2006 Insensitive Munitions & Energetic Materials Technology Symposium (24-28 April 2006)

Poster session: Modelling & Testing

J Stubberfield[1], M Cook[1], D Harrison[2], G Evans[2], P Cheese[3]

[1] QinetiQ, Fort Halstead, Sevenoaks, Kent. TN14 7BP
[2] QinetiQ, Shoeburyness, Southend-on-Sea, SS3 9SR
[3] Defence Ordnance Safety Group, Defence Procurement Agency, Bristol, BS34 8JH

High Velocity Gun Launched Fragment Impact Studies

Abstract (reference 3375)

This paper will report the development and testing of high velocity powder gun systems that will be used to launch fragments against energetic materials and munitions. To meet the requirements of STANAG 4496, a 14mm diameter, conical nosed, Fragment Simulating Projectile (FSP) is required to have an impact velocity of 2530m/s +/-90m/s. In order to meet this requirement the boundaries of gun design are taken to the limits of what is achievable with powder gun systems. The reason the powder gun route is taken is due to the rapid turn around time, required for cost effective parametric studies to be undertaken. When FSP retardation is taken into consideration, the gun muzzle exit velocity is required to be considerably greater than this figure and this means that the gun system design must be capable of withstanding the inherent high peak chamber pressures.

One difficulty which arises when launching FSP's of this type, is the safe muzzle to target distance that would be required when larger explosive filled munitions are tested for insensitive munition (IM) compliance. This consideration is more evident when the explosive filled munition is of a sufficient size that would threaten the survivability of the gun system, should high order detonation be observed. A second consideration is that of the intermediate flight characteristics of the FSP, not only does it have to impact the munition in an acceptable orientation but it needs to be accurate. Sabot design is one of the most important factors controlling the delivery of the FSP to its intended target, not only does it have to survive the in bore gun accelerations, it has to release the fragment at muzzle exit without influencing the in-flight orientation.

The gun systems will be used for testing explosive filled munitions to demonstrate IM compliance, but the requirement is not limited to IM. Beyond STANAG 4496, weapon response to larger fragments in specific threat environments must be demonstrated. For example, the UK Generic Naval Environment considers fragments including a 30mm diameter 200g cylinder. The gun systems described here will be used to launch this fragment for studies relating to ship survivability and magazine design.

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

Introduction

During the last two years QinetiQ has undertaken a study to design, build, test and use a high velocity gun system that would meet the high velocity requirements of RATIFICATION 1- STANAG 4496 (EDITION 1) [1] for a conical nosed FSP. Two options were assessed, the gas gun approach and the more difficult, powder gun approach. The gas gun approach is more suited to the laboratory environment and does not offer the easily transportable solution for both large and small scale parametric studies. Therefore, the powder gun approach was considered the most suitable solution from the two options. However, this option does come with its own inherent difficulties.

The initial stage of the study was to examine off-the-shelf proprietary gun systems that are currently available that could be used and would be capable of achieving the high velocity requirement. The outcome from this first stage revealed that no single gun system could be purchased off-the-shelf to meet the exacting requirements. These initial findings meant that a special-to-type gun system would need to be designed, built and tested to meet the requirement. This paper reports the gun systems and some experiments which take into consideration the gun design, sabot design, interior, intermediate and terminal ballistics of the FSP to its intended target.

Gun Systems and Design

Before consideration could be given to any one particular gun design, interior ballistic modelling was undertaken to understand the design parameters that would be required. Operational peak chamber pressures need to be limited to ensure that the gun design is capable of surviving use over a limited, but cost effective period of time. Consideration needs to be given to the required in-bore shot travel and overall payload in order to accelerate the sabot and FSP and use this efficiently in the system. At the same time FSP muzzle velocity, retardation and terminal velocity are also important considerations. In order to meet the at impact high velocity requirement, the FSP must exit from the muzzle considerably higher than it's at impact terminal velocity. Once these parameters are understood the mechanical design parameters of the gun system can be undertaken.

