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THE DYNAMIC MODELLING OF A NOVEL DESIGN OF 120mm APFSDS TRAINING ROUND

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A novel design for a low cost, high volume production, APFSDS training round has been proposed for use in 120mm tank gun systems. The design of this round is unusual because of the method of support between the penetrator and the sabot, and also in the way in which the forces are transmitted to the penetrator in order to accelerate it up the bore. This has meant that the standard gun dynamics model has required modifying in order to produce meaningful simulations. This paper describes the design concept and the way in which an existing gun dynamics simulation package has been used to model the round in order to optimise its design parameters. The results from these simulations have been successfully used to assist the design iterations during development, and achieve the project requirements.

INTRODUCTION

It is now accepted that the design or modification of new or existing gun systems will benefit considerably from a full dynamic analysis of the firing and launch process. This analysis should include the behaviour of the barrel, the mounting, and the shot as it travels up the bore. Over the last 25 years studies in this subject area have provided guidance in the development of mathematical models [1 to 11] which describe the interaction between the various components and can finally predict the weapon performance. Comprehensive simulations now include flexible and recoiling barrels, effects of bore wear, non-linear supports, flexible cradles, rigid or flexible shots, and the supporting vehicle. However it is almost impossible to develop a single simulation program which can cover, with basic data entry, all the possible configurations and modifications which the designer may want to introduce. For this reason, user defined programming areas are provided for development of special cases. The proposed APFSDS (Armour Piercing, Fin Stabilised, Discarding Sabot) training round, for use in a 120mm tank gun system, is an unusual design and required the use of this facility to ensure that accurate and comprehensive simulations could be made.

THE TRAINING ROUND

The design of most APFSDS rounds is centred on the principal that, to improve penetration, the actual projectile is required to be relatively long and thin, with high mass and maximum possible kinetic energy. To achieve high kinetic energy, the velocity needs to be

high, and this therefore requires high forces to accelerate it in the bore. For a certain pressure, the projectile therefore needs to have a large diameter to achieve the required acceleration. This conflicts with the smaller diameter required to increase penetration.

The solution to this problem has been to support the penetrator in a light weight structure (the sabot) which has a larger diameter than the penetrator. The pressure force from the propellant acts on the base of the sabot, which then accelerates and carries the penetrator with it. At shot exit, the sabot, which is normally in three parts, falls away and leaves the penetrator to continue to the target.

Because of the relatively high mass of the penetrator combined with the very high accelerations, the longitudinal forces between the penetrator and the sabot are very large. The sabot must also prevent bending of the penetrator, due to severe lateral motion, and the possibility of buckling deformation [12]. The interface between the sabot and penetrator, which carries these forces, is often in the form of a screw thread. This therefore requires careful design in order to prevent failure.

A large part of the cost in developing a round is concerned with trials and evaluation. Once a round has been successfully designed and tested to provide good accuracy and consistency, combined with high penetration, the costs are basically concerned with production. In this case the material costs of the high density penetrator are normally high, and the accurate machining of the interface between the penetrator and the sabot add significantly to the final total.

A training round needs to have the same overall characteristics as the service round. It must have similar overall dimensions so that ergonomically, handling the round feels no different. It must also fire in a similar way with equivalent accuracy and consistency, although penetration is not important. It is preferable if its maximum range can be reduced so that it can be fired on ranges where overshoot could be a problem. This must then be achieved at minimum cost.

This has been accomplished by RO Defence with the design shown in Fig 1.

