Application of Integrated Trials Techniques for Blast Analysis of PBX Materials

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Abstract :-

A recent series of experiments was performed to examine the effects metal cases have in diminishing the blast from an explosive charge.

This paper gives a full description of the instrumentation used in the trial and, in particular, examines the potential benefits for post trial assessment provided by the use of high speed digital image recording systems in parallel with conventional light meter recording.

The practical trials for this work encompassed a total of 31 firings – including 3 off PBX N109 and 2 fragmentation rounds for comparison purposes - of which where the following parameters were examined:

- **Two explosive types: RX1100 (ideal), RX1400 (non-ideal)**
- **Two case materials: Aluminium 6086T6, Steel EN24.**
- **Varying Case mass/charge mass ratios (0, 0.5, 2, 5, 10)**

These tests were conducted at the Ridsdale Range, (BAE SYSTEMS Land Systems) over the period February/May 2005.

This work was performed by BAE Systems, Land Systems and FGE (Fluid Gravity Engineering) in support of the ongoing Warheads 2 programme. This work has been sponsored by RAO-WPE as part of UK MoD technology investment programmes".

Introduction

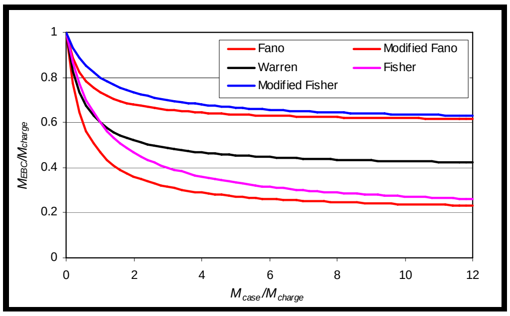
The following paper outlines the steps taken in defining an integrated trials technique for Blast Analysis of modern explosive materials within a variety of cased charges. The requirement for the activity was initially identified as part of the Weapon and Platform Effectors (WPE) domain of the MoD Research Programme – Warheads 2 – currently managed through QinetiQ. This work commenced in 2004 with an initial assessment of existing algorithms and trials results, identified and conducted a series of trials to examine this phenomenon during 2005 and this activity will continue with a further 14 firings scheduled for March 2006. Final reporting of this activity will be conducted by July 2006.

Test definition, material supply, testing and analysis has been conducted by BAE SYSTEMS Land Systems through the Lethal Mechanisms IPT at Chorley - with filling support from Glascoed, modelling at Shrivenham, Trials support from the Fast Event Facility (FEF - Chorley) and BAE SYSTEMS Trials Site Ridsdale. The fundamental analysis of blast data and associated modelling has been undertaken by Fluid Gravity Engineering (FGE), St Andrews, Scotland.

The Effects of Encasement on Charges

When an explosive charge is encased, energy from the explosion is lost by firstly breaking the case, and secondly accelerating the case fragments through the blast wave. Therefore, the blast performance for a cased charge may be significantly less than the blast performance for a bare charge. It is necessary to understand this relationship when considering the design or efficiency of explosive weapons.

Figure 1 Computed Effects due to Casing Mass



Historically a number of algorithms (loosely referred to as Fano-Fisher algorithms) have been used to predict the effects of confinement. (Figure 1). They predict a case's effect as a bare charge equivalency, i.e. the reduction in effective charge mass. A comprehensive study of these algorithms was undertaken in an attempt to baseline the current data.[1] This data , whilst extensive, is sparse in background information on charge confinement or design and, as such, provides a limited platform for algorithm modification or growth for modern materials. It was against this background that it was decided to generate a new data-set of case effects results, by performing a fresh series of experiments for which the design and set-up was well understood.

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[1] Review, Analysis and Comparison of Empirical Algorithms for the Blast Performance of Cased Explosive Charges, Document Ref. 62898 R1 Issue 3, Compiled by D. Crofts, P.Locking, L Edney, J.Wharton (BAE SYSTEMS), J Dunnet and A. Milne (FGE).