If the FSP is spin stabilised then it is likely that accuracy of the FSP at impact is improved, however, this does place more emphasis on the in-bore stress loading of the sabot design. If the FSP is not spun, then this places more emphasis on the capability of the sabot to release the FSP without influencing it's in flight orientation. This is vitally important as the FSP must remain in a good orientation whilst in flight over the given distance and just before impact. There is no fin or flare on the rear of the FSP to correct such errors. Both pitch and yaw at FSP impact will always be a difficult problem to overcome, with projectiles that have not been designed to be aerodynamic. However, two gun systems are shown at figures 1 and 2 and both systems have been used to achieve good impact conditions for the FSP. In both cases the high velocity requirements have been met in accordance with STANAG 4496 (2530m/s +/- 90m/s).

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

Figure 1: 40mm calibre, 10 m long high velocity gun system

Figure 2: 40mm calibre, 6.6m long high velocity gun system

An alternative test with a lower stimulus level is also defined in STANAG 4496 which specifies a lower impact velocity (1830m/s +/- 60m/s). This particular test is somewhat easier to achieve and the gun used does not require the very specific design parameters that are required for the high velocity gun systems. Figure 3 shows a smaller 30mm calibre gun system, which can be used to achieve the alternative lower velocity. However, the same approach regarding FSP muzzle velocity, retardation and terminal velocity still need to be considered. Additionally, the smaller 30mm systems are inherently weaker from a design and peak chamber pressure perspective

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

and consequently have limitations on how far the boundaries of their inherent design can be pushed. The advantage of the smaller calibre compared to the two high velocity guns, is the operational cost and they are relatively cheap to replace when worn, or when damaged. They are also more easily used with commercially available propellants.

Figure 3: 30mm calibre, alternative lower velocity gun system

Sabot and Charge design

Sabot design is one of the most important factors controlling the delivery of the FSP to its intended target, as are the mechanical properties of the material selected. The sabot must withstand the in bore accelerations and seal the gun barrel bore, with adequate obturation. If desired, it must also spin the FSP and then in both cases release the FSP at muzzle exit without influencing the in-flight and at impact orientations. The sabot is in effect no more than a delivery tool, which is parasitic mass and must be stripped away preventing impact with the filled explosive munition being tested. Thus, there are significant benefits in having sabots manufactured from the lightest and strongest materials. Less parasitic mass means an increase in overall system velocity with the benefit of lower shot start pressures. The sabot design must also consider FSP set back, at the highest in-bore accelerations, as this also appears to have significant influence on the resultant launch dynamics. Figure 4 shows the assembled ammunition, complete with sabot and FSP for the high velocity requirement.

The charge design must consider the detailed specifics and ignition of the propellant and be capable of functioning in a very efficient manner to be able to accelerate the FSP to the higher velocity. In addition, the propellant chosen, must be available in quantities that are cost effective and must be matched exactly to the specific requirement. If not the resultant consequences can lead to the over- pressuring of the gun system and then catastrophic failure.

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

FSP's and their associated design

The STANG 4496 FSP design is a steel right cylinder, with a diameter of 14.3 mm with a conical front end, at an included angle of 160º. It has a mass of 18.6 grams and has a length to diameter (L/D) ratio of >1. This is for stability reasons and anything less is likely to be unstable.

