The Explosive Component Water Gap Test - Recent Developments

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Abstract

Insensitive munitions (IM) improve the survivability of both weapons and their associated platforms from accident or enemy action. To achieve IM compliance each of the sub-system in the weapon, including the components in the fuze and explosive train, should also be insensitive.

NATO Standardisation Agreement (STANAG) 4187 describes the safety design requirements for fuzing systems used in operational and training munitions. It requires the explosives and/or explosive compositions to be assessed and qualified in accordance with STANAG 4170, and the shock sensitiveness of the explosive components to be evaluated accordance with STANAG 4363 using the Explosive Component Water Gap Test (ECWGT) which is described in Allied Ordnance Publications (AOP) 21.

This paper discusses the results of a modelling study and supporting practical experiments on the ECWGT. The output from the standard donor charge has been modelled and high speed video was used to determine the position of the shock wave in the water column at different times.

The work has shown that the selection of the Hugoniot data has a significant effect on the calculated shock pressure, especially in the high pressure region. Although this does not affect the criterion used to decide if a component meets the requirements of STANAG 4363, it is important when establishing a computer model of the ECWGT.

Introduction

Insensitive munitions (IM) improve the survivability of both weapons and their associated platforms from accident or enemy action. To achieve IM compliance each of the sub-system in the weapon, including the components in the fuze and explosive train, should also be insensitive.

The Explosive Component Water Gap Test (ECWGT) is used to evaluate the shock sensitiveness of lead or booster explosive components; in a modified form the test can be used to study detonating cords. NATO AC 310 Sub-Group (SG) II is responsible for the standards associated with the ECWGT; STANAG 4363 which aims to standardise the characterisation and safety assessment of lead and booster explosive components and AOP 21 which describes the ECWGT procedures and test item configuration in detail.

The ECWGT allows the vulnerability of non-interrupted fuze components to shock stimuli to be established. It can also be used to examine changes in shock sensitiveness of components following environmental stressing by thermal shock, mechanical shock or vibration. Components with a 'no-go' level equal to or less than 28 mm are considered suitable for use in an uninterrupted explosive train. This value is based on the results of the water gap test of the tetryl calibration standard.

A similar test, the Small Scale Water Gap Test, described in STANAG 4488 is used to characterise the shock sensitiveness of materials.

Background

The BICT-gap test, on which the ECWGT is based, was first described in 1967 [1]. Initially only materials were examined but by 1977 the test was being used in Germany for the qualification and testing of lead and booster components [2]. In 1982, the shock pressures for water gaps of between 7 mm and 62 mm were reported [3]. They were calculated from measurements of the time for the shock wave to pass through different column lengths of water confined in PMMA tubes with an internal diameter of 21 mm.

A review of previous work on the ECWGT has recently been published [4]; the paper also includes ECWGT data not previously available in the open literature.

QinetiQ has been working with the UK National Safety Approving Authority (NSAA) to develop a computer model of the ECWGT with a predictive capability, and define a regime for testing booster components that are larger than the current maximum allowed diameter of 45 mm.

This paper reports progress on the development of the model to accurately predict the shock pressure at different water gaps and seeks to verify the original data [3].

Modelling studies

The shock pressure produced by the donor explosive pellet at different water gaps has been modelled using GRIM, an Eulerian-based hydrocode. Since the materials used in the ECWGT are not precisely characterised, Gruneisen Equations of State (EoS) for the inert materials (water, aluminium, nylon and PMMA) were chosen directly from the GRIM materials library.

A Jones-Wilkins-Lee Extended (JWLX) EoS for the booster material was based on 97% RDX/3% wax which had been modelled in CHEETAH to provide the input parameters for GRIM. Initiation originated from a point at the centre of the booster.

The shock pressures calculated using the model and those determined by Trimborn [3] are compared in Figure 1. Good agreement was found for water gaps greater than 25 mm but there are discrepancies at water gaps below this which corresponds to the higher shock pressure region. Changing the Liquid Equation of State (EOS) of water for the Mie Gruneissen EOS had a minimal effect on the pressure predicted by the model and applying alternative physical parameters for water, obtained from published experimental results also failed to give improved agreement.

