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# MODELLING OF FUME EXTRACTORS

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The Defence Evaluation and Research Agency (DERA) has developed a computational model of the operation of a fume extractor. This computational model extended a one-dimensional (1D) internal ballistics code by incorporating an additional chamber, representing the fume extractor, on to the barrel. The computational model takes into account the volume of the fume extractor, the location of the fume extractor on the barrel, the location of the drillings and heat loss from the propellant gases to the fume extractor walls. Exchange of gas mass, momentum and energy take place according to the local conditions in the barrel and the fume extractor. The computational model simulates the complete internal ballistic cycle, starting with ignition and combustion of the propellant, shot movement and post-shot ejection of the propellant gases. Comparing its predictions with measured data has extensively validated the computational model. This paper presents details of the computational model and comparisons of its predictions with measured pressures. Details of a parametric study are also described.

## INTRODUCTION

With enclosed self-propelled guns and tanks, it is necessary to ensure that all or most of the toxic propellant fumes are carried away through the muzzle and do not flow back into the turret when the breech is opened. Fitting a sealed container, called a fume extractor, over part of the barrel and arranging small drillings into it through the barrel wall can clear the fumes. Fig 1 illustrates the action of a fume extractor. Propellant gases passing through the barrel fill the fume extractor with gas at high pressure. After the projectile exits the barrel, the gas pressure in the barrel rapidly drops to atmospheric pressure. The gas in the fume extractor exhausts as jets down the drillings which are inclined forward towards the muzzle. These forward moving jets have a sucking effect on the gases left in the chamber and rear of the barrel, drawing them away from the breech.

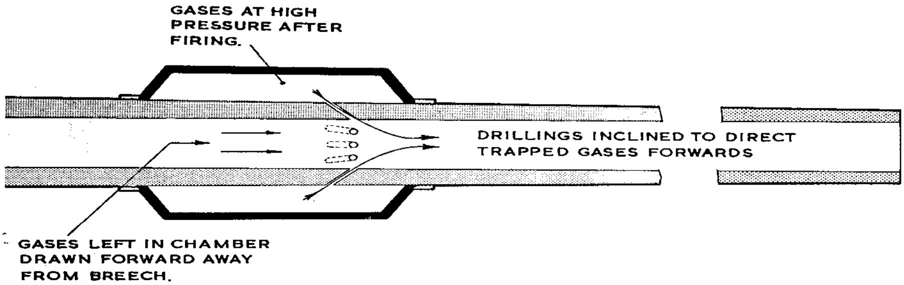

Figure 1.

It is important to note that the gases produced from the combustion of different propellants can be significantly different. For example, one propellant could produce a much greater amount of CO than another could. So, even if the mass of the CO-rich propellant gas vented through the breech is less than that of the CO-poor propellant gas, the CO-rich propellant may turn out to be more toxic than the CO-poor propellant. This paper does not address the gas composition or the toxicity of the propellant gases.

## COMPUTATIONAL MODEL

The CTA1 code [1] is a well-validated, mature computational model that simulates the internal ballistics of conventional and novel (e.g. electrothermal-chemical) gun systems. As the CTA1 code contained many features that could be used or enhanced to model fume extractors, it was modified accordingly. The CTA1 model divides the region between the breech and the base of the projectile into a number of computational cells and applies conservation laws to these cells. The fume extractor is modelled in a similar manner to the barrel. In this way the variation in pressure, density, temperature and velocity of the propellant gases in the barrel and fume extractor can be predicted during the internal ballistic cycle. The internal ballistic cycle starts from the instant the primer gases are produced, through to the instant when the projectile exits the muzzle, and ends when there is no propellant gas remaining in the barrel. Particular features of the CTA1 code that are used to model fume extractors are

- gas flow between the barrel and the fume extractor;
- gas venting through the breech into the turret;
- gas venting through the muzzle;
- heat transfer from the propellant gases to the barrel and to the fume extractor.

