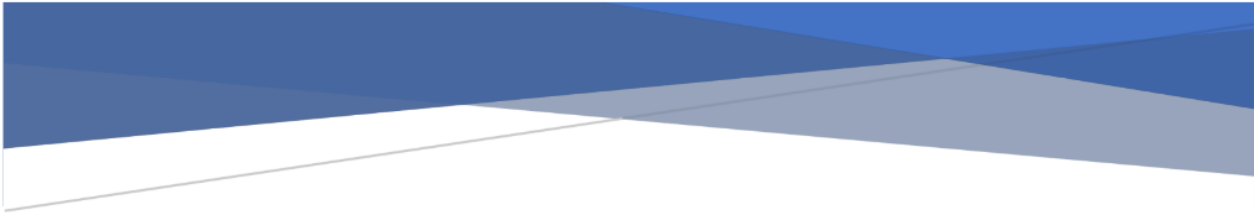


OME Assignment

by Luke Savin

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Principle of OME

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Abstract

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Introduction

During a war, the enemy is continually changing. Be it their tactics or the environment in which they are fighting, the army must have up to date technology and dependable weapons so that they are capable of fighting back the enemy. Because of this, special consideration is required when designing these new weapon systems to ensure that the customer needs are correct and that the system is safe to uses and reliable for the end-user. This report has looked at a new design for a weapon system for the UK military. It takes into consideration the on-going needs and requirements of the customer to ensure that the weapon is suitable and can provide support to the military's current mission. The report describes a testing regime that tests the design functionality and the safety of the new weapon.

Requirements

The customer has requested that the new weapon system the following requirements.

- To be carried and launched from an aircraft,
- To target buildings and structures,
- To be able to guide the missile to the target,
- The missile to have a blast or a fragmentation effect.

When bearing in mind the customer's requirements for the carrier and launcher of the weapon, this report has taken into consideration the current selection of aircraft that is in service and use by the RAF. Upon reviewing over 30 airplanes that the RAF has, this report decided that the idea launch vessel for the new weapon system was the MQ-9A Reaper. The advantage of the MQ-9A Reaper is that it is a drone that requires a remote three-person team to operate, meaning that if it were to be shot down during a mission, there would be no casualties. [1]



Figure 1: RAF MQ-9A Reaper [1]

The MQ-9A Reaper can fly at an altitude of 30,000ft with weapons attached and stay in the air for 14 hours. The drone was designed for primary missions such as Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR), and attack missions. It was used in the assassination strike on General Qassim Suleimani in Iraq by the US and has been used in similar missions, targeting high profile terrorist targets since coming into service. To take on these various operations, the MQ-9A Reaper can be a range of armaments that include GBU-12 laser-guided bombs or AGM-114 Hellfire missiles. The maximum payload of the MQ-9A Reaper is 1,700kg, of which 1,400kg is external, this must be considered when designing the missile so that it does not overload the drone. [2]

When selecting a primary target building, it was researched where the UK currently has troops deployed. At the time of writing this report, the UK has deployments across the world in places like South Sudan, Somalia, and Ukraine. For this new weapon system, it was decided that residential buildings in Iraq for its target [3]. In built-up areas such as places like Baghdad, the houses are two stories and are constructed using materials such as concrete and bricks.



Figure 2: Building in Baghdad [4]

When considering the target, the missile design was required to penetrate concrete and bricks. *'In Iraq, the common structure of the wall is 24cm of brick and an external 2cm cement layer.'* [5]. This was taken into consideration when choosing the type of explosives to create a blast or fragments effect. Another requirement that has to be taken into consideration is the temperature the missile is stored in. With temperatures that can reach above 40°C in Baghdad, it is crucial that the missile is safe for storage and transport.

To guide the weapon onto its target, it shall be using the laser guidance that is already part of the MQ-9A system. The advantage of doing this is that the aircraft does not need to be refitted with new components. The weapon, on the other hand, has a laser detector fitted on the front end. The other disadvantage of this is that the drone needs to have line of sight of the target to be accurate.

