

CHALLENGES OF INTERNAL BALLISTICS MODELLING OF NOVEL PROPELLANTS AND PROPELLANT GEOMETRY

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The desire to improve gun performance has lead to the development of novel propellants using non-uniform burn laws and/or complex geometry, both in terms of grain shape and foamed internal structure. These propellants are not readily characterised using traditional methods. This paper discusses three possible procedures for characterising such propellants in terms of the non-uniform burn rate coefficients and the complex relationship between surface area and regression distance. The work presented here is on-going with technical support from ARDEC and ATK. It is the intention to develop some of these procedures and eventually incorporate them into the FNGUN internal ballistics modelling software.

INTRODUCTION

One of the current trends in internal ballistics research is to use deterrents and novel grain geometries. In general the aim is to widen the peak of the pressure time curve to provide greater muzzle velocity without over-pressuring the tube. Deterrents modify the burn rate and/or energetic performance of a propellant through its thickness so that, for example, the gas generation rate (per unit surface area) is slower initially. The propellant geometry determines how the surface area changes as the propellant burns. Novel propellant geometries include single grains virtually filling the chamber, and propellants which are foamed, so that the bubbles within the structure change the surface area during burning. Some propellants are designed to fragment during firing thus liberating additional surface area.

An example of a novel propellant is the caseless ammunition currently being developed by a consortium including AAI, ATK and ARDEC as part of the LSAT programme [1], see figure 1. Here the charge comprises a single complex geometry

grain which encloses the projectile and ignitor propellants. One of the main advantages of the caseless ammunition is a predicted 50% weight saving.

Propellants are traditionally characterised in closed vessel (closed bomb) experiments, where a small quantity of the propellant is ignited and the pressure time (PT) curve measured. The PT data is analysed by plotting vivacity, defined as $(1/P)(1/P_{max})(dP/dt)$, against normalised pressure (P/P_{max}) . In general terms, vivacity measures the gas generation rate and its variation during the firing. The shape of the curve indicates whether the propellant is progressive (increasing gas generation rate through the firing), degressive (reducing gas generation rate) or neutral.

When the propellant burn rate is constant through the grain and the grain is a relatively simple geometric shape, the propellant burn rate can be determined from 2 or more closed vessel tests. The burn rate, along with the known geometry is used to determine the gas generation rate at any instant during the firing. This combination of burn rate and geometry is the basis of internal ballistics modelling software.

When the burn rate varies with the distance burnt or the grain geometry is complex (specifically the variation in surface area with regression distance is difficult to determine) it is difficult to obtain accurate burn rate data from closed vessel tests. Without accurate burn rate data internal ballistics models will not provide good predictions. For example a 2% change in burn rate pressure coefficient 'alpha' can lead to a 20% change in predicted peak pressure for a typical 155mm gun system.

This paper investigates alternative approaches to extracting information from closed vessel tests and using it in internal ballistics modelling codes for these complex grain types.

This paper considers three approaches to solve the problems created by these modern propellants:

- 1) Use CV test data along with numerical models to characterise the effect of deterrents on burn rate
- 2) Use an enhanced burning rate for foamed/fracturing propellants
- 3) Use experimental vivacity data directly in numerical methods.

The work presented here is currently in progress with support from ARDEC and ATK. Much of the experimental data and verification work is awaiting clearance.

CHARACTERISATION OF CLOSED VESSEL DATA

In this approach a numerical internal ballistics model of the closed vessel is compared with the experimental data. The effects of the deterrent(s) on the propellant are modified until similar vivacity traces are obtained for both model and experiment. Validation of this approach is achieved by comparing firing data with a numerical model of the test firing system.

For this to be a practical solution, the grain geometry variation with regression needs to be known in advance. This is not as big a limitation as might be expected, as modern internal ballistics modelling software, such as FNGUN [2], permit the definition of any practical grain shape, where the surface-area to regression can be predicted. This currently precludes most foamed or fracturing grains, but allows the modelling of unsymmetrical and/or complex grains such as the shape shown in figure 1.

One advantage of this approach is that the same grain geometry used in the firing system can also be used in the closed vessel test. This is an improvement on traditional closed vessel tests which are undertaken with simple grain geometry irrespective of actual grain shape. Thus, previously, if a grain geometry such as that shown in figure 1 is to be tested, single hole perf or rectangular ‘chip’ grains of the same propellant are produced from the same batch specifically for closed vessel testing. These simple geometries may not burn in a similar manner to the complex grains and so produce inaccurate data.