In the original work [3], the distance-time data were fitted to one of two functions depending on the water gap. The shock wave velocity-distance was calculated from the data and used to calculate the shock pressures for each water gap. In the high pressure region a Hugoniot published by Cook et al [5] was used and in the low pressure region one published by Woolfolk et al [6] was applied.

In order to determine whether the choice of Hugoniot had a significant effect on the shock pressure, the data in the high pressure region given by Cooke et al. [5] were applied to the shock velocities given by the model. The shock pressures calculated in this way were found to be significantly lower and agreed to within 10% of those given by Timborn [3] for water gaps as small as 12 mm. Application of a Hugoniot for water published by Los Alamos National Laboratories [7] to the Trimborn results [3] increased the calculated shock pressure to within 6% of those originally determined using the model.

Experimental

To support the modelling studies, experimental work has been conducted to confirm the distance-time relationship for the shock wave passing through a column of water gap using high speed video.

For all of the experiments, the column of water was contained by a thin sheet of cellulose acetate and high density polyethylene plugs were used to seal each end of a tube formed from the cellulose acetate sheet; the upper plug was designed to hold the donor pellet and detonator. In each test, a flat faced, double end pressed donor pellet of 95% RDX/5% wax with a mass of 10.00 ± 0.01 g was initiated using a low intensity N38B electric detonator.

High speed video recordings were made of each event and three different frame rates were used in order to optimise the definition and inter-frame period (Table 1). Line scale markers were positioned 10 mm apart, to allow the shock wave distance-time curve to be determined; for the higher framing rates the line scale markers were interspersed with 5 mm dot markers.

Initially tests were performed using water columns with a diameter of 50 mm and a length of 240 mm. These experiments were used to determine the optimum lighting levels and timings but also allowed visualising of the early phase of shockwave transition. Further tests were performed at two higher framing rates with a shorter 75 mm column; these experiments provided more data over water column lengths of 70 mm and 50 mm (Figure 2).

Results and discussion

Three experiments were performed using 240 mm long tubes. Each frame from the high speed video was analysed to determine the position of the shock wave. Initially, the centre of the shock wave was in advance of the edges but by 70 mm an almost linear shock wave was achieved. The shock wave becomes progressively weaker and beyond 150 mm it is too faint to identify on the video record.

Although the time between frames on the high speed video is known accurately, the time that the shock wave first enters the column of water does not correspond exactly with the timing of the camera. It was therefore necessary to estimate the initial time of arrival of the shock wave in the water column and the values selected were based on a constant velocity of 4.5 mm μs^{-1}. This value was determined from the results given by the 70 mm water column.

The shock waves in the first frame of the video of the tests on the 250 mm long water column were found to be at 4.5 mm, 6.9 mm and 8.4 mm from the top of the water column; the times of arrival at these positions were calculated to be 1 µs, 1.5 µs and 1.9 µs respectively. The corrected time and distance travelled (water gap) data for the three experiments are shown in Figure 3 along with a polynomial fit to the data. Although there was good agreement between the experiments, the data for the third test showed some differences at higher water gaps.

A comparison of the results with the data reported previously [3] (shown by the solid line on the graph) especially in the region of interest (water gap of 10 mm to 50 mm) showed very good agreement (Figure 4).

To increase the number of data points obtained, an additional experiment was performed with a framing rate of 390,000 frames per second; this reduced the inter-frame period to 2.56 µs. This change also results in the resolution of the image decreasing and a reduction in the length of the water column that can be observed. Despite the reduced resolution, the determination of the shock wave position generally improves because the size of each pixel had increased.

For this experiment the shock wave position in the first frame was at 8.9 mm which corresponded to an arrival time of 2 µs, the time and position data for each frame are shown in Figure 5 along with the curve for the previous data [3]. Once again, good agreement between the two data sets was observed.

This test was used to determine the initial velocity of the shock wave which was calculated by fitting the experimental data to a polynomial curve of the form

$$t = as^2 + bs$$

where t is the time and s the water gap.