The shape of the drillings is taken into account by the use of discharge coefficients, which can be different, depending on the gas flow direction. Fig. 2 shows a typical profile (not to scale) of the drillings between the fume extractor and the barrel. For a 155 mm gun the ratio of the diameters at A and B is about 3:1. The total length of the drilling would be about 100 mm. Depending on the direction of flow in the drilling, the gases either encounter two sudden enlargements or two sudden contractions. All of these contribute

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toward the flow losses. Frictional losses will depend on the roughness of the wall of the drillings. Furthermore, the losses will be dependent on the flow conditions, i.e. whether the flow is laminar or turbulent. To resolve fully the flow losses in the drillings would require the use of a viscid two-dimensional or three-dimensional code. The level of complexity of such calculations would lead to very long simulation times and would still be subject to errors due to uncertainties in the roughness of the wall of the drillings. An alternative approach was pursued and is described in [2]. The flow losses become simply an algebraic sum of the flow losses in and between each segment of the drillings. For example, for the case of gas flow from the fume extractor to the barrel, referring to Fig. 2:

total flow loss = frictional flow loss in section AC +
flow loss due to sudden contraction at C +
frictional flow loss in section CD +
flow loss due to sudden contraction at D +
frictional flow loss in section DB +
flow loss due to sudden expansion at B.

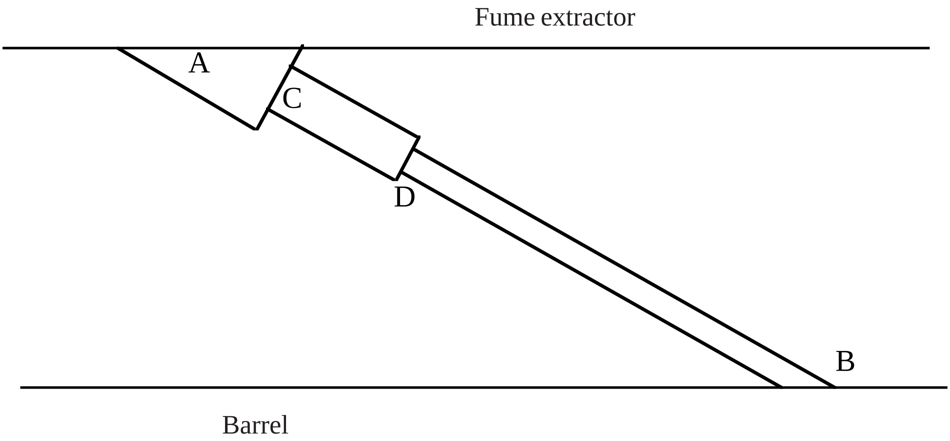

Figure 2.

Using this method, typical dimensions of the drillings and the coefficients stated in [3] then the effective flow loss through the drillings is in the range 20–30%. This flow loss is used in the modified CTA1 code as a discharge coefficient. The calculations showed that there was little dependence on the direction of the flow, i.e. whether to the fume extractor or from the fume extractor.

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Fig. 3 shows the average pressure in the fume extractor and the gas mass flow into the fume extractor for a typical 155 mm gun firing (maximum chamber pressure of about 350 MPa). The fume extractor is pressurised quickly, at about 12 ms, after the projectile has travelled past the location of the drillings. After reaching a peak pressure of about 0.6 MPa the fume extractor pressure begins to decrease, initially due to heat loss to the barrel and fume extractor metal. Even though gas is flowing into the fume extractor, this increase in mass and energy is insufficient to compensate for the heat loss. When the drillings are first exposed to the combustion gases the pressure at that location in the barrel is about 120 MPa. This high pressure causes a very large gas flow rate, peaking at about 1000 kg/s, into the fume extractor. The gas pressure in the barrel, and also the gas flow rate, rapidly decreases until, at about 76 ms, the pressure in the barrel has fallen to less than that in the fume extractor. Gas then flows from the fume extractor into the barrel at a rate of about 8 kg/s, and decreasing. This reverse gas flow can not be seen clearly in Fig. 3 because of the scale of the graph. The gas flow from the fume extractor to the barrel continues for over 0.5 s.

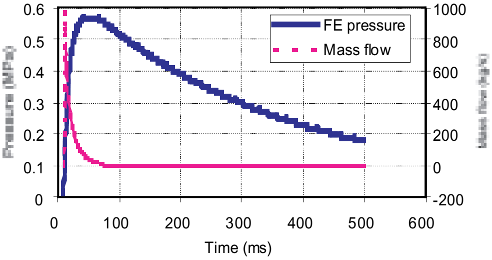
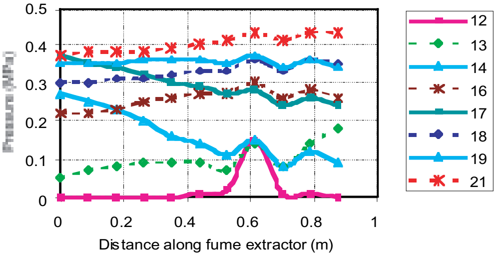


Figure 3.