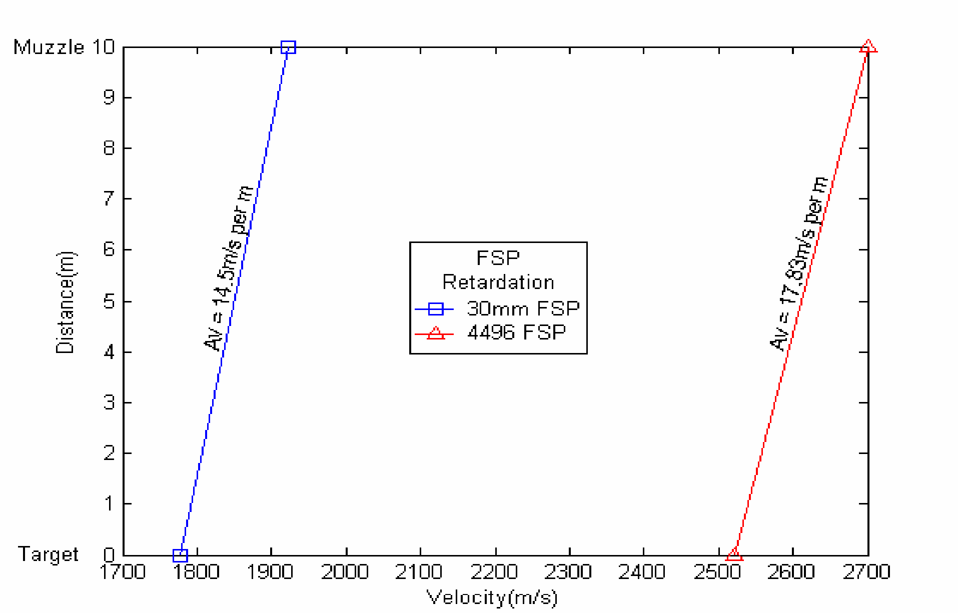
In specific threat environments such as those considered by the UK Generic Naval Environment, the STANAG 4496 FSP is not considered to be fully representative. A larger 30mm diameter FSP, which has a mass of 200 grams is considered, and is to be used to assess ship survivability and magazine design. In order to design the larger diameter FSP, comparisons were drawn from the STANAG 2920 (Edition 2) [2] which defines the BALLISTIC TEST METHOD FOR PERSONAL ARMOUR MATERIALS AND COMBAT CLOTHING. In particular one design of FSP stated in STANAG 2920, is 20mm in diameter with a chisel shaped front on the nose of the FSP and is designed to be fired from a 20mm calibre gun. A similar application was considered for the larger Naval Environment 30mm FSP. This has led to a new design for a 30mm FSP with a mass of 100 grams which has now been tested and used for IM studies. This has an L/D ratio of 1, and is again a right cylinder but has a flat front face. This is capable of being launched to achieve impact velocities of ~1800m/s from the 30mm gun system and is a stop gap solution. Although the requirement considered by the UK Generic Naval Environment is slightly higher than this velocity, further work is likely to be undertaken in due course with a 200 gram 30mm FSP. This will see the higher velocities achieved with the larger 40mm gun systems. Figure 5 shows the cartridge case and 30mm FSP design.

Figure 4: Assembled STANAG 4496 ammunition

Figure 5: 30mm FSP and case

In flight retardation for the FSP

In order to achieve the desired impact velocity, the muzzle velocity needs to be considerably greater to take into consideration the retardation of the FSP over a given distance. The averaged retardation from a number of fired rounds is plotted for both the STANAG 4496 FSP and the 30mm Naval environment FSP in Graph 1. It can be seen that the two FSP's retard at 14.5m/s and 17.8m/s per meter of flight travel. It can also be seen how high the initial muzzle velocity needs to be, when the muzzle to target distance is set at only 10m (2700m/s for the 4496 FSP). When testing larger explosive filled munitions for IM compliance, the safe muzzle to target distance is an important consideration. Especially when the explosive filled store is of sufficient size to threaten the survivability of the gun system should a high order event be observed. This therefore dictates the requirement to build protective walls in and around the gun system, as can be seen in Figure 1.



Graph 1: Retardation over a given muzzle to target distance of 10m

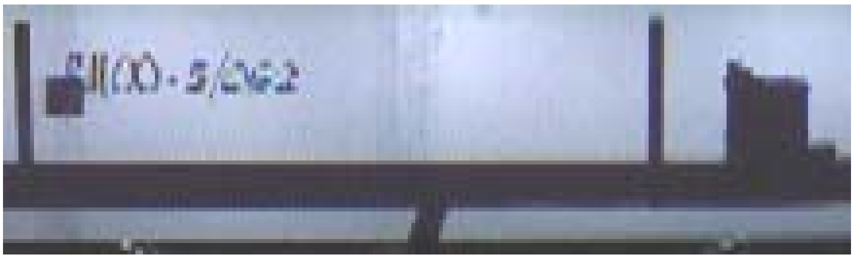
Instrumentation and observed impact velocity

In order to have confidence that the FSP impact velocity meets the specific requirements, a number of instrumentation methods can be used. Copper etched make foils linked to counter timers are often used, but with flat fronted and shallow conical nosed FSP's the results given are sometimes open to interpretation and confirmation is often required by other methods. High speed ballistic range cameras are also used successfully to observe sabot exit conditions and muzzle and impact velocities. However, there are limitations with the time frame intervals, and to the number of frames that can be observed.