The first five data points were used for the calculation, including (0, 0) and (8.9, t_1) where t_1 is the time for the shock wave in the first frame. For each set of data the constants a and b were determined and the value of t_1 was changed until the difference between the starting value and the calculated value was minimised.

The 70 mm test was selected for the calculation because it had sufficient data points in the region up to a water gap of 30 mm which was previously identified [3] as the range over which a good fit was obtained. There were insufficient data for the tests on the 250 mm water columns and too many data points missing at the start of the 50 mm water column test. However, using the limited data available for these experiments also confirms a value of around 4.5 mm μs^{-1}.

The images from the test on the 70 mm water column are shown in Figure 6. They show the shockwave’s progress from the initiation flash of the donor pellet in the first frame, through the curved wave-shape in the early phase, to the 70mm point by which time it has become almost planar.

In the final experiment, the framing rate was increased again so that the inter-frame period was 1.47 µs; the water column length that could be viewed was further reduced to 50 mm. The shock wave was obscured on the first two frames of this test, so it was not observed until it was at 14.47 mm in the water column; the estimated arrival time at this position was 3.4 µs. The data for this test are also plotted in Figure 5 and they show good agreement with the experiment using the 70 mm long column of water, the limited data obtained in the same region for the 250 mm long water column and the previously reported data [3].

Conclusions

The choice of Hugoniot used in the model of the explosive output from the donor charge was found to significantly affect the predicted shock pressure. Since the shock pressure is fundamental to modelling the input to an acceptor charge, additional experimental work that will directly measure the shock pressure in the water column is required.

The high speed video experiments agreed well with the shock wave position-time data determined by Trimborn [3] but it was necessary to estimate the time for the shock wave in the first video frame. Future experiments would benefit from the incorporation of a technique to determine when the shock wave first enters the column of water.

An improved resolution of the shockwave position could be achieved by recording the ECWGT using an ultra-fast camera.

References

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Tables

Rate (Frames per second)	Inter-frame period (µsec)
110,000	9.09
390,000	2.56
680,000	1.47

Table 1: Framing rate and inter-framing period.

