The Development of Launch Methods for High Velocity Fragment Simulating Projectiles

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This paper describes the development of small-scale high velocity fragment launch methods which might be used to reproduce the effect of EFP-IED warheads. Two methods are described, both are capable of accurately delivering 50cal Fragment Simulating Projectile (FSP) to velocities in excess of 1500ms^{-1}. The first method uses an explosive launcher to accelerate the projectile whilst the second method launches the saboted projectile from a gun. The explosive launch method allows relatively easy scale up to larger projectile sizes, and was capable of attaining a muzzle velocity of 1718ms^{-1} in the current series of tests. The gun launched method proved to be particularly controllable with respect to velocity (up to a maximum of 1832ms^{-1}) but is more difficult to scale up.

INTRODUCTION

The explosively formed projectile (EFP) warhead has become a major threat to land forces particularly in asymmetric and counter insurgency operations. . In order to fully protect against this threat there is currently great interest in launching fragments at a high velocity in order to investigate the target effects. The terminal ballistics of EFPs can be investigated by using full scale surrogate warheads but this results in relatively large scale and complex trials. Therefore the current work aimed to provide a means to recreate the terminal effects of individual EFPs or fragments of EFP in a controlled manner.

The current NATO reference used to evaluate threat level protections for light armoured vehicles, STANAG 4569 [1], states that "any launching device may be used provided it is capable of consistently and reproducibly propelling test projectiles at the required aiming point with an acceptable accuracy, impact velocity and angle of impact yaw". In view of this requirement it was decided that the work would investigate the feasibility of delivering a small fragment with a view to scaling the work up if successful. It was decided to accelerate a standard 50cal FSP by two separate methods; explosively launched and gun launched

EXPERIMENTAL

The Projectile

The chosen projectile for this small-scale experimental project is a 50cal FSP. This is a standard test projectile [2] that is manufactured from cold rolled, annealed steel. The finished FSP must weigh between 13.26g and 13.52g and have a hardness of 29-31 HRC. The weight, length and diameter of each FSP was accurately recorded prior to launching.

Explosive Launch

The explosive launcher may be approximated to a by a thick layer of explosive behind ametal plate (the FSP). When the launcher is thought of in these terms it approximates to an open faced sandwich.   Equation1, from Walter *et al* [3] was used as to determine the approximate explosive quantity as shown in figure 1.

$$Velocity = \sqrt{2E}\left[\frac{\left(1+2\frac{M}{C}\right)^3+1}{6\left(1+\frac{M}{C}\right)}+\frac{M}{C}\right]^{-\frac{1}{2}} \qquad (1)$$

Where
M   = Mass of metal or fragment (i.e. the FSP)
C   = Mass of explosive
$\sqrt{2E}$ = Gurney constant for explosive

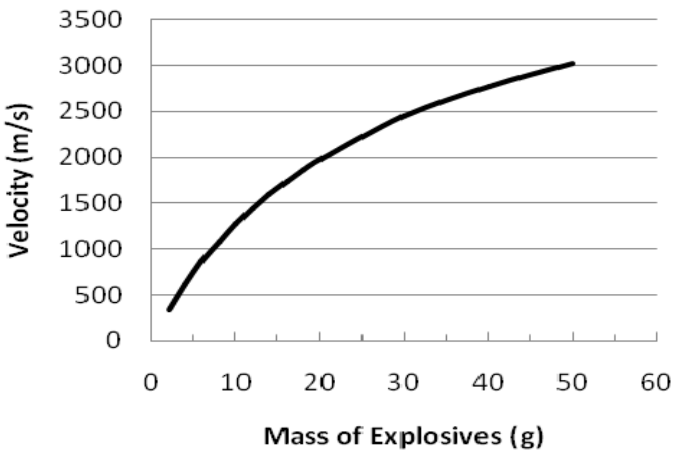


Fig 1 Calculated launch velocity of a 50cal FSP as a function of the mass of PE4 explosive used according to equation 1.

