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EXPERIMENTAL AND SIMULATION ANALYSIS OF SETBACK IN GUN LAUNCH

P. Church, W. Huntington-Thresher, C. Herdman

Guns&Warheads, DERA Fort Halstead, Sevenoaks, Kent, TN14 7BP, United Kingdom

With the advances in modern target configuration, there is a pressing need to be able to launch more powerful explosive compositions from gun barrels. A major obstacle is the problems due to setback in the gun launch process which can induce significant events within the barrel. At present the evaluation process requires many thousands of full scale proof shots which is hugely expensive and sheds little light on any disadvantageous mechanisms that may operate. To aid this problem flash X-rays of inert shots have been taken through a 40 mm aluminium barrel portable gun launcher to observe the setback within the barrel. The DYNA3D hydrocode has been used to simulate the launcher and the shell which has identified the friction between the filling and the case as being a major issue for further studies.

INTRODUCTION

At present in the UK standard gun launch munitions generally utilise RDX/TNT which has been unchanged since World War Two. Due to ever increasing demands on gun system performance and the increasing complexity of targets, there is a pressing requirement to be able to use higher performance and IM explosive compositions within gun launch munitions. The current evaluation process for a proposed new composition requires many thousands of shots to gain the necessary confidence that the proposed munition is robust in performance and safety. In the present fiscal environment this is simply not a feasible option and therefore a more scientifically based and cheaper methodology is required to assess compositions in the gun launch environment, before they are fired in a gun.

A Corporate Research Proposal (CRP) was defined to address this issue and to determine a methodology for evaluating new gun launch compositions. One of the main challenges in the programme is to try and link a mechanism to an event in real life. Therefore the programme was based on a fundamental integration of precise small scale experiments, numerical simulations and material tests of the mechanical behaviour of the compositions. One of the major issues was to attempt to observe the motion of a munition progressing along the barrel to determine the nature and extent of the spatial and temporal setback within the munition. This was then compared with the simulation studies which were used to identify any major mechanisms for further study. This paper describes the experimental testing programme, the simulation methodology and results.

EXPERIMENTAL PROGRAMME

The trial objectives were to establish an experimental technique capable of providing physical evidence of events "during" a gun firing. The trial set-up replicates the actual confines of a real gun firing but in addition enables radiographs to be taken by utilising an all aluminium barrel. This meant that it was feasible of viewing the cavity or filling within the projectile using flash X-radiography. The gun used was capable of imparting accelerations of about 20000 g, which is comparable to a 155 mm full-scale gun system.

Early static tests showed that in comparison to an empty projectile cavity, the various inert materials used was easily discernible and visible to the X-ray equipment employed. By altering the intensity of the X-ray pulses, distance from the objects of interest, and position of the Radiograph 'cassettes' themselves, an optimum set-up was devised that provided sufficient clarity to enable visual analysis.

As previous firings had indicated, exact timings between firing pulse and propelling charge initiation were erratic and therefore to ensure accurate timing of X-ray pulses an alternative trigger start point was sought. Utilising historic pressure time graphs and controlled initiation trains and propelling charge masses, the peak breech pressure from a 50 Mpa pressure point was virtually constant and gave a time period accuracy that would satisfy the trial objectives.

Three identical firings were conducted where-by the Flash X-ray head was positioned at varied positions normal to the central axis of the launcher. On the third and last firing the position of the head was such that a radiograph was produced which displayed, with no parallax error, the inside face of the test vehicle cavity and how the filling therein was separated from it (i.e. setback) by approximately 1.25–1.75 millimetres. This radiograph was concluded to being a physical record of the maximum displacement for the test material as it was taken at peak breech pressure when the projectile was experiencing peak acceleration forces. The observed setback was maintained throughout the shell's progress along the gun barrel. An example of the flash X-ray picture obtained is given in Figure 1.