Figure 2 shows the modelled vivacity trace for a single perf grain with different levels of deterrent. It can be seen how the model predicts the change in behaviour from degressive to a more neutral profile as the amount of deterrent is increased. The actual shape of the vivacity curve will depend on the applied deterrent profile – an arbitrary profile has been used for this example.

A variation on this method is when the burn rate variation is known and the variation in surface area is determined iteratively. This approach could be employed to model the actual variation in surface area for foamed propellants. It is unlikely however that it could be used to investigate grain fracture as the gas dynamics and mechanical loads that the propellant experiences in a gun system are not recreated in closed vessel tests.

ENHANCED BURN RATE FOR FOAMED/FRACTURING GRAINS

The problem with foamed propellants is that the actual surface area can increase significantly during initial burning as the holes burn into each other. Open and closed foams (those where the ‘bubbles’ connect or are discrete) will show slightly different behaviours, see figure 3.

Determining exactly how the surface area of all of the holes varies with time is difficult and depends on the detail of the foamed geometry. For this reason an approximation approach for foamed propellants has been used. Here the actual solid (non-foamed) geometry is used in the model and the effective burning rate increased. This is based on the principle that the gas generation rate (vivacity) is a combination of the surface area and burn rate. Thus, to a reasonable approximation, an increase in burn rate can be used to compensate for a lower surface area. The effective density is also modified to produce the correct energy per unit volume (force constant).

This approach enables the effect of foaming to be separated from the overall geometry. So for a complex foamed grain, the variation in the basic geometry can be modelled as a solid grain, whether this is a simple single perf or a complex shape-filling grain.

A certain amount of experience and trial and error is needed to determine how to modify the burn rate, although iterative techniques such as those described above can play a part.

DIRECT USE OF VIVACITY DATA

The vivacity curve encompasses both geometry variation and burn rate variation with regression distance. Using this directly as the basis of the propellant definition in a numerical model would have many advantages including:

- 1) No requirement to determine individually the geometry variation with regression distance or the effects of deterrents on burn rate variation, as is required at present
- 2) The numerical gun systems models would be based on the actual measured performance of the same grains

Unfortunately there are many issues with the direct use of closed vessel data, such as:

- 1) Closed vessel data is typically obtained at lower loading densities so at lower pressures than obtained in gun systems
- 2) Closed vessel are fixed volume, where as gun systems the volume into which the gas is expanding increases
- 3) Closed vessel tests have a monotonically increasing pressure time curve as opposed to the familiar gun system curve

Extensive work has been undertaken at Frazer-Nash to investigate methods of overcoming the above issues. At present extrapolation methods which allow vivacity data at relatively low peak pressures to be applied to the higher pressures required have been developed and verified.

However the requirement to model the decrease in pressure has proved difficult and may limit the applicability of such methods to the period up to peak pressure. Figure 4 shows a 'vivacity' plot for a typical gun system, demonstrating the complex pressure-time behaviour that would need to be extracted from a closed vessel test.

CONCLUSIONS

This paper has described three possible procedures for characterising novel propellants in terms of the non-uniform burn rate coefficients and the complex relationship between surface area and regression distance. Two of the procedures

(characterisation of closed vessel data and enhancing the burning rate) require significant input from skilled operators to produce acceptable results. The third procedure of using closed vessel vivacity data directly in internal ballistics modelling has not yet been verified.

The work presented here is on-going with technical support from ARDEC and ATK. It is the intention to develop some of these procedures and incorporate them into the FNGUN internal ballistics modelling software.



Figure 1 Prototype caseless propellant, (Image courtesy of ATK)