Test Definition and Design

Any integrated test approach requires a balance of the test vehicle and its characteristics within a controlled, suitably instrumented test arena. The first of these requires an understanding of critical parameters which will affect output. Initial calculations indicated that, at the very least, the case effect was sensitive to both the case material and fracture mechanics. The test vehicle should therefore allow variation of these aspects with minimal growth in cost or complexity (Figure 2).

The initial programme was chosen to allow case effect measurements to be made for two different case materials and for systems containing both "ideal" and "non-ideal" charge types. (Here a non-ideal explosive is defined as one in which a significant fraction of the energy release occurs behind the Chapman-Jougeut plane). The "ideal" explosive choice for the experiment was Rowanex 1100 (88% RDX, 12 % Binder/plasticiser). The "non-ideal" explosive was Rowanex 1400 (66% RDX, 22% Aluminium 12% Binder/plasticiser). In addition to these fully assessed charges further charges of PBX N109 (64% RDX, 20% Aluminium and 16% Binder/plasticiser) were fired as comparators for current service charges.

Case Materials **-** Aluminium 6086T6 alloy and EN24 steel were chosen as the two case materials. These metals were selected because of their contrasting fracture mechanics, with the aluminium having a relatively high ductility, while the steel is more brittle. These needed to be configured to a range Case Mass/Explosive Mass ratios covering 0.5, 2, 5 and 10:1.

Test Vehicle Definition

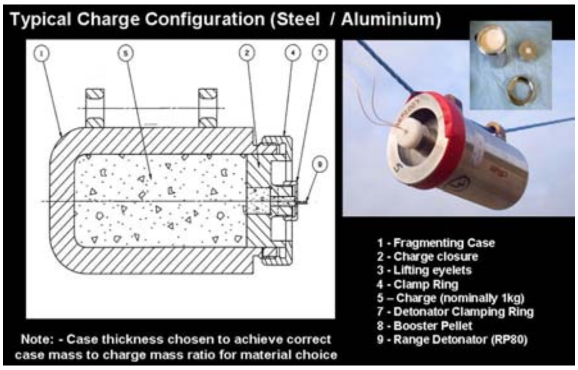

Figure 2 - Typical Charge Configuration

Whilst a perfectly spherical charge would present the ideal test configuration, for representation of the blast field, this would have been difficult to manufacture and assemble. This fixed mass (1kg) cylindrical approach allowed a low risk, consistent design, which also had a higher level of control on ejection angles for fragments, easing protection challenges within the arena. This was defined on a 2:1 length to diameter (72mm) ratio. A further advantage of this design was the use of a fully modular charge. This gave a flexible design providing both bare and cased charges with the potential for transposition of hardware as required. As the maximum mass of the "all up round" was 11kg this allowed direct handling to the 2m height - without mechanical intervention further reducing complications during test.

Firing Programme

As the test series need to examine a number of parameters for both charge and case material configuration it was decided that a "matrix" approach be used. This allowed definition of duplicate firings, with both bare and cased charges. The firing programme was split into two series (initially 14 firings in February, followed by 17 firings in May 2005). Details of the firings can be seen below in Table 1.

Firing Configurations (Feb-May 2005)		Case Mass to Charge Mass Ratio					Total	
Explosive	Casing	0	0.5	2	5	10		
R 1100	Bare	3					3	15
	EN 24		2	2	2	2	8	
	6082T6		2	2			4	
R 1400	Bare	3					3	11
	EN 24			2	2		4	
	6082T6		2	2			4	
PBX N109	Bare	3					3	3
Total		9	6	8	4	2	29	
One R1100 round (Steel 5:1) used as fragmentation check								

Table 1 Firing Configurations

It should be noted that two of the original sequence were configured as EDC1 filled Fragmenting Warheads and that the data provided by these has not been used in this study. This sequence maximised data for the high mass ratio steel configurations with Rowanex 1100 with lower limits applied to the Rowanex 1400 filling.