Choice of Explosives

The chosen explosive was PE4 which has density of 1600kgm^{-3} and a velocity of detonation (VoD) of 8210ms^{-1}.   However, it was noted that PE4 was "developed to produce an explosive shattering effect" [4]. With this in mind it was envisaged that PE4 may damage or shatter the FSP during detonation.   Wenzel *et al* [5] recommended placing an "inert material" between the explosive and projectile in order to decouple the shock wave. Therefore a shim was designed to fit inside the launcher, three sizes of shim were manufactured from PVC; 2, 4 and 6mm thick. The experiments were repeated with a second RDX based explosive with comparable VoD and density but a lower brisance. A sheet explosive, Demex 200, was found to contain the same percentage of RDX (88%) and a slightly lower VoD of 7850 ms^{-1}.

Explosive launcher design

For ease of handling and in order to provide a means to control the launch direction it is convenient to contain the explosive and the projectile within a lightweight tube. Saburi *et al* [6] describe such a devise, and it was concluded that an aluminium tube provided good results whereas a poly methyl methacrylate launcher failed to launch the projectile in a stable manner. In the current work the tube was manufactured from commercial off the shelf ¾OD x 16swg 6063 aluminium alloy tube. An internal diameter of 15.7mm would allow the FSP, with a widest diameter of approximately 13mm, to be centrally retained prior to detonation. Figure 2 shows the components of this launcher and figure 3 a diagram of the assembled system.

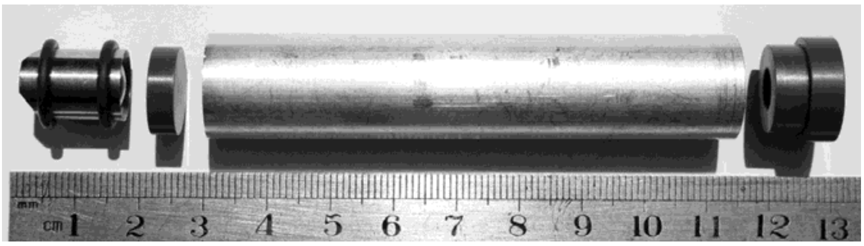


Fig 2 Disassembled components of the explosive launcher

The design of Saburi *et al* [6], was used in which rubber o-rings are used to secure the projectile prior to launch. In the present work a pair of o-rings where used.to align and securely retain the FSP.

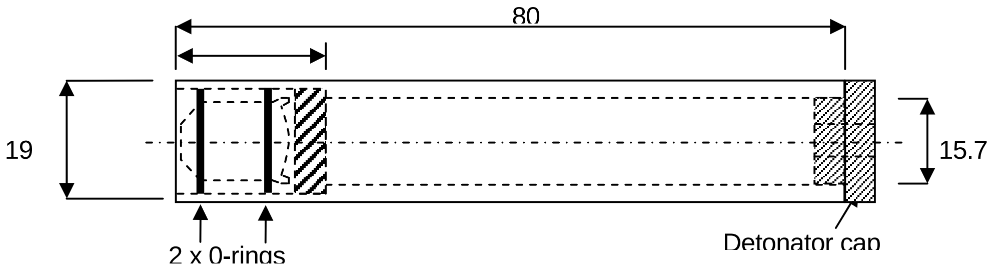


Fig 3 Explosive launcher general layout, (dimensions in mm).

The experimental setup can be seen in greater detail at fig 4. The launcher is positioned on a 200mm length of tube with polystyrene blocks and timing foils at each end. Velocity was recorded by the timing screens and the projectiles where soft captured in a witness pack 900mm below the lower foil.