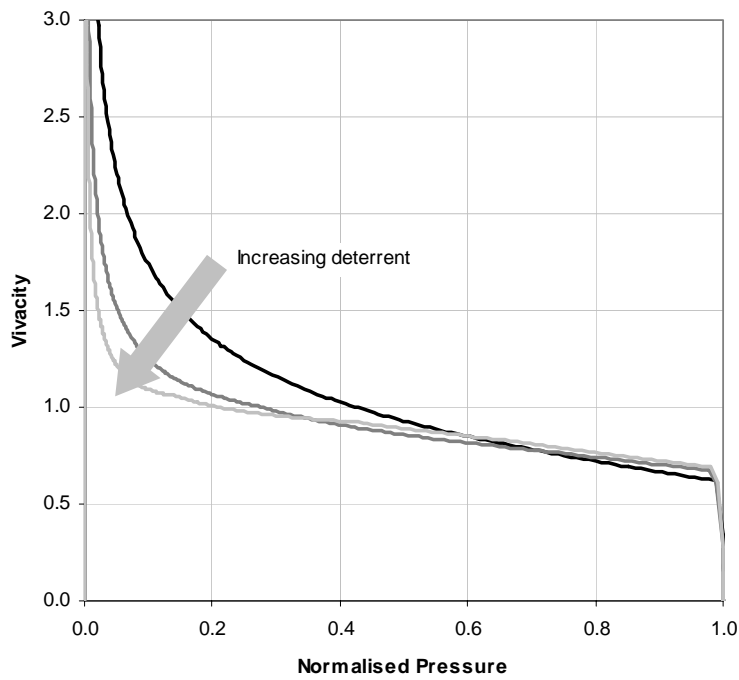


Figure 2 Modelled vivacity curves for un-deterred (black) and deterred short single perf grains.

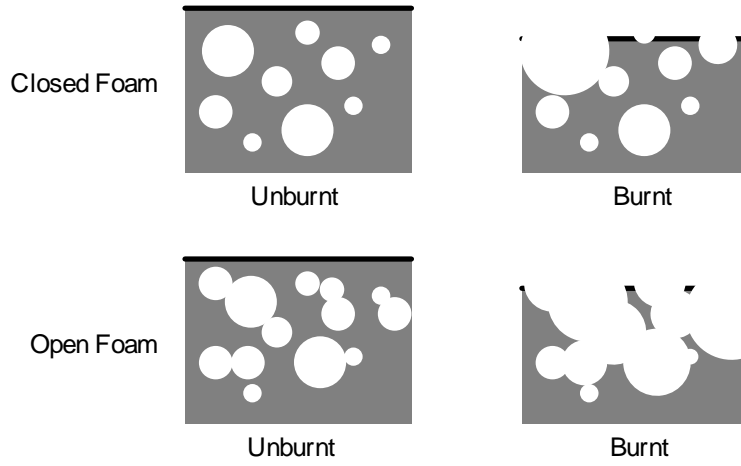


Figure 3 Schematic of different burning properties of open and closed foam. Burning is assumed from top face only

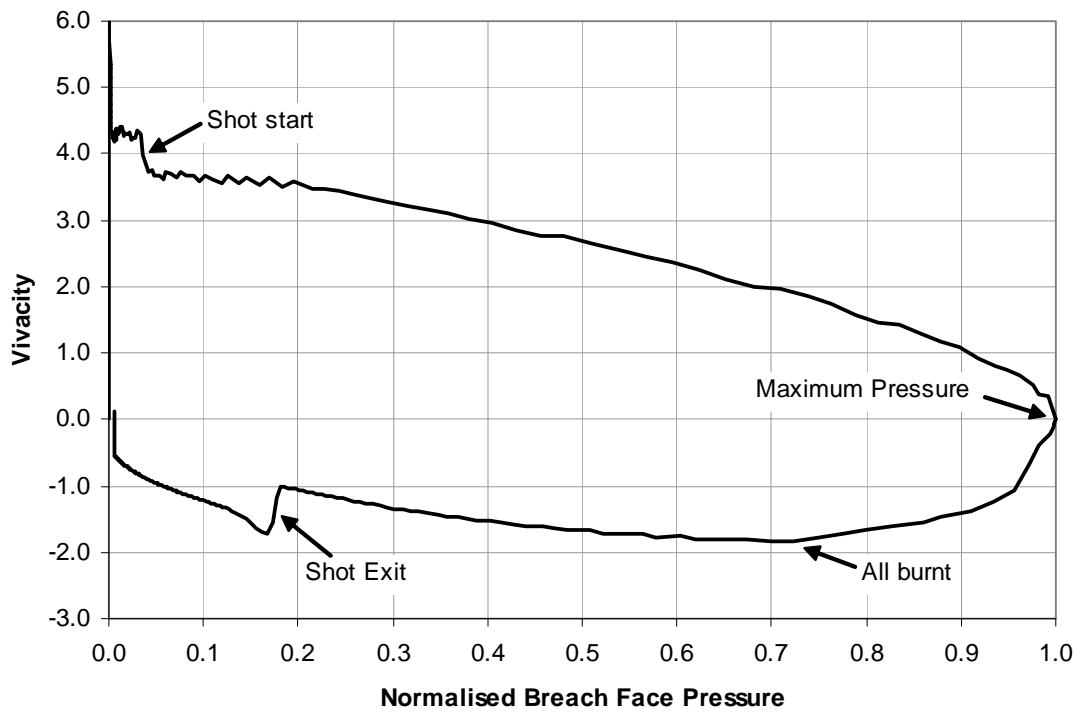


Figure 4 'Vivacity' curve for gun system firing