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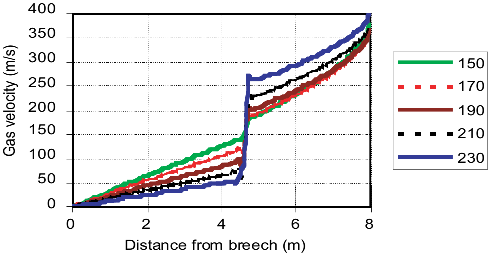


Figure 5.

Fig. 4 shows the spatial pressure profiles in the fume extractor during the first few milliseconds after it has been pressurised. The sudden pressurisation of the fume extractor causes comparatively large pressure waves for the first few milliseconds. However, after about 19 ms the pressure waves have subsided. The numbers in the legend key refer to milliseconds.

Fig. 5 shows typical spatial velocity profiles in the barrel for times in the range 150–230 ms. The shapes of the velocity profiles indicate that the jets of gas from the fume extractor are having the desired effect of increasing the gas flow rate in the forward part of the barrel.

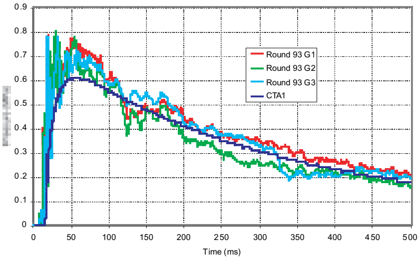
# VALIDATION OF FUME EXTRACTOR MODEL

An extensive series of gun firings were carried out in the 155 mm Extended Range Ordnance (ERO) in order to provide data for validation of the fume extractor model. The ERO has a chamber volume of approximately 231 and a barrel length of approximately 8 m. These gun firings investigated the effects of differences in the fume extractor volume, locations of the drillings, gun elevation and charge mass. Measured data included gas pressures at three locations in the fume extractor and gas pressures at the breech.

## Fume extractor pressures

Fig. 6 compares the predicted and measured gas pressures in the fume extractor for the top charge of a modular charge system (MCS) in the ERO. The pressure gauges were mounted at the two ends and at the middle of the fume extractor. The peak predicted pressure is about 10 % lower than that measured. There is excellent agreement between the predicted and measured pressures for the rate of fall in pressure. Fig. 7 compares the predicted and measured gas pressures in the fume extractor for the bottom charge of the MCS in the ERO. The peak predicted pressure is similar to that measured. The predicted pressures decrease at a faster rate than those measured. The stepped nature of the predicted pressure profile is due to the pressures being printed to two decimal places only by the CTA1 code.

Predictions were also conducted for a fume extractor that was 50% larger than the standard fume extractor. Fig. 8 compares the predicted and measured gas pressures in the larger fume extractor for the top charge of the MCS. Rounds 108 and 110 were fired at similar conditions. The predicted maximum fume extractor pressure is slightly less than those measured. However, the agreement between the predicted and measured pressures after maximum pressure is excellent.



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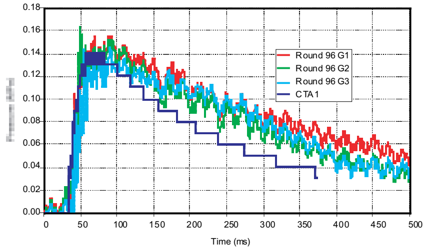

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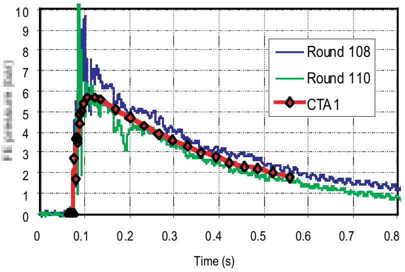
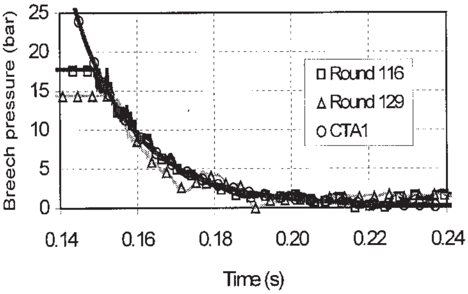


Figure 8.