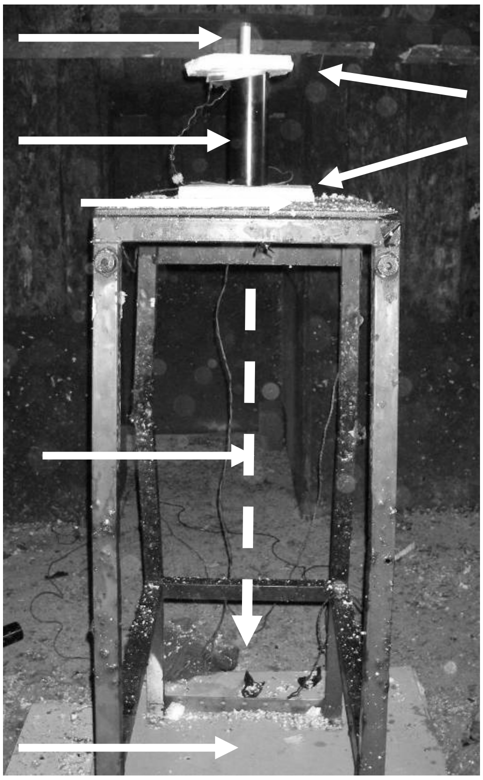


Fig 4 General layout of the explosive launch method.

Gun Launch

When a 50cal FSP is fired from a 50cal barrel the maximum velocity is primarily restricted by the amount of propellant that can physically fit in the cartridge case. The average muzzle velocity for a fixed Browning 50cal projectile is 890ms^{-1} [7]. Initial trials showed that a maximum muzzle velocity of approximately 1100 ms^{-1} could be achieved. By changing to a 20mm gun and cartridge case the propellant mass can be increased from approximately 17g to more than 60g. A sabot is then required to launch the 50cal FSP from the 20mm gun and the sabot design was further investigated

Sabot Design 1 – ‘Pot and slot’

Sabot 1 is based on a tried and tested ‘pot and slot’ design that is currently used for smaller FSPs and similar to that used by Dooley *et al* [8] to launch small Tungsten fragments. The design is based upon, and scaled up from, an existing sabot used for the 1.1g FSP and is also similar to that within MIL-DTL-46593B [2]. Mechanical failure within the barrel is to be avoided and would result in poor forward obturation, low velocity and poor accuracy [9]. In order to overcome this eventuality the design included a choice of 3mm pusher plates manufactured from steel or aluminium.

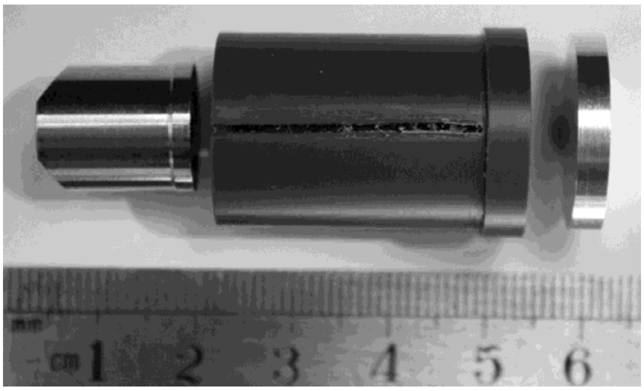


Fig 5 Sabot design 1, pot and slot.

Sabot Design 2 – 'PVC Pot'

The second design is manufactured from PVC, is shorter than sabot 1 and is designed such that the entire length of the sabot will engage the rifling of the barrel. Compression of the PVC sabot along the entire length should force the sabot and FSP together throughout the length of the barrel and aid with the angular acceleration of the FSP. As with sabot 1, this design may be used with a 3mm pusher plate if required. An angle of approximately 45° is cut into the forward wall to aid sabot separation from the FSP.