Further trials scheduled for March 2006 (14 firings) will introduce higher mass aluminium cases for both configurations and expand the steel data for Rowanex 1400. In addition the bare charge results for PBX N109 will be supplemented with EN24 confinement data.

Arena Layout

In order to, as far as possible, isolate the experiment from the effects of the ground reflected shock or any adjacent structures it was decided that the test vehicles would be suspended above the ground to a height of at least 2m. Whilst a greater suspension height would assist in reducing ground effects it was found that this would lead to severe handling problems for the trial and would result in more complicated, costly and time-consuming arena re-build between firings. The suspension lugs were incorporated at the top of the case body to allow insertion of a suspension line to achieve this. Whilst it was recognised that these would have some effect on local pressure release, their position was chosen to minimise this effect along the line of the pressure gauges. In all cases the charge was mounted so that its centre line was perpendicular to the blast gauges.

Arena Layout and Instrumentation

A schematic and picture of the trials layout for both series can be seen below at Figure 3. In Series 1, the blast pressure was measured using 4 ICP137A (Pencil) and 4 B12 gauges, mounted as pairs, along the centre line of the charge and mounted at distances of 3m, 4.5m, 6m and 10m from the charge.

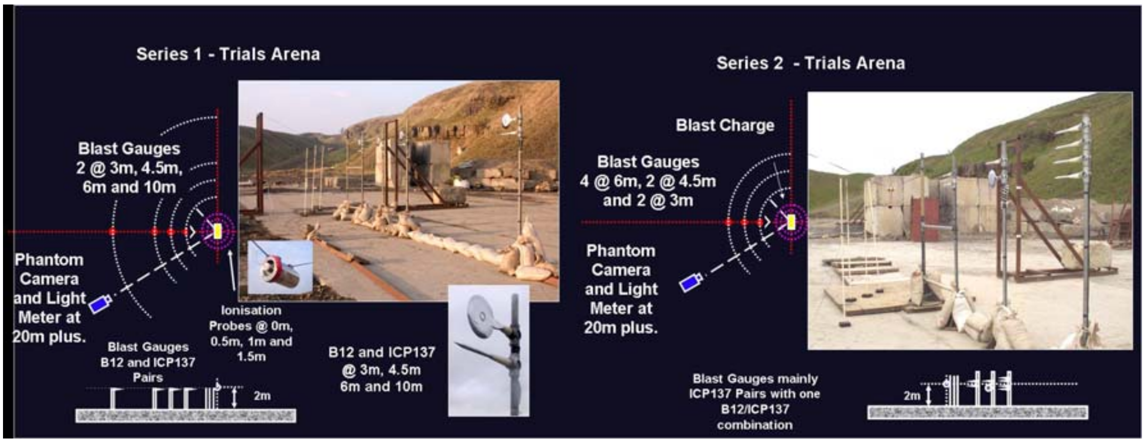

Figure 3 – Trials Arena for series 1 and 2 tests.

The progress of the fireball and products was recorded using a high-speed Phantom camera and a series of ionisation gauges were placed in close proximity to the charge in an attempt to record the time of arrival of the fireball region at 0m (i.e. intimate contact), 0.5m, 1m and 1.5m for the bare charges. This was attempted on bare charges only. A light meter was positioned adjacent to the high speed camera.

Due to the threat to the survival of the gauges posed by fragments from the cased charges striking the gauges, a protection pole was placed on the same line as the gauges. The protection pole was constructed of a sand-filled scaffold pole (nominally 50mm diameter) and to this was affixed 90 degree "angle iron". This would provide two major characteristics – capture or deflection of any large or damaging metallic fragments coupled with a cleaner separation point for the passage of the pressure wave. This was positioned 1.5m in front of the first gauge. This distance being in line with the ITOPS guidance for wave reformation.

