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FLUID MECHANICS OF IGNITER DISCHARGE IN LARGE CALIBRE GUNS

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ABSTRACT

A theoretical and experimental investigation has been undertaken to look at the flow phenomena of particles and gases associated with ignition of gun propellants. A one-dimensional two-phase flow interior ballistic code has been employed to study the influence of igniter discharge functions on interior ballistic predictions. The experimental work was conducted recording open air and gun simulator firings using high speed film. The study shows the importance of optimising igniter design to avoid pressure waves in gun chambers.

INTRODUCTION

The interaction between igniter and propellant influences the performance of a gun charge to a large degree [1]. Ignition occurs through the convective and conductive energy transfer from the hot ignition gases and particles to the propellant grains. Effective Ignition of a gun charge is strongly dependent on temperature, local distribution and mass flow rate of these ignition products throughout the propellant bed. In a 127 mm charge for example, a black powder filled bayonet igniter (see Figure 1) is utilised where the ignition products are vented radially through holes in the tube. Ideally the whole charge should be ignited simultaneously, however the geometry of the tube and the location of the vent holes are such that the distribution of the hot gases/particles flowing through the propellant bed is uneven [2]. This results in localised ignition of the propellant bed, followed by high local gas generation rates which are responsible for pressure differences inside the charge. The flame spreading through the charge is also affected by the porosity of the bed which is in turn a function of grain geometry. The pressure differences can be amplified by high loading densities which can result in acceleration of the propellant bed and cause fracture of grains against the base of the projectile (or against the cartridge closure plug). This increases the grain surface area, which in turn leads to an increase in burning rate, and may ultimately lead to the generation of pressure waves [3] within the chamber which can result in gun damage and crew fatalities.

In this study the influence of igniter design on interior ballistic model predictions is studied. Initial open air and gun simulator firings were conducted to visualise the flow of the ignition products.

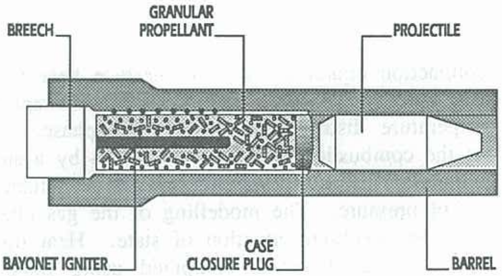

Fig. 1 Schematic diagram of propellant charge

MATHEMATICAL MODEL

One of the classic two-phase interior ballistic models is the NOVA code [4]. It was developed by Paul Gough Associates in conjunction with the US Naval Ordnance Station, Indian Head, Maryland and the US Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. The code was used for the parametric studies conducted here. It is based on a numerical solution of a one-dimensional formulation of the equations of unsteady, heterogeneous two-phase flow using the finite difference MacCormack predictor/corrector scheme. The code employs a macroscopic description of a quasi one-dimensional two-phase flow. The balance equations use average values over regions large enough compared to the heterogeneity of the mixture. The gas and solid phases are coupled through mass, momentum and energy transfer, interphase drag and heat transfer. These processes are modelled by empirical correlations which connect the complex micro phenomena to the bulk properties of the flow. The igniter is treated as a source of hot gas and discharge rates of the igniter are specified as a function of position and time. The igniter function can be obtained experimentally by firing igniters into inert propellant beds and recording the process by high speed camera and pressure gauges. The flame is assumed to spread axially through the propellant bed and is modelled by convective heat transfer. Ignition is assumed to occur when the propellant grains reach a predetermined surface temperature. The propellant temperature is computed using an unsteady-

Table 1. Propellant data

THERMO PHYSICAL DATA				
Impetus (kJ/kg)	1096			
Molecular weight	20.954			
Ratio of specific heats	1.281			
Covolume (m^3/kg)	1.028			
Flame temperature (K)	2012			
BURN RATE DATA				
Pressure (MPa)	40	100	200	350
Burn rate (mm/s)	24.46	42.21	78.20	149.74
GRAIN GEOMETRY				
Grain diameter (mm)	9.75			
Grain length (mm)	9.75			
Perforations	7			
Perforation diameter (mm)	1.0			

heat conduction equation with an interface heat transfer boundary condition. A cubic temperature profile represents the temperature distribution in the solid phase. After ignition the combustion process is modelled by a steady-state correlation using the burn rate of the propellant as a function of pressure. The modelling of the gas phase is based on the covolume equation of state. Heat transfer between the two phases is computed using fixed and fluidised bed correlations. The model also includes correlations for intergranular stress and compaction of propellant grains.