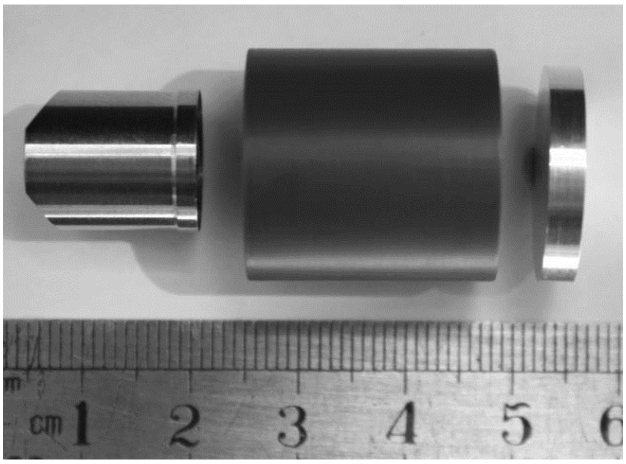


Fig 6 Sabot design 2, PVC pot.

Sabot Design 3 – 'Aluminium Pot'

This design is very similar to sabot 2 but is manufactured from a aluminium 6082 T6 which is significantly stronger than the PVC. The external diameter is reduced to ensure that the frictional forces involved when engaging the rifling are not excessive and therefore detract from the final muzzle velocity. As the entire sabot is manufactured from aluminium it was not envisaged that it would require a pusher plate. The thickness of sabot's rear wall has also be reduced compared to the PVC.

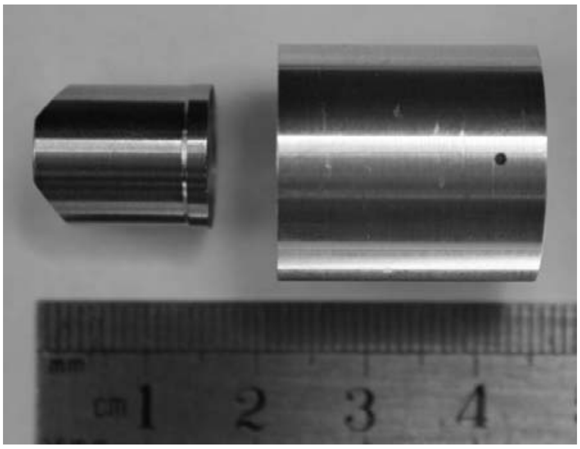


Fig 7 Sabot design 3, aluminium pot.

Sabot Design 4 – 'Short PVC Pot'

This design is a shortened version of sabot 2 including a chamfer in the forward facing wall and an optional pusher plate.

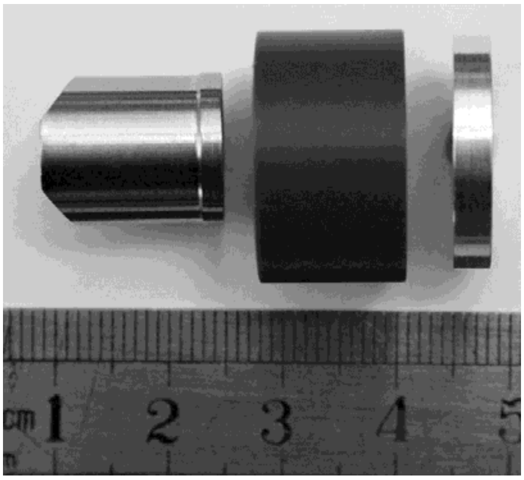


Fig 8 Sabot design 4, short PVC pot.

RESULTS

Explosive Launch Method

Initial firings contained the maximum amount of Demex 200 (17.3g) and the size of PVC shim was varied. As can be seen in figure 9 the velocity of the FSP deceases in a linear fashion as the depth of PVC shim is increased. The second (grey) trace is a measure of the mass of FSP lost during the explosive launching process. In order to ascertain the optimum depth of PVC shim to be used, it was necessary to find an acceptable medium between maximum velocity and minimal mass lost following launch. Form figure 9 and table 1 it is apparent that a 2mm PVC shim would maximise both the velocity and final mass of the FSP when launched by Demex 200.

