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FACTORS AFFECTING THE ACCURACY OF INTERNAL BALLISTICS, INCLUDING THE SIMULATION OF PROPELLANT MOTION

M. Pocock, J. O'Neill and C. Guyott

Frazer-Nash Consultancy Ltd, Dorking Business Park, Dorking, Surrey, RH4 1HJ, UK
www.fnc.co.uk

Internal ballistics modelling software can provide high quality results and insight into the physical systems being modelled. As with any complex numerical model however, the fidelity of the results can be sensitive to detailed modelling assumptions.

In this paper experimental results are compared against two sets of predictions obtained with the FNGUN internal ballistics software [1]. The first models are high quality, but based on common modelling assumptions of 'ideal' behaviour. The second set of models takes account of realistic effects such as non-ideal grain shape and propellant movement.

It is shown that there are significant improvements in accuracy of pressure-time traces when the additional features are modelled.

INTRODUCTION

Modelling software is widely used for simulating internal ballistics and predicting experimental results, as demonstrated by the number of papers on this subject in [2] and [3]. Recently there have been major advances in the tools available and the techniques used to optimise the models and provide ever more realistic models [4] and [5]. However as with any complex numerical model, the fidelity of the results can be sensitive to detailed modelling assumptions. Furthermore, whilst most codes should produce an adequate result initially, it can take considerable experience to get a good result first time. This paper shows how initial predictions can be improved by refinements to give excellent agreement with experimental data.

To improve the accuracy of the ballistics model it is necessary to include in the model actual features of the breech, barrel, shot and, especially, the charge. This paper describes the effects of propellant grain size variation and propellant movement, as well as the effect of refined meshing on the accuracy of the model. Some of these may be unique to the system being modelled, others may be more general properties; either way it is important to have good information about the gun system being modelled.

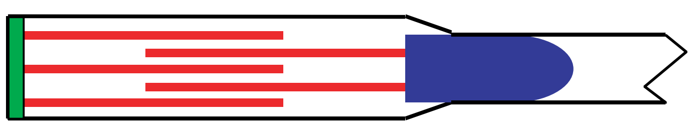
Direct comparisons between an experimental gun system and simulations are presented to demonstrate these effects and to show the potential for improvement in the modelling accuracy. The experimental system is described below; the modelling software used is FNGUN [1]. The FNGUN software employs a one-dimensional, two-phase flow, finite difference solver, coupled to a numerical representation of a grain's geometry throughout burning. These features permit the physical effects listed above to be modelled without the overhead associated with full 3D codes.

EXPERIMENTAL SYSTEM

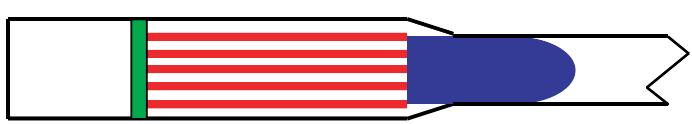
The experimental results presented here were obtained by DERA UK from a 120 mm gun system. The gun has been modified for experimental use, and contains several pressure tappings along the breech and barrel so that direct comparisons of experimental and modelled pressure can be made.

The charges and projectiles used were developed especially for the purposes of comparison with numerical modelling. The projectile base was flat, and simple charge designs using slotted stick propellants were employed so that the pressure variations recorded during the firing could be more accurately attributed to effects of the propellant layout. It should be noted that the principles described in this paper apply to more complex systems, the simple systems presented merely allow easier presentation of the modelling effects. Three charges are considered, each one having a different initial configuration of the same slotted stick propellant, as shown in Figure 1.

Charge 1 — 9.0 kg slotted tube propellant, adjacent to igniter



Charge 2 — 4.5 kg slotted tube propellant, adjacent to igniter
4.5 kg slotted tube propellant, adjacent to shot



Charge 3 — 9.0 kg slotted tube propellant, adjacent to shot
(Note new position of igniter)

Figure 1: Propellant layout for the 3 charges considered

The results presented in this paper include direct comparisons of experimental and predicted pressure (at a quarter of the distance along the chamber) as well as comparison of the pressure difference between two points (at one quarter and three quarters of the distance along the chamber).