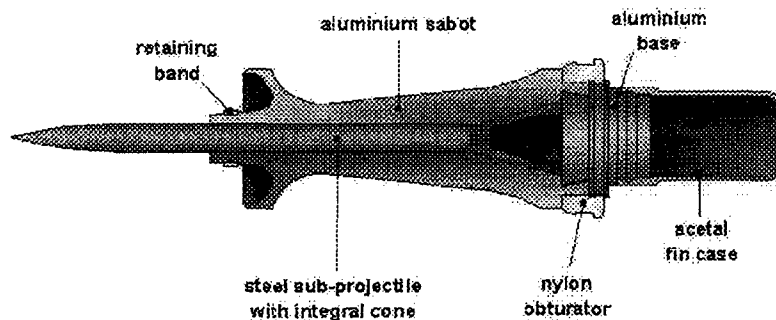


FIGURE 1. THE 120MM TRAINING ROUND.

It should be noted that this round is part of a separate three piece ammunition system consisting of the round, the charge and a detonation cartridge. The round shown in Fig 1 is therefore handled separately from the charge.

The basic construction of the round consists of three main components, the penetrator (sub projectile), the sabot, and the aluminium base block. The penetrator is considerably shorter than that of the service round. It is made of steel and, instead of stabilising fins, it has

a cone at its base which modifies the aerodynamic characteristics. This ensures that its operating range is reduced, which enables it to be fired on ranges where over shoot may be a problem.

The internal shape of the sabot is considerably different from that of the service round and the cone of the penetrator fits within it. The sabot is in three parts, split radially, so that discard can be achieved in the same way as normal.

The significant difference between this round and the service round is the interface between the penetrator and the sabot. There is no screw thread to transmit the longitudinal forces between the two parts, therefore an aluminium base block has been added which takes the base pressure and then acts on the back of the penetrator. Although this effectively adds an extra component, the reduction in manufacturing costs, in not having to produce an interfacing thread between the penetrator and the sabot, is very significant. The major components are then held together with the nylon obturator at the rear of the sabot and a simple retaining band at the front.

A further point to note is that the service round has a much longer penetrator than the training round and protrudes well behind the back of the sabot with its stabilising fins. It then has a combustible protective cover, which fits over the fins. The training round has a similar dummy component, the acetal fin case, so that the overall dimensions and appearance remain the same as the service round. When fired, this case is designed to disintegrate immediately at shot start so that the propelling gases act directly on the aluminium base and the nylon obturator.

THE MODEL

The Main Considerations

The modelling of the training round was based on the gun dynamics simulation package SIMBAD [13,14]. The round is fired from a rifled barrel, so although spin is reduced by a slipping driving band, the spinning two piece flexible shot model was used. This assumes the standard configuration which is found in the service round. It was therefore modified to meet the requirements of the training round by using the 'User Defined Routines' of the program [14].

The first and most obvious difference is the aluminium base block, which takes the majority of the base pressure and rests squarely against the rear of the penetrator. It is held together with the sabot by the nylon obturator (the driving band), and the taper ensures that it cannot easily be detached once it is assembled. There is a gap between the base block and the sabot at each perpendicular face.

The transverse stiffness of the driving band is a significant parameter in the simulation, and the force from this normally acts directly on the sabot. In this design the force must be split between the sabot and the base block. Similarly, the torque produced by the rifling through the driving band must also be split between the sabot and the base block.

The standard model assumes that this rifling torque is imparted to the sabot, and hence to the penetrator by the threaded interface. In the training round the transmission of torque must be from the base block to the penetrator at the rear interface, and/or from the sabot to the penetrator through contact at the top edge of the cone. (It may be noted that the tapered

section at the rear of the penetrator is such that contact with the sabot is only around its greatest diameter.)

It has already been stated that the pressure acts on the base block, which pushes against the rear of the penetrator. Pressure will also act on the driving band, and the force generated will act on the sabot. If the exposed rear area of the band was large compared with the exposed rear area of the base block, it may be possible that the acceleration of the sabot may try to exceed that of the base block and move forward relative to the penetrator. This would also depend on the relative masses of the components. However, the design is such that the penetrator should always act to push against the sabot, but even so, both cases should be considered in the model.