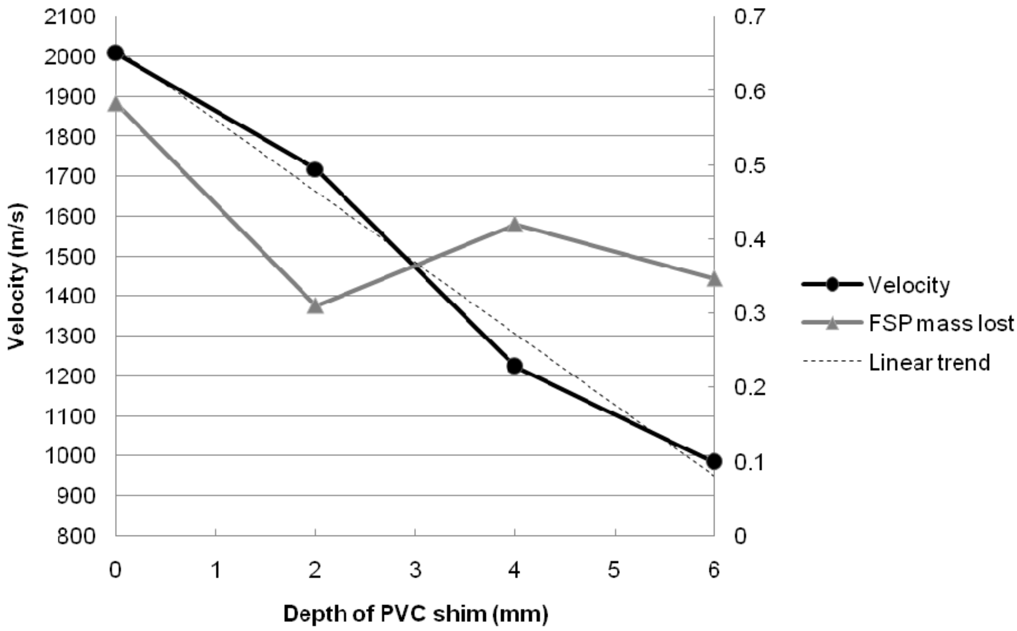
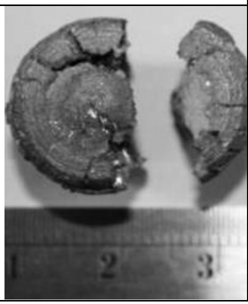
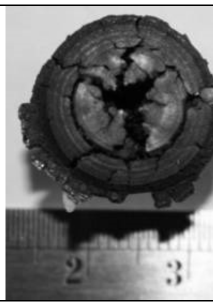


Fig 9 Velocity and mass loss as a function of shim thickness for Demex 200 explosive launch.

TABLE 1 APPEARANCE OF SOFT CAPTURED FSPs AS A FUNCTION OF SHIM THICKNESS FOR THE DEMEX 200 EXPLOSIVE LAUNCH.

Shim depth (mm)	**0**	**2**	**4**	**6**
Demex 200				

The same method was repeated for PE4 explosive and results are shown in figure 10 where it can be seen that the optimum depth of shim was found to be 4mm. It should be noted that the mass loss scale in this figure is 20 times that shown in figure 9. Using PE4 explosive the two larger charge weight firings caused the FSP to lose at least 8g, equating to approximately 60% of its mass. Table 2 shows the appearance of the recovered FSPs and it can be seen that PE4 causes extensive damage at higher charge weights.

