadvertent reactions or detonation. Missing meeting any requirement could be significant enough to send the design back to the design stage. This would lead to a loss of the reputation for the designing company and a loss of time and money as work has to be re-done.

Designs

There are numerous, current in-service aircraft mounted guided munitions and bolt-on guidance systems which can be applied to “dumb” bombs. Adapting any of these designs, such as the GBU Paveway series [9], to work with the specified aircraft and to attack the target building type would be a simple way for the designer to quickly and easily meet the requirements.

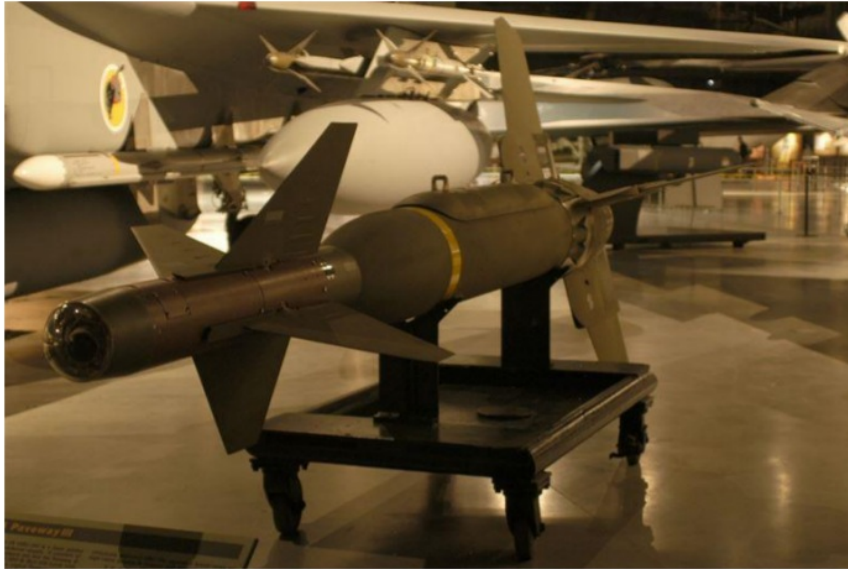


Figure 2 GBU-24 Paveway III aerial bomb

The guidance system could use lasers or GPS. GPS is the most reliable in low visibility and poor weather conditions but more expensive and less accurate than laser systems. A laser system reflects a laser off of a target, the reflection returns in a cone dubbed the “basket”. Sensors in the bomb “look” for the basket and make continuous course corrections to keep the bomb in the basket. GPS systems use pre-loaded coordinates to guide the bomb onto the target.

The main charge of the explosive needs to produce a large amount of energy, rapidly to shatter the casing and propel the fragmentation at high velocities as well as producing a significant blast effect. It also needs to be sensitive enough to be detonated from a suitable booster composition. Mixtures of RDX, TNT and HMX make good main charges as they can have low enough melting points to be melt casted into the shells and produce large amounts of energy.

The casing needs to be made of a dense enough material that the fragments will have a large penetration power such as steel. The whole unit also needs to be light enough to be carried by an aircraft, the thickness of the casing will depend on the target and the requirement ratio for blast effects to fragmentation.

Another important component of the bomb is the fuze which sets off the explosive train after a certain stimulus. There are different options that would be dictated by the target, for

example, an impact fuse with a delay timer would start the chain upon impact with the building and the delay would allow the bomb to reach the centre of the structure before detonating to maximise damage. The impact of falling on the target pushes a firing pin into the detonator material which is shock sensitive to start the explosive train. There are more complicated styles of fuze, but the more complicated the design the more there is to go wrong.

Testing

Each component would need testing individually and then each sub system and system would need to be tested. A series of standard tests undertaken by the British Ministry of Defence (MOD) are undertaken to test new munitions. These tests include temperature and humidity climatic chambers, vibration and shock testing, rough handling tests, drop/bounce/crane swing, altitude and rapid decompression, ingress testing, hot and cold immersion testing, high and low pressure tank test, non-destructive tests and energetic material sectioning [10]. For an aircraft mounted weapon, the altitude, vibration, rapid decompression and pressure tank tests will ensure that the munition is stable through the flight of the aircraft. Other tests such as rough handling, shock testing and ingress testing test that the weapon will survive the day-to-day handling of in-service life. Other tests such as temperature and humidity tests ensure that the munition will be stable throughout storage in different environments.