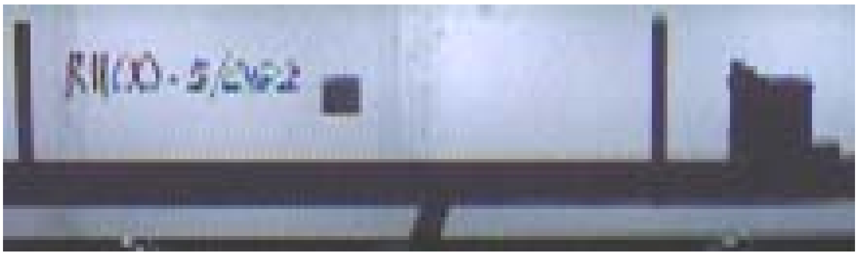
Without question the best method of observing the relevant criteria, is by use of a high speed cine records, such as those that can be achieved with the Photosonic's Phantom 7 camera system. This system has the advantage that its specific image definition can identify the exact detonation criteria. The four frames shown in figure 6 show the results from small scale experiments that are used to assess the detonation criteria for the larger scale experiments. It can be observed that the explosive compound on the right hand side has been subjected to a prompt shock and its detonation type is a shock to detonation transition (SDT) which can be ranked accordingly. The

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

four individual frames have been extracted from a complete cine record. The time interval between the 3rd and 4th frame is no more than 20µs between the FSP at impact with the explosive target at the 3rd frame, to the observed SDT condition in the 4th frame.

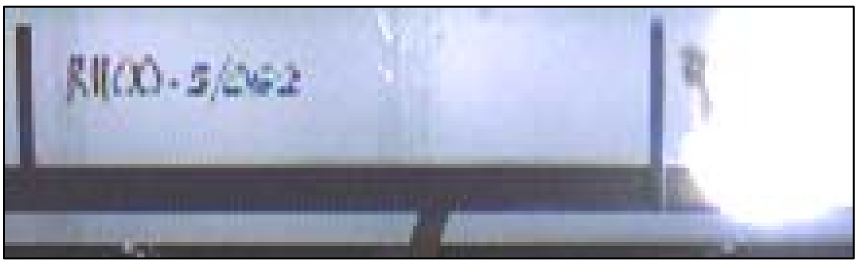


1st Frame



2nd Frame

3rd Frame



4th Frame

Figure 6: Individual frames from Phantom camera cine records

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

The first powder gun, high velocity STANAG 4496 test to be conducted

Several tests have now been conducted which have met the exacting requirements of STANAG 4496 at the high velocity. The first all up weapon test was conducted by QinetiQ at the Shoeburyness test site using the longer 10m long 40mm calibre gun system. The second test has more recently used the slightly shorter 6.6m long 40mm calibre gun system. Figure 7 shows the first test for the Raytheon Precision Guided Bomb (PGB) just prior to the firing.

After the FSP impact at a velocity of 2533m/s, the PGB reached the point where it torched and vented violently through the FSP impact hole, but remained IM compliant. After waiting several hours for the cooling off period, the photograph at Figure 8 was taken to show the final result.

Figure 7: Raytheon Precision Guided Bomb prior to the high velocity STANAG 4496 test

Figure 8: Raytheon Precision Guided bomb after a cooling off period showing IM compliance from the high velocity STANAG 4496 test.

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com

CONCLUSIONS

Special-to-type transportable powder gun systems have now been designed, built, tested and proven, which can meet the exacting high velocity requirements of STANAG 4496. Smaller calibre gun systems are available which can meet the alternative lower velocity requirements of STANAG 4496.

Launch packages and ballistic solutions have been designed, developed, tested and proven which can meet the high velocity and alternative lower velocity requirements of STANAG 4496.

FSP's can impact their intended targets at 2530m/s and 1830m/s in a perfect orientation over given muzzle to target distances allowing for known acceptable retardation values.

It is concluded that the boundaries of useable and transportable powder-gun design has been pushed to a new level. This has meant that small scale experiments can now be conducted in appropriate environments to validate predictive ignition and growth models and obtain experimental detonation criteria at the higher velocities. Large scale experiments can now be conducted which will provide unequivocal evidence for explosive filled munitions to demonstrate IM compliance in accordance with STANAG 4496.

REFERENCES

1. Ratification Draft 1-STANAG 4496 (Edition 1) Fragment Impact, Munitions Test Procedure.

2. STANAG 2920 (Edition 2) Ballistic Test Method for Personal Armour Materials and Combat Clothing.

John Stubberfield, QinetiQ, Email jstubberfiel@qinetiq.com