The payload for this missile comes in two parts. The first part includes a shaped charge (SC), which is designed to penetrate the roof or outer wall of the building. This can give the missile the capability of being able to pierce any light armour that the building may have. The requirement for the SC to penetrate buildings realises on several design components of the SC. These include the material of the cone, cone angle, diameter, and thickness of the liner.

Once the missile has gone through the outer skin of the building, the second part detonates inside the building. This releases fragments around the room, making it effective against any personnel inside. Careful consideration was taken when deciding the material and the thickness as this can affect the shape and size of the fragments.

Other requirements that need to be considered when designing the new missile system, that has not been stated by the customer include the propulsion method and the control system.

The need for propulsion on the missile is to accelerate the weapon towards the target. For effective propulsion, it has to overcome the resisting forces such as aerodynamic drag and rolling resistance that occurs during the flight. When choosing the propulsion system, several factors must be considered in the design phase. The rate at which the fuel burns, and the weight of the missile itself. These factors will all affect the range of the missile and how far it can travel.

For the weapon to be accurate and hit the desired target, a control system was installed. The control system keeps the missile stable throughout the flight and guides it to the laser mark on the target.

Design

For the missile to function correctly while still meeting the requirements that have been started, the components must be carefully selected. For this report, the following parts were selected as they have the most effect on the requirements.

- Guidance
- Warhead
- Propulsion

For this weapon, it was decided to use the laser targeting system. This was since the MQ-9A Reaper drone already fitted with the targeting system. This saves the cost of refitting new technology to the drone and having to test a new guidance system.

Laser-guided missiles can be incredibly accurate as it can be directed straight to the target, be it a stationary or mobile. For the missile to be guided by the drone, it requires line of sight (LOS). Once the operator has confirmed the target, they illuminate it with a laser from the drone. When the missile is fired, it travels along the beam till it hits the mark. This is also known as Line of Sight Beam Riding (LOSBR). The disadvantage of using a LOS system is that the operator needs to be able to see their target before they can fire. To overcome this, the MQ-9A is fitted with a *'full sensor suite, with targeting, daylight TV, and infrared'* [1]. With the optics that are installed, it makes it possible for the operator to find targets in poor weather conditions or at night.

The design of the warhead contains two parts, making it a Tandem missile system. The first part consists of a shaped charge, and the second includes a fragmentation shell. The effect of this causes the missile to be able to penetrate the walls of the building or light armour using the shaped charge. Once through, the second part of the warhead detonates, causing fragmentation and killing or incapacitating the occupants inside. The advantage of this means that the building keeps the majority of its structural rigidity and any possible high-value intelligence that could be recoverable.

As stated earlier in the report, several requirements need to go into designing the SC for it to function correctly. The depth of the penetration is directly related to the length and density of the jet. For the jet to fully form, the correct stand-off distance is required. The jet can be affected by the material and thickness of the liner and the angle of the cone. These factors can be calculated and worked out through the testing phase.

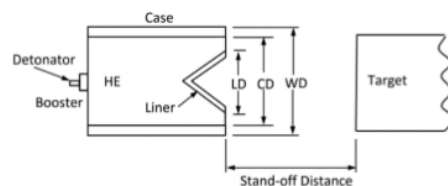


Figure 3: Shaped Charge [6]

The liner of the SC can be made from various materials such as aluminium, steel, or glass. For this warhead, the liner was made of copper. Copper is widely used as a liner in SC as it's cheaper to manufacture than other liners and is well tested. Below is how to calculate the dimensions of the liner and how far it can penetrate.

$$H = \phi \times k_1 \times k_2 \times \sqrt{\frac{\rho_{jet}}{\rho_{target}}} \quad (\text{Eq 1})$$

Where H Depth of penetration (mm)
 ϕ Warhead calibre (mm)
 k_1 Coefficient for jet length (Table 1) (-)
 k_2 Coefficient for target material (Table 2) (-)
 ρ_{jet} Jet density (kg/m³)
 ρ_{target} Target density (kg/m³)

Warhead	Calibre [mm]	k_1
Sub-munition	< 70	8
Hand-held anti-tank weapons	< 110	8/12/16*
Light anti-tank missiles	< 130	12/16**
Heavy anti-tank missiles	< 180	12/16**
Ballistic missiles	< 350	12/16**

* $k_1 = 8$ is used only for older ammunition with a depth of penetration into steel up to 4 diameters, else $k_1 = 12$.
 ** $k_1 = 12$ is used for all munitions, except late versions, with a depth of penetration into steel corresponding to 8 calibres.