The LPTA MOD tests are designed around testing the safety of the munition. Other tests are needed to measure the performance of the munition. These can be done initially with modelling and then field trials. Initial field trials of the munition would start with static trials before any full tests where the munition is attached to the aircraft and launched as it would be in service. Once the prototypes have been made and tested, the manufacturing process would also need thorough testing to ensure that the process is safe, fit for purpose and produce articles within the design tolerances.

The likely hazards that the tests may identify would be different at each stage. The safety tests would be looking for hazards such as accidental detonation from shock, heating or heat cycling. A less obvious hazard that the tests would also identify would be if the main charge underwent changes during heating or heat cycling which affected the sensitivity of the detonating charge, booster or main charge.

Post-Procurement

Once the munition had been testing and approved for service, it can be procured by the end user. The end user then needs to follow all the guidance that has been collated from the testing regime. This may refer to lifetime of the munition, not storing it longer than necessary, and the storage conditions such as heat and humidity. Any weaknesses identified in tests like the rough handling test will also have been identified and come with guidance to avoid injury. The user will have to follow all handling guidance such as how to hold and carry the munition, not lifting it above a certain height or moving too fast.

As well as manufacturer guidance there will be legal guidance to follow post procurement such as the joint service publications (JSPs) [11].

Conclusion

When designing a new munition it is important to think of all aspects from design and testing to use, storage and end of use. For example, whilst the munition may be built in one climate it could be used and stored for considerable lengths of time in one or more different climates with extremes of temperature. This would affect different casings and energetic materials differently and some could undergo dangerous changes with regular temperature cycling; reducing hardness or increasing sensitivity. Which could lead to malfunctions or accidental detonations which would endanger life, structures and company reputations.

A holistic systems engineering approach can help design all aspects of a munition and its lifecycle helping to reduce potential problems occurring after the design stage. The most important part of designing a system, however, is its application to the target. However well designed the lifecycle of the system and the interactions with aircraft these will not be of use if the system doesn't meet the required performance. History has shown that innovations and adaptations happen quickly as with the design of new guidance systems for bombs and so modular units such as JDAM that can be fitted to numerous different current and future bombs will be preferred over cheaper or even better performing systems as long as it does meet the requirements and function as required on target.

Customers are unlikely to provide a full list of requirements needed for the design of the system and so it is important to meet those stated as much as possible but also to identify the unspecified, requirements which could affect the service of the munition such as national and international legislation.

Modern developments in a wide number of areas such as in materials science, energetics compositions and electronics means that there are multiple potential solutions for each part of bomb. This makes it even more essential to know exactly what disruption of the target it required so the best options can be chosen and to take a systems engineering approach to ensure which choices will work best together.

A well designed munition, with the confidence of its' users, has the potential to be used for years whilst only undergoing minor changes such as with the JDAM which has been in use since the late 1990s.

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Principles of OME Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

55/100

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JENNIFER
MUNGHAM

55.20

RESEARCH-INFORMED LITERATURE



Good breadth of technical and scientific references but there is a lack of regulatory reference (JSP 428etc)

5.5

KNOWLEDGE AND UNDERSTANDING



"Good understanding of the parts of the system but some of the interactions and consequences of the interaction are missed Equations are given for certain effects but a higher mark would have been achieved if a simple example of the use of each and the relevance to the design was given. What do the symbols actually mean?"

17.7

ANALYSIS



Logical discussion of the functioning of the design but I could do with more detail on the selected design and why it was selected. For example how would, in big handfults, you use the equations you've mentioned to help select and explosive / case combination

18

PRACTICAL APPLICATION AND DEP.

 A good use of standard argument. More systems thinking and design trade off would help immensely

10

SKILLS FOR PROFESSIONAL PRAC.

 Communication is good and of a high standard. The overall report promised such a lot more and I think it missed the brief.

4