PARAMETRIC STUDIES

Parametric studies have been conducted to investigate the influence of igniter discharge function on interior ballistic performance of the charge. The burning rate of the propellant, its thermochemical data and propellant grain size used for the simulations are listed in Table 1.

Figures 2a-d show various igniter discharge functions which were used to asses igniter design for the following model calculations.

The igniter discharge function for a standard igniter as displayed in Figure 2a shows an erratic discharge behaviour over position and time and this was assumed to lead to the predicted high pressures differences between breech and a position at 686 mm from the breech as shown in Figure 3. The magnitude of the pressure difference is an indication for pressure wave development.

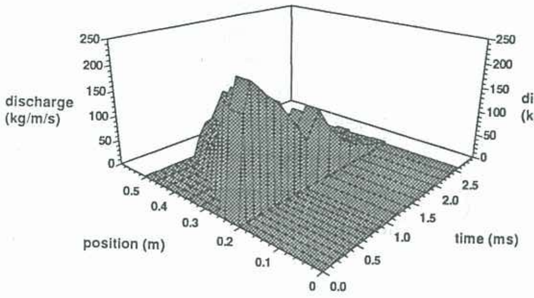

Fig. 2a Standard igniter discharge function

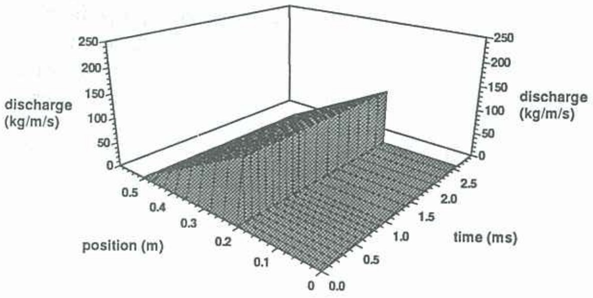

Fig. 2b Discharge function igniter 1

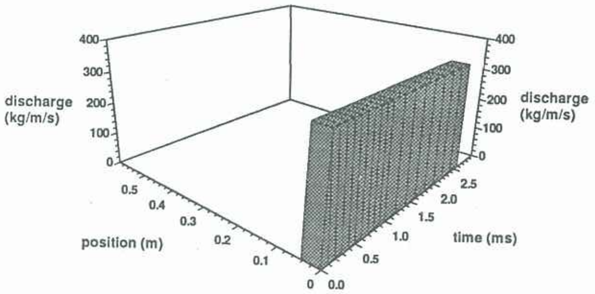

Fig. 2c Discharge function igniter 2

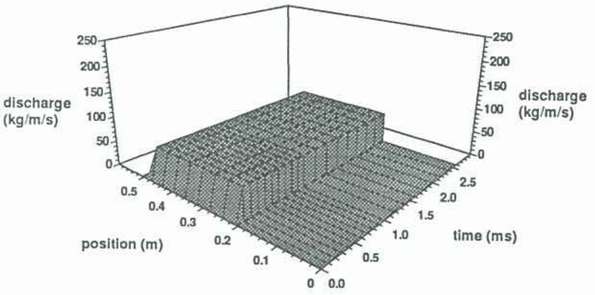

Fig. 2d Discharge function igniter 3

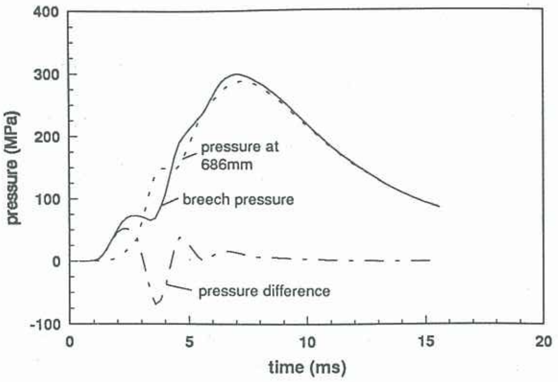

Fig. 3 Pressure-time curves for standard igniter

For all simulations the same igniter mass (52 g) was assumed with only the flow rate and the discharge positions being varied.