Table 1. Coefficient, k_1 , for jet length.

Target material	Density, appr. [kg/m ³]	k_2
Sand, gravel	1600	1.0
Ordinary concrete (C40)	2400	0.8
High-strength concrete (C140)	2500	0.5

Table 2. Coefficient for target material, k_2 .

Figure 4: SC Formula [6]

For the ideal penetration of the jet, a high explosive was required that has a high detonation velocity and pressure. A secondary explosive such as TATB was used as it has properties that make it heat-resistant. To initiate the TATB charge, a booster was used to set off using a proximity fuse. This sets the stand-off distance for the jet to fully form and penetrate the building.

The fragment section of the warhead consists of an outer casing that is pre-scored. Once detonated, the casing breaks apart into fragments along the pre-scoring, which also determine the size of the fragments. To break the casing apart, a mixture of RDX and TNT was used. This mixture was used as it can be cast when manufacturing as it has a low melting temperature. The RDX and TNT mix is initiated with a delayed fused. This gives SC to form and break the outside of the building.

The missile is fitted with a solid rocket motor to propel it to the target. The advantage of using a solid rocket motor is that it is well tested and straightforward in design, which makes them highly reliable. In its design, it is high in density, meaning that even for a small, it can still produce large amounts of thrust. This can also be beneficial if the whole missile design is limited for space. The disadvantage of using solid rocket motors is its difficult to varying the thrust levels. Once it is ignited, the amount of thrust cannot be changed. The ambient temperature can also play a role in the performance of the trust. The choice in propellant must be carefully selected as some may produce dense white smoke exhausts, which has been known to interrupt radio signals or cover the field of vision.

For this type of missile, double-base propellants are commonly used as fuel. In this design, the double base propellant is a mix of Nitrocellulose (NC) and Nitroglycerine (NG). This is because it has been well tested and is highly reliable. When mixed with a plasticiser and stabiliser, it improves its mechanical properties, shock sensitivities, and chemical stability. Another advantage of using NC and NG as the propellant is that when it burns, it is smokeless. When manufacturing the NC and NG for the missile, it is cast into a geometrical tube shape. This shape increases the surface area, which in turn increases

the burn rate. The propellant is initiated using an electrical system, as this is mostly used in other systems.

If the guidance were to fail by the LOS breaking, the missile could hit the wrong building resulting in the deaths of civilians. Or if the explosives did not initiate, then the weapons design and technology could end up in the wrong hands. Both of which can result in damaging the UK's reputation. In the event of design function not working on the missile, a fail or contingency needs to be incorporated into the design. For this, a self-destruct firing system is installed. In the event of the guidance system losing the targeting laser for more than a certain amount of time, then it can trigger the explosives. The explosives will again be detonated if, after launch, the missile hasn't detonated within a specific time. This contingency design should never have to be used if the correct and thorough testing plan is implemented.

Test

To ensure the weapon is fully functional and to identify any shortcomings with the system itself, a test program should be developed to guarantee the quality and safety that can provide reassurance to the customer.

The first initial functionality test is to develop computer models of the individual parts of the warhead, such as the SC and the fragmentation part. With modelling, it can determine the size and thickness of the liner of the SC. Modelling can verify the size of the fragments that are created from the blast and the pre-scored lining. These models can then be proven with live small-scale testing, for example, testing the penetration of the SC or catching the fragments. To test the explosives' performance, several small-scale tests can be developed. One of the vital factors to examine is the detonation speed. It is vital to know the detonation speed for the explosives as it can give the timings for setting off the SC and the delay need for the fragmentation device. These tests include cylinder test or rate sticks, which can also be used to evaluate the wave shape that is created during detonation. The wave shape is required as it can help understand how the jet is formed and the shape and length of the jet. The initiation train was tested to ensure that the fuses and boosters have enough energy to initiate the next explosive chain. The explosives and the propellants are going to be used in areas with high temperatures; this requires a cook-off test to find what is the safe storage temperature. The explosives will undergo aging trails to determine the life of the explosives and how long it can stay out in service before being replaced or disposed of.