Our belief is that previous studies [1] have only taken flash X-rays of the shell emerging from the barrel after the propellant forces were released. Thus DERA has achieved a World experimental first in this area.

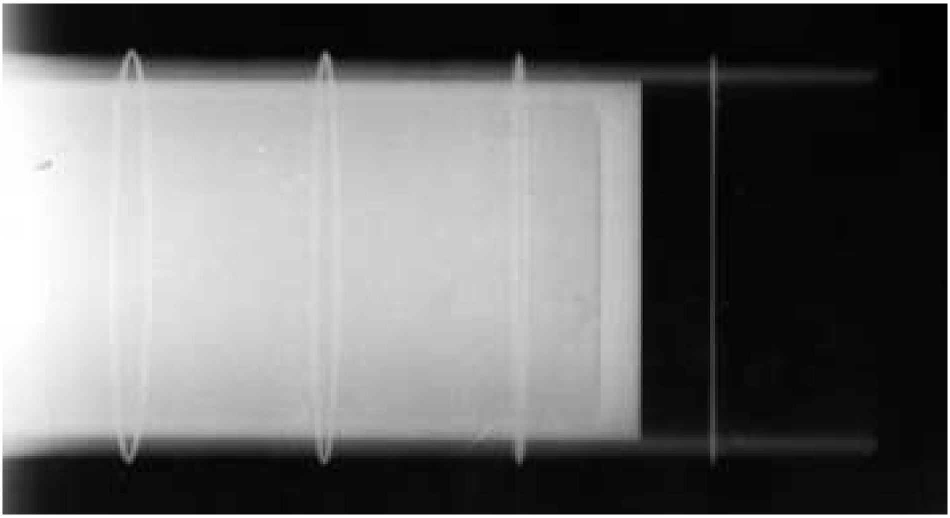

Figure 1 – Flash X-ray showing explosive setback during gun launch.

NUMERICAL SIMULATIONS

The purpose of the computational simulation programme was to exercise the material model developed and validate it against the experimental flash X-rays. Once confidence had been obtained in the integrity of the model modifications could be applied, both to refine the its representation of the experimental conditions, and later to explore mechanisms likely to lead to increased explosive sensitivity during gun launch.

Material data for the high strain-rate environment present during gun launch was unavailable for the explosives of interest. Consequently material testing of a PBX of interest was performed using Hopkinson bar tests to provide data in the high strain-rate regime and compression tests in the low strain-rate/quasi-static regime. Analysis of the material samples indicated that after the loads were removed they returned approximately to their original shape, despite experiencing large strains within the tests. This indicated a predominately elastic response, rather than elastic-plastic. It was therefore considered that the visco-elastic models within LLNL DYNA would be most applicable. The fit of data from the material testing to the form of the models within DYNA was not considered adequate, and a new model was required. It was proposed that the new visco-elastic material model should mimic the qualitative mechanisms within a PBX. There are essentially two competing mechanisms, which occur as the PBX deforms, the first increases the modulus as the explosive particles and polymer chains interact, the second reduces the modulus as the PBX progressively damages. This two term modified visco-elastic model was encoded into DYNA, with the constants derived from the PBX material tests.

The simulations were completed using DYNA3D using two planes of symmetry. The rear of the round was loaded by the recorded breech pressure time history from one of the experimental firings. The firings were completed using an explosive simulant, however the PBX material model was used in the simulations.

The initial simulation was completed without friction between the explosive fill and the case. Despite the differences between material model and experimental material the result was encouraging in that the maximum displacement was similar, and occurred at similar times, Figure 2. Analysis of the setback against time was illuminating in that far from the strain monotonically increasing during launch, as was assumed from the experimental firings there were some oscillations after the peak pressure load was applied.

The experimental and simulation results both showed little global deformation of the fill. This indicated that the direct strains within the model were likely to be low, hence the attributes of interest were therefore likely to be stress rather than strain based. Furthermore as the direct strains were low it was the shear rather than direct stresses that would be most informative. Figure 3 shows a snapshot of the initial simulation when the shear stresses were greatest. Analysis of these results showed that the maximum shear stresses occurred at the bottom corner of the shell, but otherwise were generally low.