Figures

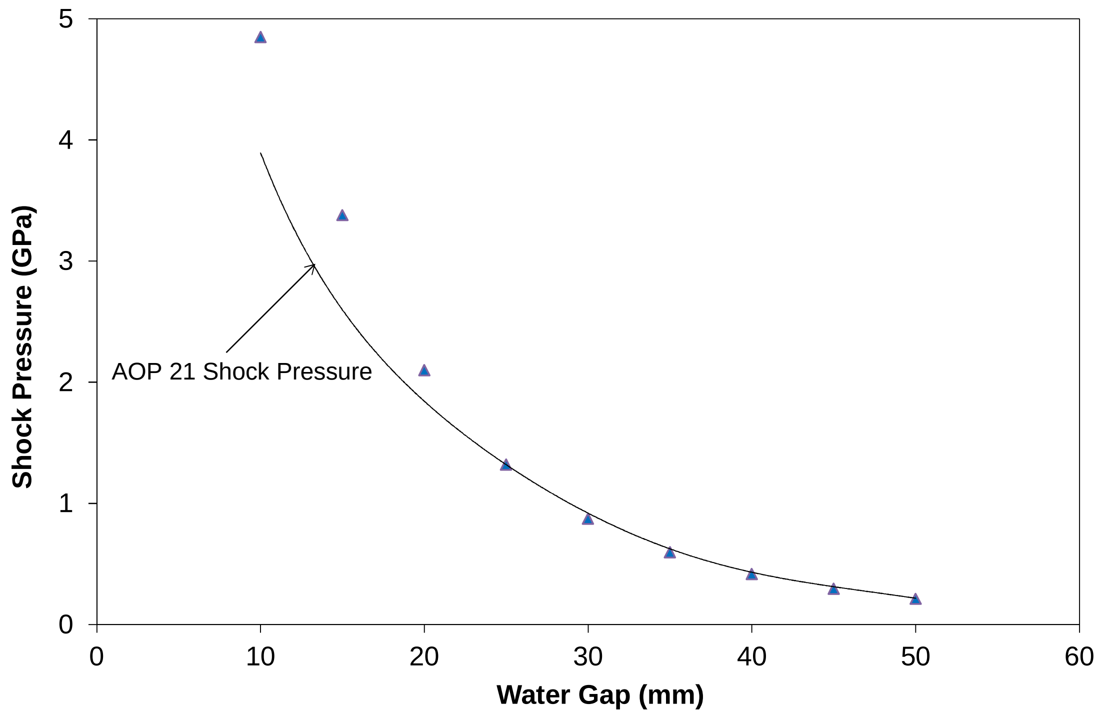

Figure 1; Curve of Shock Pressure against Water Gap.

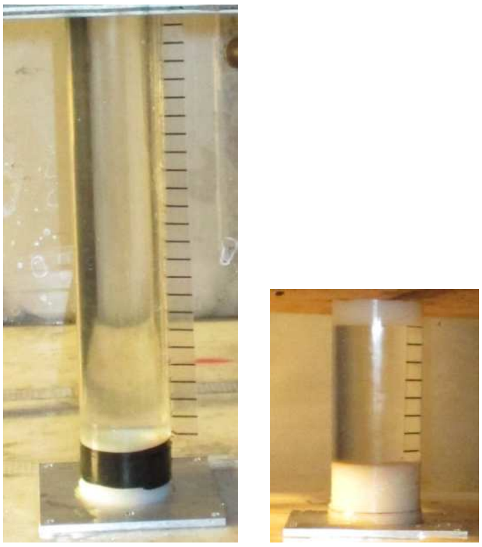

Figure 2; 240 mm and 75 mm water gap tests prior to firing.

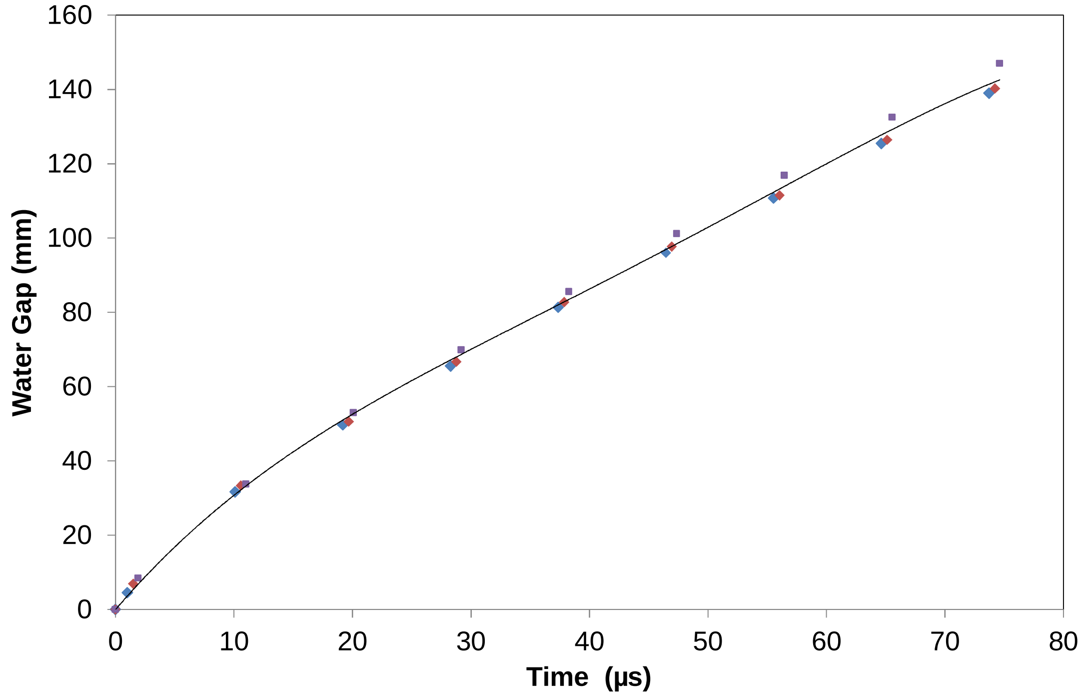

Figure 3; Curve of Water Gap against Time for 250 mm tubes.