INITIAL MODELS

The initial model for each charge accurately models the following aspects:

– Chamber volume and shape
– Igniter Charge – chemical properties; grain shape; location within chamber
– Main Charge – chemical properties; grain shape; location within chamber
– Combustible Case – chemical properties; location within chamber
– Shot mass, location and approximate engraving forces
– An initial mesh of 30 equally spaced cells through the chamber

The results of these models are shown with the experimental measurements in Figure 2. Pressure difference curves, as shown in Figure 3 offer an extremely effective method of comparing data from the model and the experimental gun. Whilst two pressure curves may appear similar, the pressure difference data will show slight differences in any pressure waves – if there is good correlation between the predicted and experimental pressure differences then the model is likely to be a good representation of the experimental set-up.

MODELLING TECHNIQUES

Propellant grain tolerance, propellant movement and mesh refinement are important modelling features that can aid the accuracy of the gun models. The actual changes that were made to the models and the physical phenomenon that they represent and their effects are discussed in the following sections. The effects of these changes on the predictions are presented in the conclusion.

PROPELLANT GRAIN TOLERANCES

Due to manufacturing methods there are usually slight variations in propellant geometry, for instance:

– spherical grains may not be truly spherical
– tubular grains may not have cylindrical holes or a cylindrical outer surface, the hole may be offset, slots may be tapered and offset
– cross propellants may have tapered fins of different thicknesses
– non uniform composition can lead to different burn rates through the grain [6]

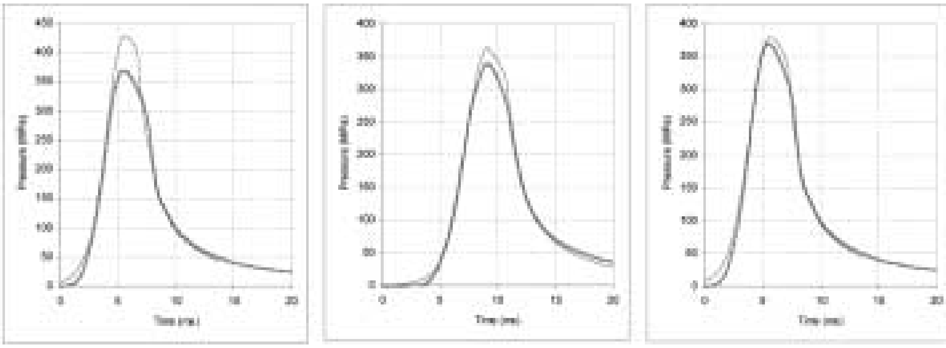


Figure 2: Pressure time curves for charges 1, 2 and 3 (left to right). Experimental pressure is shown in wide-grey, initial model in fine-black.

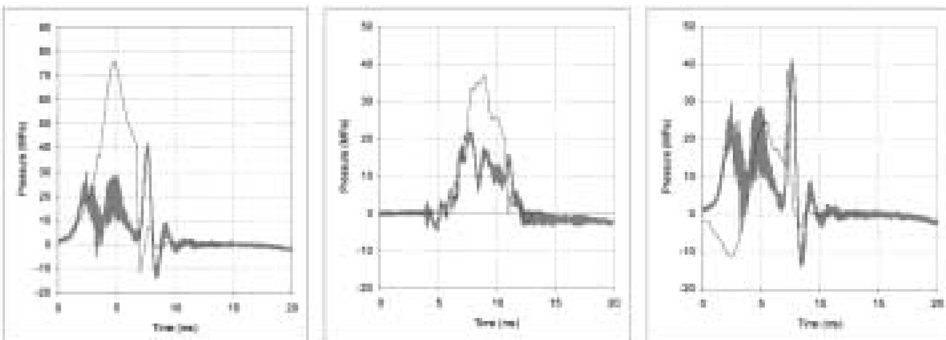


Figure 3: Pressure difference curves for charges 1, 2 and 3 (left to right). Experimental pressure difference is shown in wide-grey, initial model in fine-black.

These variations will cause some of the grains to be completely burned before others and in extreme cases it can even cause 'slivering' of grains that with, perfect geometry, would not sliver. For the slotted tube grains considered here (as well as strip and cross grains), an 'ideal' model would result in a abrupt cessation in burning when all the grains simulatenously burn-out. Modelling the variation will result in a gradual reduction in burning (and gas generation).