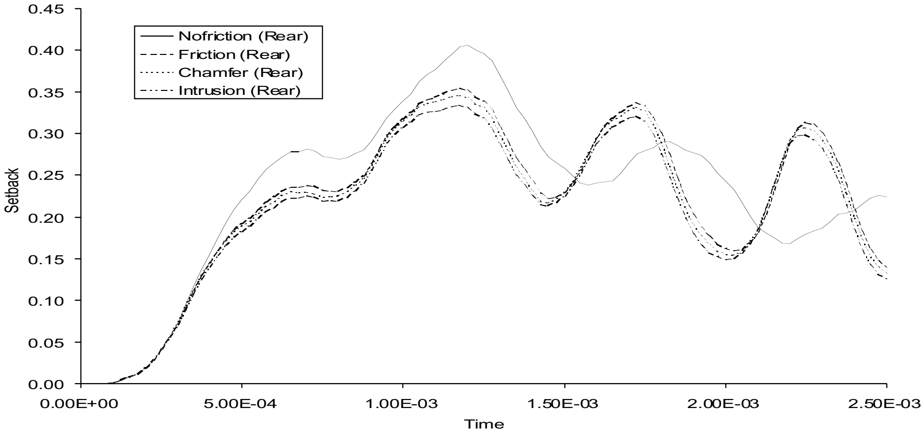

Figure 2 – Explosive setback during gun launch.

Analysis of the initial DYNA model raised questions over the loading and the assumption of zero friction coefficient. The pressure load data was obtained from a gauge in the breech rather than at the shell base. This location would have measured higher pressures than those acting on the base of the shell, hence over accelerating it, increasing the setback. As any modification of the pressures would have been rather arbitrary they were left unchanged.

Analysis of the effects of including friction within the model suggested that if it was included the oscillations should be damped, and that the total deformation would also decrease. These considerations indicated that friction between the simulant and case would therefore have a significant effect on the distributions of the stresses. Data on the likely friction coefficients was unavailable, particularly as there was likely to be adhesion between the simulant and case. This adhesive effect could not be simulated with a classical frictional slide line. A sensitivity study was therefore performed varying the friction coefficient from 0.05 to 0.2.

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The result of the 0.05 friction coefficient simulation is shown in Figure 4. It showed significant differences in the stress distributions compared to the zero friction simulation. The peak occurred part way along the case rather than at the corner, an extra area of enhanced shear stress was also observed on the axis of the round. The stresses were 2–4 times greater (depending on friction coefficient) and occurred marginally earlier. The behaviour of the setback along the simulant, Figure 2, was also interesting, partly as the inclusion of friction far from damping the oscillations enhanced them, and changed the frequency. The overall level of the setback was little changed, however in this simulation the maximum setback did not occur at the rear face of the simulant but a short distance in from the rear. The limited number of firings was unable to confirm or deny this behaviour.

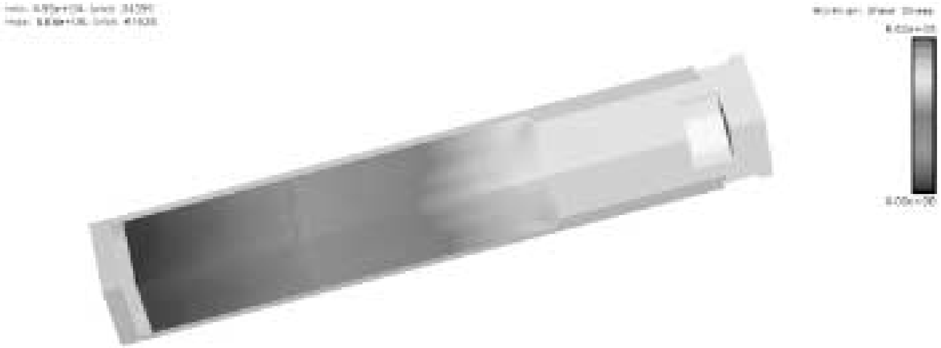

Figure 3 – Maximum stress state without friction between the explosive and case.