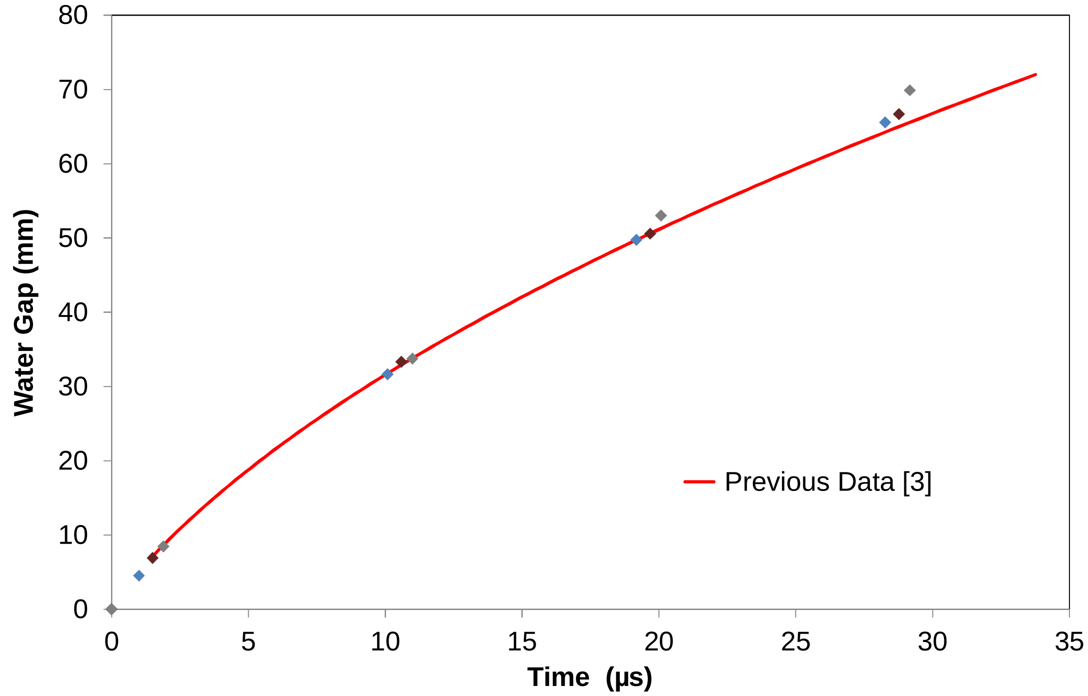

Figure 4; Comparison of high speed video for 250 mm water column and data reported previously [3].