There are several methods that can be used to model grain to grain variation. The first method is to explicitly model the inaccuracies of the propellant. Employing this approach the user defines a custom geometry for the propellant grain, rather than being restricted to ideal grain geometries. Complex surface area algorithms are used to calculate how the surface area varies with regression distance. These have been shown to provide greater modelling fidelity than simple shape functions. This technique is explained in the following section with an example using the "user defined grain" function of FNGUN.

Home
Table of Contents

Modelling of an imperfect Grain Geometry

This section considers a long tubular grain with an eccentric hole. These are typical of the imperfections found in practice, and illustrate the difference in regression distance and the surface area characteristics that are obtained with slight geometrical errors. Such a grain is shown on the left in Figure 4.

During the initial phase of burning, this grain will perform like an ideal grain, with the surface area gradually reducing. Eventually, the inner and outer surfaces will coincide at one point, as is shown in the center of Figure 4. Subsequently, the cross-sectional area of the grain will take on a crescent shape, as is shown in the right of Figure 4. The surface area will then decrease to zero in a non-linear fashion.

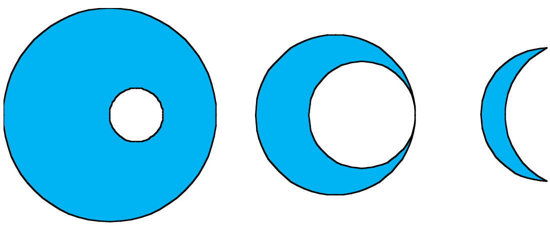


Figure 4: Grain shape for an eccentric tube. Before ignition; at burn-through; after burn-through

Figure 5 shows how modelling the eccentricity causes the surface to reduce gradually rather than abruptly cease. As the generation of gas is dependent on the surface area, this also means that the effective burn rate reduces.

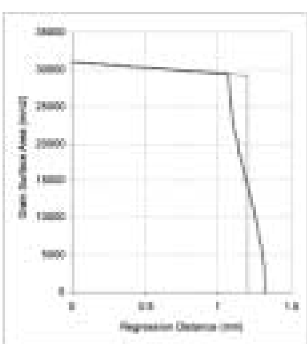


Figure 5: Surface area for an eccentric (wide-grey) and ideal grain (fine-black)

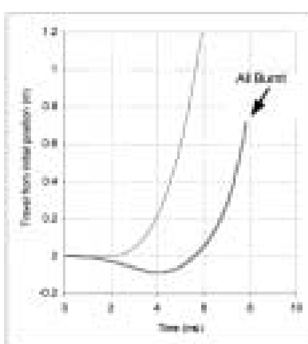


Figure 6: Shot travel (fine-black) and propellant movement (wide-grey) for Charge 3

Using several bundles of propellants

A slightly cruder, but still very effective, method of modelling the variations in propellant geometry is to split the propellant model into several bundles, each with a slightly different geometry. A typical set-up would be:

50% at specified web dimensions

25% at specified web dimensions plus 10%

25% at specified web dimensions minus 10%

These bundles, although technically separate propellants, are modelled as filling the same part of the chamber simultaneously and effectively create one charge with varying geometry.

Since each propellant is a different size, the length of the burn differs. This results in a stepping down of the effective surface area and hence the overall gas generation rate as each bundle burns through.

PROPELLANT MOVEMENT

During the firing of a gun it is likely that the propellant bundles move about in the breech and barrel, as long as there is space for them to move in and a pressure gradient to drive the process. Allowing at least some of the propellant to move within the breech and barrel has significant effects on the accuracy of the model. As well as improving the accuracy of the model, introducing propellant movement can give a better insight into the mechanism of firing.

In each of the final models propellant was permitted to move within the breech and along the barrel behind the shot. Figure 6 shows that in the final model for charge 3 the propellant initially moves backwards (that is, away from the shot base) before it begins to follow the shot along the barrel, and then finally burning out. It is found that incorporating propellant movement into a ballistics model can “smooth” high peak pressures. In addition modelling of burning propellant along the barrel can be useful in erosion studies.