Series 2 Trials Arrangement

Following analysis of data generated during the first test series a number of changes were identified for the arena layout. It should be noted that even with these changes the majority of the trials instrumentation was retained to ensure parity within the resulting test data. The improvements made are detailed below:

<u>10m-gauge position was removed.</u> It was concluded that the usefulness of data captured at the 10m range was being reduced due to the effects of ground reflection of the blast wave. This effect, which becomes more noticeable at large radial offsets, was producing sufficient interference with the gauges that assessment of the full passage of the blast wave was impossible. Following discussion within the team it was decided that enhanced data capture at the 6m range would be a preferable compromise.

Additional Gauges Added to 6m Position. The gauges that would have been included at the 10m position were re-deployed to the 6m position. In the new arrangement 4 sensors were placed at this station rather than the original doublet considered in Series 1. The intention being to increase the number of readings acquired, improving statistical validity and increasing redundancy should fragment strike damage occur.

Light Meter. The light meter readings generated during the Series 1 tests were minimal in content. Adjustment and removal of filtration increased the light sensitivity. Whilst some variation in output was recorded the signal strength was somewhat masked within the overall noise of the signal. The removal of this filter allowed greater output from the instrumentation however, further work is required on achieving an ideal utilisation for a range of explosive materials exhibiting extreme variation of intensity per test. Further work is required on the filters used to achieve an optimised trials set-up. It was decided that the majority of intensity data would be assessed via analysis of the high speed camera data.

B12 Replacement. Examination of results from Series 1 showed that the ICP137A gauges produced, as expected, extremely similar results to the B12 gauges. Since the ICP137A gauges provide a more modern, commercially available and therefore technically supported blast gauge than the older B12 units, it was decided that the majority of gauges for the Series 2 tests should be ICP137A units. A single B12 was retained at the 4.5m position as a comparator unit and this also provided an instrumentation baseline between the test series.

Ionisation Probes. In an effort to increase the output from the ionisation probes alternate configurations were to be assessed during the second series. These would use a small gap between probes rather than simply using a single probe. This was to prove problematic in the test and again the camera information was used for assessment of fireball growth.

Fragment Capture. In an effort to better define the appropriate models used for fragmentation it was decided that one of the rounds, a 5:1 steel bodied RX 1100, should be assessed purely as a fragmentation round and not used for blast assessment. This was tested purely for fragment capture and did not incorporate blast instrumentation or recording from Camera or other light sensor instrumentation.

Blast Pressure Results

The data achieved during both series of tests was used to assess the effective reduction on local pressure for each of the charges when considered against a bare charge equivalent of similar size. It was evident that the signals generated in the bare charge tests were significantly less noisy than those associated with cased charges. This data did allow direct comparison of the gauges and allow streamlining of the tests for the second series.

This noise appears to be directly related to the supersonic passage of the metallic fragments around the sensor area. This noise being generated by the passage of the associated bow-wave over the sensor area.

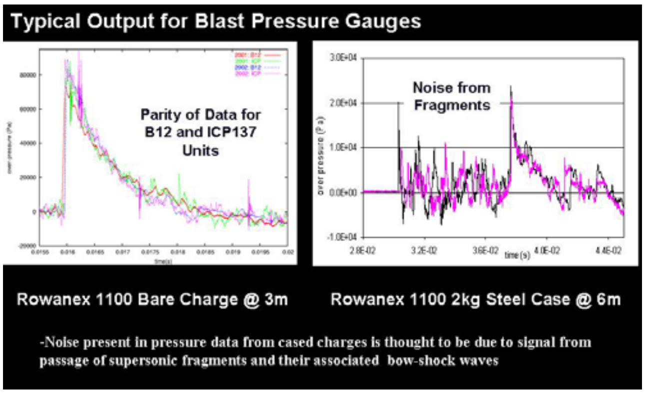

Figure 4 – Typical output from Blast Pressure Gauges

Because of this high level of noise, it was not possible to obtain accurate assessments of peak blast pressures from the cased charge experiments. Consequently, it was not possible to determine the effect the case has on peak pressure, directly from these experiments. Instead, the results were used to determine peak impulses.