Figures 4a shows the predicted pressure differences for igniters 1, 2 and 3. A marked difference in pressure wave development can be observed for the different igniter designs. As expected the homogeneous discharge of igniter products over time and position using igniter 2 predicts the least severe pressure waves. Igniter 3 (discharge at breech end) displayed the highest pressure differences, this simulates the case of a broken igniter tube. Figure 4b depicts the pressure-time curves for igniters 1,2 and 3 at the breech end. The best ballistic performance, muzzle velocity 934.5 m/s at a maximum pressure of 408.7 MPa was predicted for igniter 2. As can be seen the homogeneous discharge results in a smooth pressure-time curve. The muzzle velocity achieved with igniter 1 was 927.2 m/s and igniter 3 was 900.0 m/s. The maximum pressures were 399.9 MPa and 398.1 MPa respectively.

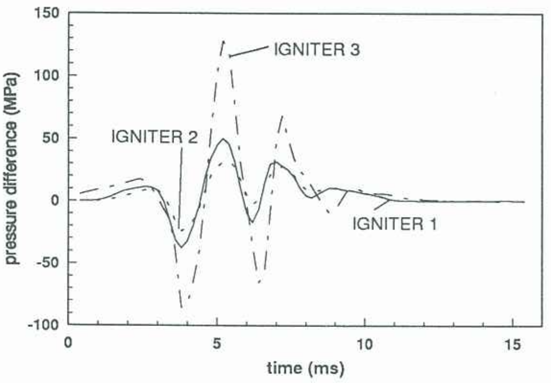

Fig. 4a Pressure difference-time curves for igniters 1,2 and 3

EXPERIMENTAL INVESTIGATION

An initial experimental investigation was conducted using open air and gun simulator firings utilizing a standard igniter tube. The events were recorded using a high-speed camera.

Figure 5 shows photographic data for the first 3.5 ms of an open air firing. The gases first vented at the breech end of the igniter tube and spread from there over the entire length of the tube, however as one can see the discharge was not evenly distributed.

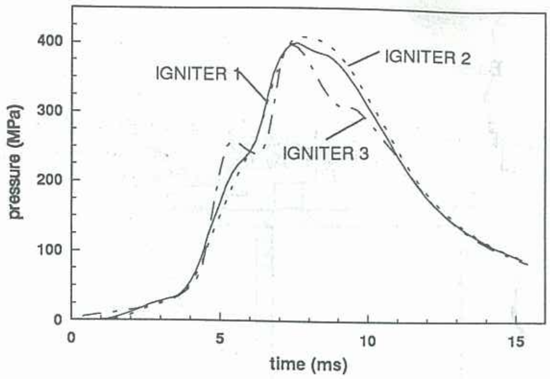

Fig. 4b Pressure-time curves igniters 1,2 and 3

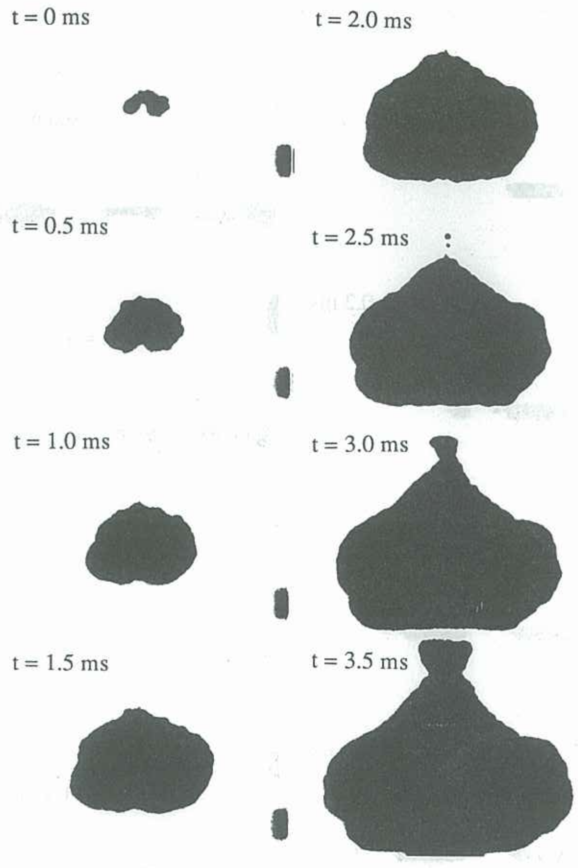

Fig. 5 Flame spreading for open air firing

A gun simulator was used for the next step of the experimental work. Figure 6 shows a schematic diagram of the experimental set-up. The gun chamber is fitted with three viewing windows along the axis of the chamber to allow recording of the ignition event visually, additionally instrumentation ports permit the recording of pressures along the axis. In Figure 7 the photographic data for the first 1.4 ms of the event are shown. A flame could be observed for more than 20 ms. The flame spreading initiated from the rear flash holes and expanded to the front of the tube, with the densest distribution towards the two ends. This indicates that the venting takes place only in a small segment of the chamber. The film also showed that the flame front travelled forwards and backwards between the chamber ends which is consistent with the fluctuating pressures recorded.