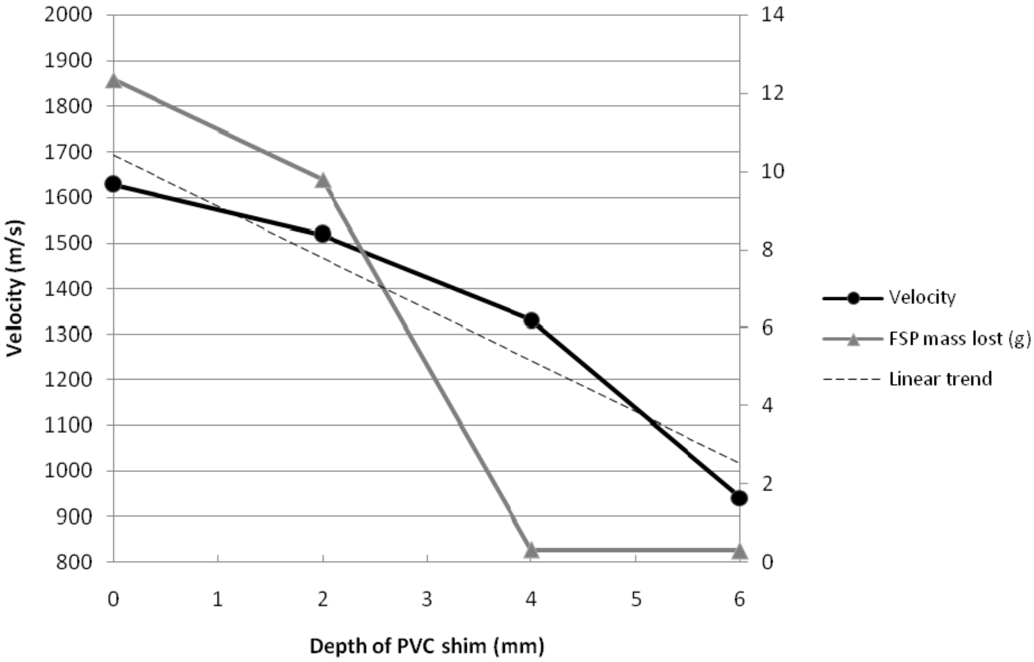
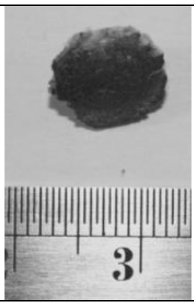


Fig 10 Velocity and mass loss as a function of shim thickness for Demex PE4 explosive launched FSP.

TABLE 2. APPEARANCE OF SOFT CAPTURED FSPs AS A FUNCTION OF SHIM THICKNESS FOR PE4 EXPLOSIVE LAUNCH.