MESHING EFFECTS

As with any numerical method, a finer mesh generally increases the fidelity of results and increases computational time. By locally refining the mesh around features that are likely to affect the gas flow, (such as igniters, endcaps and at the ends of propellant bundles) the benefits of a refined mesh can be obtained with little computational time penalty. An example of a simple locally refined mesh is shown below in Figure 7, this contains fewer cells than the initial model but has a higher cell density where required.

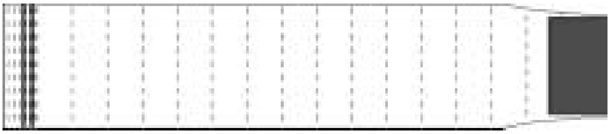


Figure 7: Locally refined mesh

FINAL MODELS

All of the techniques discussed above have been incorporated into models of the 3 charges. Figure 8 and Figure 9 show a comparison of these final models with the experimental measurements in the same format as used for the initial models in Figure 2 and Figure 3.

CONCLUSIONS

Although the charge systems discussed here appear reasonably simple they exhibit the complex 2-phase transient fluid dynamics problems of any gun system. The initial models are detailed, and represent an accurate reflection of the 'ideal' system. These models are shown to produce adequate fidelity for many uses. It should be noted that even these initial models are more realistic than lumped parameter models, which would predict identical results for each of the 3 charges.

When refinements are made to the models to simulate a more realistic gun system, the predictions become much closer to the experimental measurements. Of the different features simulated, propellant movement had the greatest effect on the gun system models considered in this paper.

ACKNOWLEDGEMENTS

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Home
Table of Contents

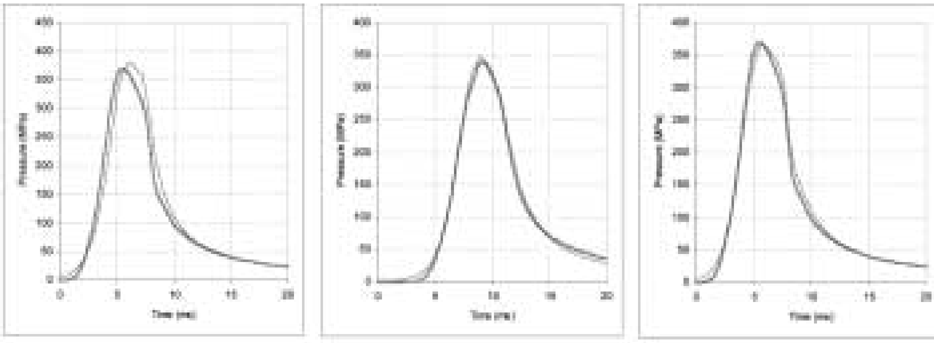

Figure 8: Pressure time curves for charges 1, 2 and 3 (left to right). Experimental shown in wide-grey, final model in fine-black

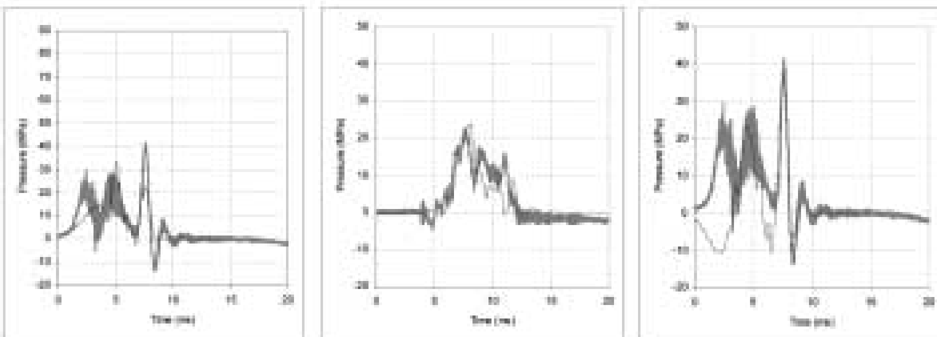

Figure 9: Pressure difference curves for charges 1, 2 and 3 (left to right). Experimental shown in wide-grey, final model in fine-black