Figure 4 – Maximum stress state with friction coefficient of 0.05 between the explosive and case.

The rear corner geometry of the round appeared to be responsible for the peak stresses. This geometry was unlikely to be representative of internal shell geometry’s, hence the model was modified to include an internal chamfer, friction was again included with a coefficient of 0.05. The results of this simulation, Figures 5 and 2 show little difference in the deformation or level of the shear stresses. The region of enhanced shear stress on the axis decreased slightly.

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Figure 5 – Maximum stress state with the chamfer including a friction coefficient of 0.05 between the explosive and case.

Consideration of the mechanisms likely to lead to increased sensitivity of the explosive fill indicated that the following attributes were of importance:

1 internal geometry,
2 voids with in the fill, and
3 modified accelerations.

The effects of modifying these attributes were to be explored within the modelling programme. An initial simulation was completed to initiate this exploration, with an inclusion added at the bottom corner to form a step, the friction coefficient was maintained at 0.05. The results show little modification to the maximum shear stresses or little to the setback, Figures 6 and 2. The inclusion of the step led to a region of high shear stress on its apex, however its level was no greater than those seen along the case wall. The region of enhanced shear stress on the axis was much reduced in level and extent.

This result indicated that internal geometry had some effect on the maximum shear stresses at any sharp corners and should be avoided. However due to the low global deformation sensible modifications to the internal geometry are not expected to be of high importance.

Figure 6 – Maximum stress state with a sharp intruson including a friction coefficient of 0.05 between the explosive and case.

DISCUSSION

The study has demonstrated the importance of obtaining precise experimental data for the setback as the shell proceeds up the barrel. This is vital when attempting to validate a hydrocode simulation and material model.

The simulations have immediately indicated that the interface friction between the filling and the case is of prime importance to the gun launch issue. The simulations are clearly predicting that the friction will induce preferential localised stress regions which could give rise to hotspots and hence premature events within the gun barrel. The key parameter that the simulations at present do not predict is the localised temperature within these localised stress zones. The problem is that there is very little quantitative data on the general cohesion and adhesion of explosives to shell cases. These simulations indicate a requirement for more precise instrumentation so that the precise conditions within the shell can be ascertained. A possibility is to embed sensors within the filling which can be soft recovered after firing and then interrogated to determine the conditions during transit down the barrel.

The setback problem is further complicated in that deformation of the filling can occur along the barrel and also during the release of the load as the shell exits the barrel and finally during the soft recovery process. This makes it difficult to quantify the problem and to isolate mechanism which could give rise to events within the gun barrel. This is the area where predictive simulations could give real guidance to gun designers when they are trying to design new shell systems incorporating higher performance or IM fillings.

The eventual aim is to use this integrated approach between experiments and modelling to validate simulation tools which can be used to investigate full-scale gun and shell systems.

CONCLUSIONS

1. The setback has been observed in a shell as it progresses along the barrel using Flash X- rays for the first time.
2. This indicates that the setback is relatively modest and occurs around the maximum load on the projectile and then is maintained along the barrel.
3. The simulation studies have qualitatively reproduced the setback and have illustrated the importance of friction between the filling and the shell case.
4. The simulation tools are being expanded to account for full scale gun systems including projectile spin.

REFERENCES

1 J. F. Moxnes, “Prediction of Deformation of the Powder within the Nose Cap of a an MP-Projectile During Set-back and Spin”, *Proceedings of the 17th International Symposium on Ballistics*, Midrand, South Africa, March 1998. ISBN: 0-620-22078-3.

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