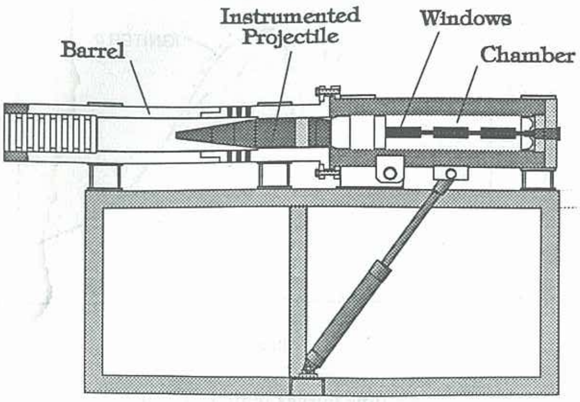

Fig. 6 Schematic diagram of gun simulator

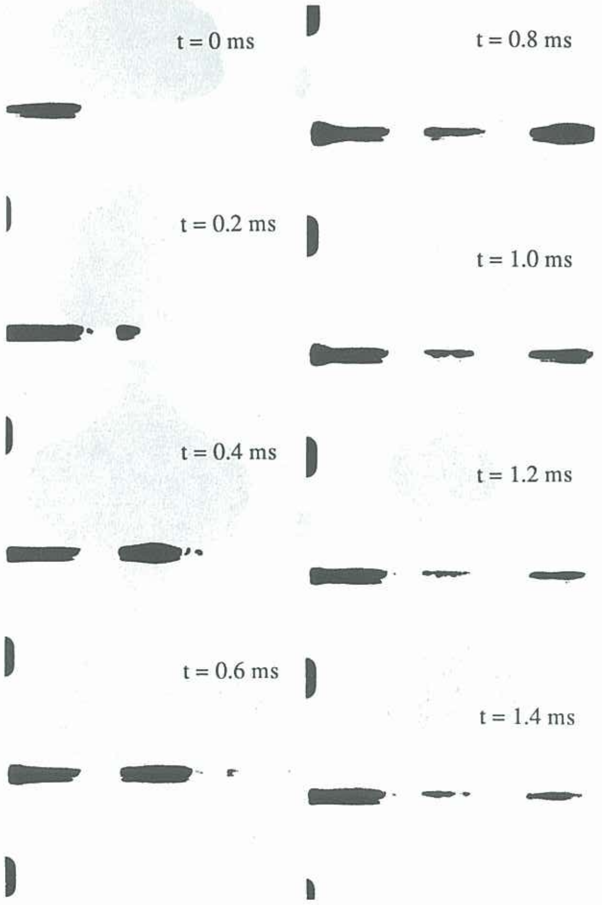

Fig. 7 Flame spreading for gun simulator firing

Optimisation of igniter design to obtain a better distribution of the ignition products through the chamber is planned for the near future.

The aim is to minimize pressure wave development. An igniter with a similar discharge characteristic as modelled in igniter 2 would be the best choice.

CONCLUSIONS

The study showed a marked influence of igniter design on interior ballistic model predictions. Validation of the model predictions using live firings and gun simulator tests with live propellants are planned in the future.

The recording of open air firings of igniter tubes and gun simulator firings using high speed cameras are useful tools for optimising igniter design.

ACKNOWLEDGEMENTS

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REFERENCES

1. Varney, A.M.(1988), Gun propulsion technology, Chapter 1, Progress in astronautics and aeronautics, American Institute of Aeronautics and Astronautics, Inc.

2. Chang, L-M, (1987), Formation of high amplitude pressure waves in a5"/54 LOVA charge, (BRL Report TR-2838), Ballistics Research Laboratory, US

3. Horst, A.W., (1988), Gun propulsion technology, Chapter 4, Progress in astronautics and aeronautics, American Institute of Aeronautics and Astronautics, Inc.

4. Gough, P.S., (1980), The NOVA code: A user's manual, Volume 1, Description and use, (IHCR 80-8) Indian Head, MD: Naval Ordnance Station.