The rocket motor was tested to measure the performance of the propellant mix of NC and NG. This was to measure the thrust and power that is produced. This can be used to calculate to measure the distance and range of the missile.

The explosive casing requires x-raying to review the quality of the casting. It necessitates that there no air gaps as it detonates more consistently and at a steady rate.

Before the missile can enter service, environmental tests are required to ensure the weapon is safe for transport/storage and the various conditions and environments it can be used in throughout its lifecycle. These tests are covered by NATO STANAG 4370, which covers '*Allied Environmental Conditions and Test Publications (AECTP) which give guidelines on the management of environmental testing of defence materiel, to characterise environments and to standardise environmental testing processes.*' [7] These tests include.

- AECTP 100 - Environmental Guidelines for Defence Materiel
 - Provides guidance on the management of the total environmental engineering task for materiel development projects.
- AECTP 200 Environmental Conditions
 - guidance on climatic, mechanical and electrical environments that are induced in materiel during its life cycle.
- AECTP 300 - Climatic Environmental Tests

- provides a series of climatic test methods for use during the design, development and qualification of materiel.
- AECTP 400 - Mechanical Environmental Tests
 - provides a series of mechanical test methods for use during the design, development and qualification of materiel.
- AECTP-500 - Electrical/Electromagnetic Environmental Tests
 - provides a series of electrical test methods for use during the design, development and qualification of materiel. [8]

Once each component of the missile has been thoroughly tested, a full-scale test of the whole weapons test can be undertaken at a range. This tests the functionality of the whole system and how each component works and interacts with the other components. The range test also allows testing and evaluating of the targeting system.

Conclusion

This report has gone through in detail the requirements, design, and testing for a new missile system. The requirements were for a defined aircraft to launch a guided missile with a blast or fragmentation effect, targeting a specific building.

The MQ-9A Reaper was chosen to launch the missile as it carries advanced technology, making it able to carry out a variety of missions. It also has the advantage of; if one were to be shot down, there would be no casualties. To guide the missile to the target, the decision to use laser optics was that the MQ-9A Reaper already had it fitted. It also has the advantage of being able to guide the missile by someone on the ground. It was decided that a residential building in Iraq would be used as the target building. It was selected because the UK currently has troops deployed there. It was decided that the missile's warhead shall carry an SC and fragmentation casing as the shaped charge would penetrate the building, and then the fragmentation would detonate inside. This effect would cause casualties but leaving the building intact.

With these requirements, a design was purposed along with a test program to guarantee the functionality, safety, and quality of the missile system to ensure the customer's satisfaction with the final product.

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OME Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: SMU GENERIC_GJ

LUKE SAVIN

62.20

RESEARCH-INFORMED LITERATURE

-  A good range of technical publications is cited. Perhaps JSP 428 missing from the regulatory perspective?

5.9

KNOWLEDGE AND UNDERSTANDING

-  "Knowledge is accurate with a good understanding of the field of study. There is a good description of the tandem warhead concept though a schematic or diagram, however conceptual would be useful."

17.7

ANALYSIS

-  "Sound, logical, analytical thinking; synthesis and evaluation. Justification of launch vehicle and guidance system sound. Selection of explosive not ""IM"" this is subject matter not yet disseminated on the course. Use of modelling for the preliminary assessment of the design is proposed"

20.1

PRACTICAL APPLICATION AND DEP.

-  A good and appropriate application of standard methods, materials, tools and/or techniques.

11.6

SKILLS FOR PROFESSIONAL PRAC.



Can communicate well, confidently and consistently in a suitable format.

6.9