Shim Depth (mm)	**0**	**2**	**4**	**6**
PE4				

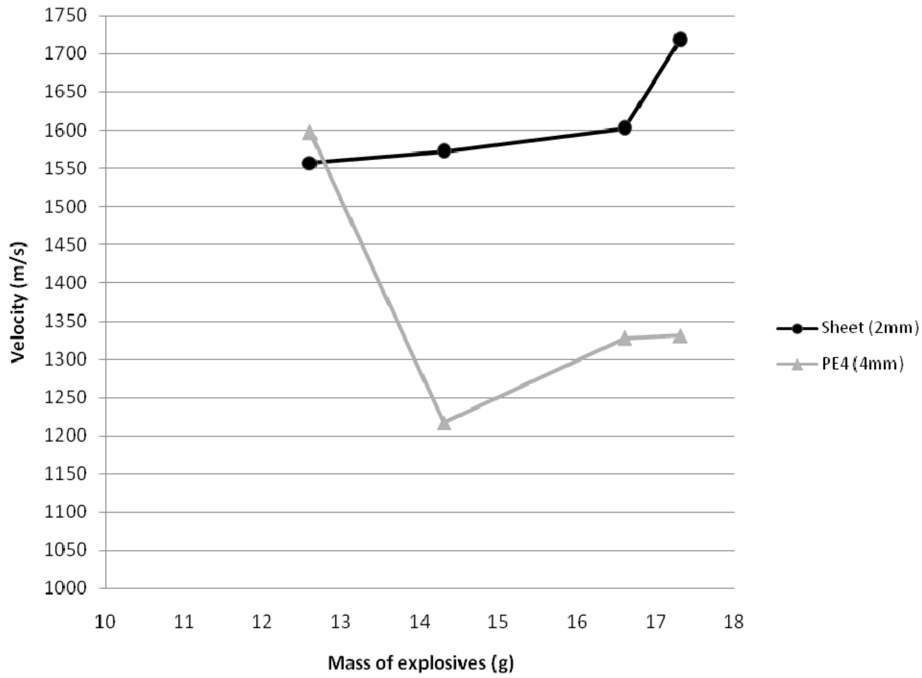


Fig 11 FSP velocity as a function of explosive mass, note that the 1600ms^{-1} result for PE4 is probably not the main fragment and should be discounted.

Once the optimum depth of PVC shim was identified for each explosive main charge, a further 3 firings were conducted with varying amounts of explosive. The results are presented graphically at Fig 11. The maximum velocity, attained using 17.3g of Demex, was 1718ms^{-1}.

Gun Launch Method

From the high-speed video it was evident that the PVC sabots were completely stripped from the FSP and that the FSP was not tumbling upon impact. Following each firing the range was checked for sabot remnants which were recovered and analysed.

Sabot 1 – 'Pot and slot'

From the high speed video evidence it was apparent that sabot 1 was imparting sufficient spin on the FSP to ensure the projectile did not tumble in flight. Following examination of the markings on recovered bits of PVC sabot it was evident that only the rear 4mm of the sabot was engraving the rifling as designed.

Sabot 2 – 'PVC Pot'

As with sabot 1 the high speed video confirmed that an FSP launched in sabot 2 arrived at the target without the sabot and without tumbling. Recovered parts of the sabot indicated that the entire length of the PVC sabot was engaging the rifling.

Sabot 3 – 'Aluminium Pot'

Although sabot 3 was not recorded using high speed video it was clearly evident from analysis of the target and the Doppler radar trace that this sabot type did not strip from the FSP in any firing.

Sabot 4 – 'Short PVC Pot'

Analysis of the Doppler radar plot showed very similar traces to sabots 1 and 2 indicating that sabot 4 separated both early and easily from the projectile. Despite recording the highest velocity of all sabots this particular design proved to be the most difficult to load. As the sabot did not fully enclose the front end of the FSP the centre of gravity was toward the front section. This caused the saboted round to topple forward and caused the FSP to catch during loading. As with sabot 2, recovered broken parts of PVC confirmed that the entire length of the sabot was engaging the rifling of the barrel.

Four FSPs were launched with a full cartridge containing 60g of single base gun propellant. Despite the propellant having a relatively high energy content of $3650 Jg^{-1}$ [10] the average velocity for a 'full charge' shot was only $1777 ms^{-1}$. It is considered unlikely that a 50cal FSP can be launched from a 20mm cannon using conventional single base solid gun propellant at over $2000 ms^{-1}$. If velocities in excess of this are required it is recommended that double base, triple base or even high energy Nitramine propellants will have to be employed.