### Breech pressures

Gas pressures were measured at the breech face to provide further data for validation of the code and to increase confidence in the predictions of the code. The breech pressures were measured by allowing the breech pressure gauge to become 'active' only after the instant of maximum pressure, during the later stages of the internal ballistic cycle when the gas pressures were less than about 5 MPa. However, for some gun firings the pressure signal drifted with time due to the temperature sensitivity of the pressure transducer that was used. The accuracy of the breech pressures was estimated to be about 0.1–0.2 MPa.

Fig. 9 compares the predicted and measured breech pressures for the top charge of the MCS. Rounds 116 and 129 used fume extractor volumes equal to a 25% volume increase and a 100% volume increase respectively. The agreement between the predicted and measured breech pressures is excellent. Fig. 10 compares the predicted and measured breech pressures for the bottom charge of the MCS. Both rounds 75 and 149 used a 25% larger fume extractor volume. The measured pressures show some round-to-round variability. The agreement between the predicted and measured breech pressures is good. However, the predicted breech pressure does not decrease as quickly as the measured pressures.



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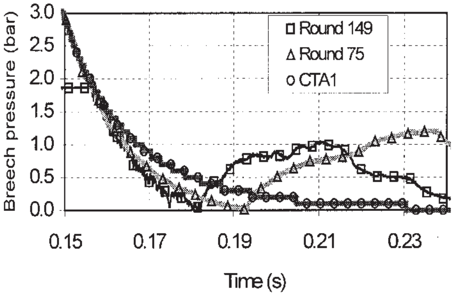

Figure 10.

## PARAMETRIC STUDY

Having validated the computational model, and gained considerable confidence in its predictions, a parametric study was conducted to investigate the effects of various parameters on the fume extractor pressures and the gas mass vented through the breech. The parametric study investigated the effects of the following parameters: outer radius of fume extractor, length of fume extractor, location of fume extractor, location of drillings and the number and diameter of drillings.

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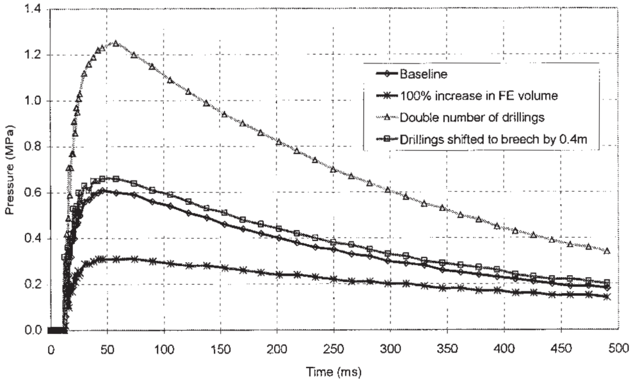

Figure 11.

Fig. 11 shows the predicted fume extractor pressures for the top charge of the MCS for various conditions. Increasing the volume of the fume extractor has the expected effect of decreasing the pressures in the fume extractor. Increasing the number of drillings increases the maximum fume extractor pressure. Shifting the drillings from the muzzle end of the fume extractor, towards the breech end, has the effect of increasing the fume extractor pressures. This increase in the pressure is expected because the gas pressure in the barrel increases in the direction of the breech. Similar trends occurred for the other charges of the MCS.

During the recoil of the gun, the breech is opened automatically to allow the loading of a new projectile and charge. The time at which the breech began to open and the time at which the breech became fully open were measured in several gun firings. For a typical firing these times were about 0.3 s and 0.5 s respectively. The CTA1 code was used to compare the gas mass vented through the breech for a range of conditions. Increasing the number of drillings, which is equivalent to increasing the flow area, has the effect of increasing the gas mass vented through the breech. This finding is supported by experimental data that found increased levels of carbon monoxide when the diameter of the drillings was increased [4].

## CONCLUSIONS

A 1D internal ballistics code has been extended to simulate the operation of fume extractors by incorporating a secondary chamber and allowing exchange of gas mass, momentum and energy between the secondary chamber and the barrel. The computational model takes into account the volume of the fume extractor, the location of the fume extractor on the barrel, the location of the drillings and heat loss from the propellant gases to the fume extractor walls. The fume extractor model does not address the problem of the toxicity of the propellant gases.

The behaviour of the fume extractor model is consistent with that seen in gun firings. Extensive gun firings have allowed the fume extractor model to be successfully validated for a wide range of different conditions.

# ACKNOWLEDGEMENTS

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