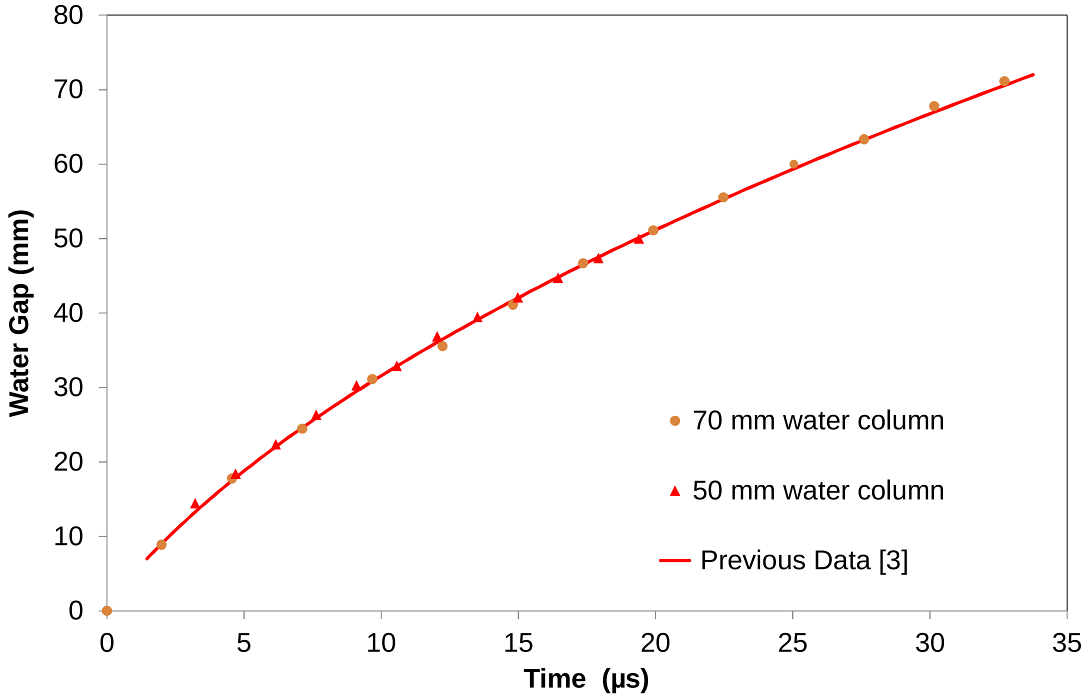

Figure 5; Comparison of high speed video for 70 mm and 50 mm water column and data reported previously [3].

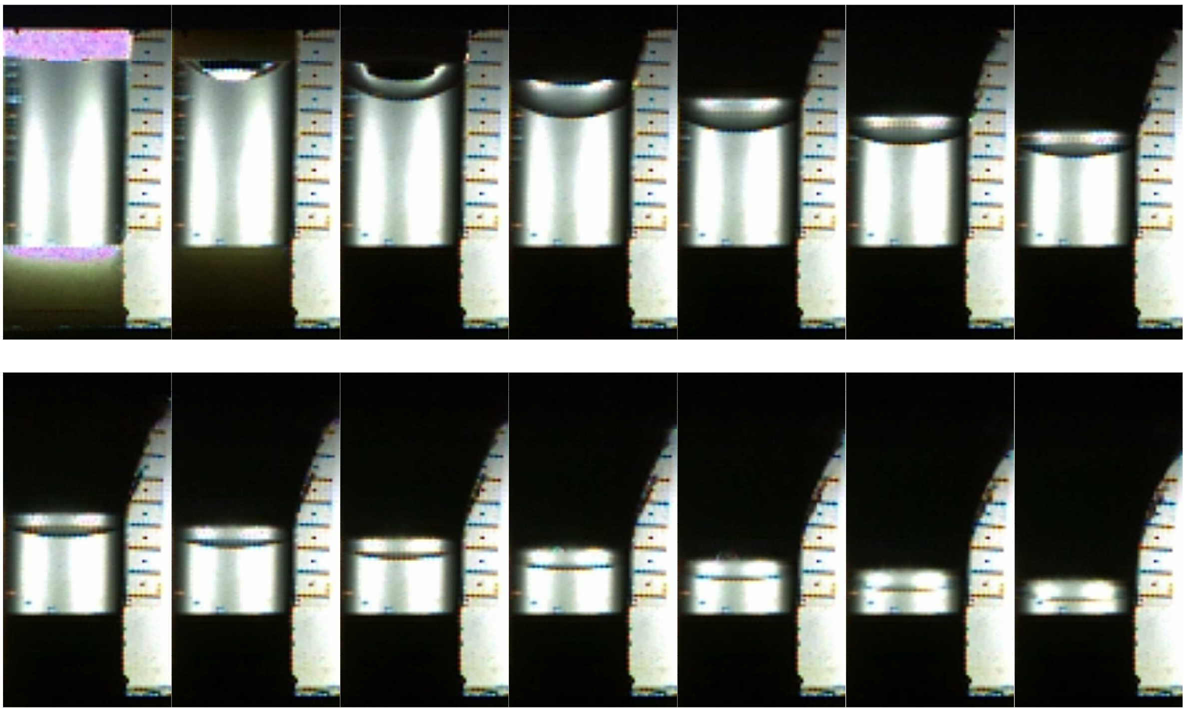

Figure 6; Screen shots from high speed video with an inter-frame period of 2.56 μsec.