In this new concept, the support which the sabot gives to the penetrator is only in the transverse direction. With a threaded interface, as used in the service round, any transverse clearance is normally reduced as the threads engage when the shot starts to accelerate. With the proposed design this support may not be consistent from shot to shot, and may even vary while the shot travels up the barrel. This is because manufacturing tolerances may produce varying clearance between the sabot and the penetrator, and this clearance may increase during firing. This could occur because the three petals of the sabot may be forced apart by either the gas forces on the front of the sabot, or by the penetrator at the tapered rear interface. The effect of this could be to allow the penetrator to move transversely within the sabot, and possibly increase shot transverse motion (linear and angular).

Application to the Model

The penetrator and base block were modelled directly using the penetrator model in SIMBAD. The modulus and density factors for the base block were set to give the correct properties for aluminium. It was assumed that contact was maintained on the complete interface between the two parts. This was considered justified following initial calculations, which showed that, once shot motion commenced, the reaction between the two parts should not drop below 100kN. The interface was therefore modelled as a perfect joint.

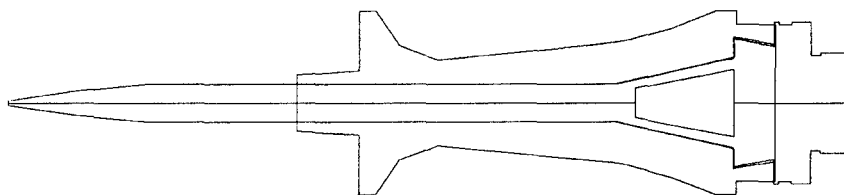


FIGURE 2. THE COMBINED PROFILES AS ENTERED FOR THE SIMULATION.

Later analysis of the results confirmed that any resultant moments due to flexing of the penetrator were unlikely to cause separation at any part of the interface. Furthermore, recovered components from actual firings confirmed that no slip or movement occurred between the two parts.

The sabot was modelled in the normal way. Fig 2 shows a plot, directly from the program, of the combined profiles for the two basic parts of one of the early designs. It may be noted that the program automatically reduces each profile into the individual elements, and following this the modulus and density factors for the base block were changed.

The interface between the sabot and the penetrator normally assumes a stiffness between each corresponding node of the sabot and penetrator. There are separate stiffnesses for the longitudinal and transverse directions, and also for the spin. In each case this stiffness can be non-linear with or without clearance. To model this unusual design, the longitudinal and spin stiffnesses were set to zero, and the transverse stiffness was modelled with clearance. Separate stiffnesses were then introduced to act between the sabot and the penetrator at the nodes which corresponded with the rear of the cone on the penetrator. These stiffnesses acted in the longitudinal and spin directions. By monitoring the resultant forces from these stiffnesses it was possible to determine the torque and the longitudinal force transmission between the sabot and the penetrator.

The distribution of the transverse forces and spin torques from the driving band to the sabot and the base block is difficult to define. SIMBAD allows for non-linear compression of the driving band, and will also allow for the initial compression of the band as it enters the bore. The calculation of the forces uses the relative displacements between the sabot and the barrel, plus the initial diameter of the band and the bore profile. The calculated forces are then applied to the sabot. The program does not model the force distribution along the band so, in order to split the forces and torques between the sabot and base block, it was assumed that the driving band stiffnesses could effectively be factored between the sabot and the base block. This factor was based on the contact areas between the band and the sabot and/or the base block. Two independent calculations were then made using the relative displacements between the sabot and the barrel, and the base block and the barrel.

[It may be considered that a simpler solution was to apply the existing single calculation of the band forces using the relative displacements between the sabot and the barrel. These could then be factored between the sabot and the base block. However it must be noted that there is relative movement between the sabot and the base block. Even though this may be very small, application of a force on the base block, which is dependent upon the sabot deflection, can result in an unstable solution.]

The slipping driving band was modelled by setting the rifling stiffness of the driving band to a very low value, and setting the viscous torsional damping coefficient to a value which gave the correct spin rate at shot exit. In practice the actual process is much more complicated, but this model of a viscous coupling gave very close correlation to the accepted behaviour.