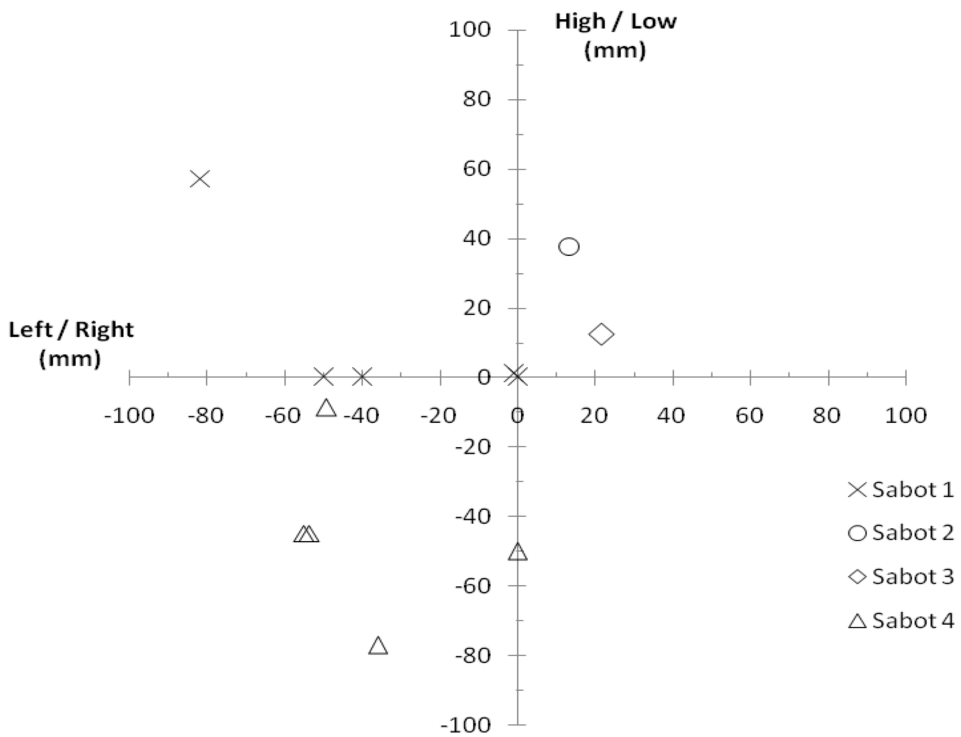


Fig 12 All velocity data for PVC sabots as a function of propellant mass.

As can be seen in figure12, the most accurate sabot, with respect to aim, is the pot and slot (sabot 1) with 2 of the 5 shots scoring a direct hit. Due to the superior accuracy sabot 1 is considered to be the best performer.

Some firings used 3mm pusher plates but these resulted in miss distances of more than 200mm at 10m range. The pusher plates were manually centred and attached to the back of the sabot. It is believed that misalignment of the plate could have caused centrifugal anomalies in the bore or during sabot separation which may have translated in an unstable flight. Review of the high speed video for one of these firings clearly showed that the FSP struck the target at an angle and the resulting witness hole is elliptical in shape indicating that the projectile had excessive yaw. No sabots broke up in the barrel during these firings so it can be concluded that for the conditions used here pusher plates are not required.

CONCLUSIONS

There remains a requirement, and much academic interest, in the launching of larger projectiles and/or fragments at velocities in excess of 1500ms^{-1}. This work has demonstrated two methods of projectile launch which may be used to simulate EFP-IED warhead fragments on a small scale. Fragments may be delivered at impact velocities in excess of 1500ms^{-1} with minimal yaw, good velocity control and accurate placement using two different methods; explosive launched and gun launch.

Explosively Launched Method

The following conclusions can be drawn from the design and experimental trials using the explosive launcher to accelerate the FSP.

A maximum of 1718ms^{-1} was achieved via the explosive launching method using Demex 200 explosive.

Analysis of the witness pack indicated that some of the explosively launched projectiles may have had a small component of yaw. In order to ensure normal impacts the distance between explosive launcher and target must be kept to a minimum.

The velocity of the projectile can be decreased or increased by adjusting the charge mass.

It is necessary to decouple the shock wave from the projectile in order to ensure the projectile is accelerated whole.

Gun Launched Method

The following conclusions can be drawn from the sabot design and experimental firings using the 20mm rifled barrel to accelerate the FSP;

Three different sabots were designed and proven to successfully and repeatedly launch a 50cal FSP in excess of 1500ms^{-1}.

Review of high speed video and analysis of targets/recovered FSPs indicate that the gun launch method produced minimal yaw.

The gun launched method can produce reasonable accuracy at a distance of 10m and displayed repeatable results.

Sabot design 1 is considered to have performed the best with good ease of loading, high velocities and the best accuracy.

It is considered very unlikely that a 50cal FSP can be launched from a 20mm canon at speeds in excess of 2000ms^{-1} using conventional single base gun propellant.

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