The acetal fin case on the rear block was ignored because it is assumed that the design is such that it will disintegrate quickly in the bore at shot start, and will not affect the remainder of shot travel.

SIMULATION PROCESS

Once the model had been completed, various tests were applied to validate the modifications to the basic model. These included changing the diameter of the base block, and changing the factor used to distribute the driving band forces between the sabot and the base block. In this way it was possible to demonstrate how the direction of the longitudinal force between the sabot and the base block would change as the diameter of the base block was reduced. It was also possible to show how the torque transfer between the sabot and the penetrator would vary with the driving band force distribution factor.

It is not the intention of this paper to give a detailed description of all the simulations which were made to optimise the design of the training round, but the few results below are designed to show how the simulations can be used to influence the design decisions.

The table shows the change in penetrator pitch velocity at shot exit for changes in the driving band force distribution factor. A factor of 1 indicates that all of the driving band sits on the sabot. A factor of 0 indicates that all of the driving band sits on the base block. The indication is that as the force distribution from the driving band is increased towards the base block, a reduction in pitch velocity at shot exit should occur. Previous experience has shown that this will normally result in a reduction in dispersion.

Factor	Pitch Velocity rads/s.
1.00	-2.70
0.75	-1.93
0.50	-1.13
0.25	-0.806
0.00	-0.425

It must be emphasised that this set of results is achieved with all other parameters fixed. The situation may change if, for example, the length of the sabot was changed or the clearance between the penetrator and the sabot was different. There are many other possibilities, and it is for this reason that many simulations need to be made with different barrel profiles, different pressure time curves, and many shot design possibilities. An optimised solution can then be achieved.

In this particular case the main variables chosen for investigation on the shot are shown in Fig 3. The temperatures indicate the use of different pressure time profiles, which would be expected at those temperatures.

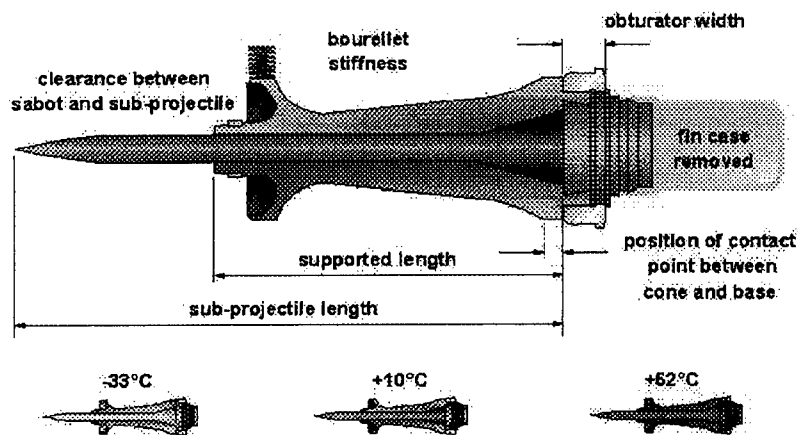


FIGURE 3. CHOSEN VARIABLES FOR ANALYSIS WITH SIMBAD.

The time for each simulation was approximately 5 minutes on a 733MHz Pentium 3 PC. The simulations were made using the multiple run facility which also enables the parameter analysis function of the program to be used. Many simulations were made to cover a wide range of the chosen variables.

APPLICATION OF RESULTS

The results from the analysis have been used together with experimental firings to assist in the optimisation of the design of the new training round. The aim has been to achieve

the same accuracy and consistency of the service round, and also give the same handling characteristics.

At the stage of writing this paper, over 600 rounds of various designs have been fired. This has helped in understanding the interaction between the main physical parameters of the shot. Supported by the theoretical analysis and the trials data, significant improvements to the design of the projectile have been accomplished. All the parameters shown on Fig 3 have been optimised, and the required objectives of the project have been met.

ACKNOWLEDGMENTS

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