A full analysis of the pressure/impulse data has been conducted within the overall test report for this activity and this aspect is covered in the associated Blast Algorithm Poster generated by Jim Dunnet of FGE (Abstract Reference 3342). This has been used to determine a series of Modified Fisher formula for each of the charge/case configurations. These are shown below at Figure 5 and clearly identify a specific formula for each case/charge configuration.

Full details of the firings can also be found in the Warheads 2 milestone report[2]

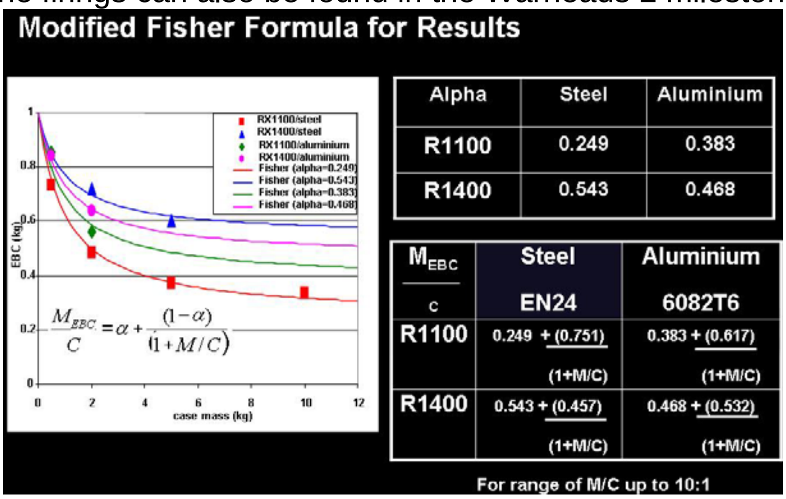

Figure 5 – Modified Fisher Formula for all tests

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[2] Blast Algorithm – Trials Results and Explosive Type Modelling (MWS-CRP M16) Document Ref. 63969 R1, Issue 1. Authors D Flynn, J Wharton, BAE SYTEMS

Results – Phantom Camera

The use of an integrated arena allowed examination of data from a variety of sources. This was particularly evident when considering the fireball/products growth and associated intensity analysis. Whilst an integrating light meter allows generic assessment of light across the field of view it was evident from the camera data that modification of this data may be needed to fully refine this data. Whilst the digital camera cannot sample at the high rates associated with the light meter it is apparent that these images can be visually or automatically assessed (using ancillary software) to supplement transient response output.

The Phantom camera was positioned to capture the blast event yet avoid potential damage from fragments. The camera was placed over 20m away, slightly off-axis to the charge, within a splinter-proof chamber with an armoured glass viewing port.

The camera can be used using varying image size, resolution and framing rates dependant on data writing speed requirements. This equipment can be used in full colour mode with a 512 x 512 pixel area at 1000 frames per second (fps). Rates of 32,000 fps can be achieved for full colour images when the pixel resolution is dropped to 32x128. Using only greyscale data will allow a 3x higher writing speed. For these trials the camera used a resolution of 256x256 pixels, at 8-bit greyscale. This gives an effective writing speed of 12000 (fps). This was felt to balance the requirements for resolution (necessary for edge definition) and integration area for intensity. The 8-bit image differentiates 255 individual intensity layers for each pixel, over an area of 65,536 pixels.

Output from the camera is in a specific Phantom based cine file and the individual frames can be directly interrogated to assess positional data. An example of kind of output is shown at Figure 6 below. This shows the variation in response for a bare and aluminium cased charge of Rowanex 1100. The first montage shows the first 25 frames of a firing sequence. Some over-exposure of the sensor occurred in the first 5 frames but this settles down into a measurable image by frame 6. It is evident that whilst some reflected light is present at the base of the products this is not excessive. The second montage demonstrates the effects of light/medium confinement with aluminium. Aluminium interaction with the concrete arena is clearly shown which gives an extreme effect on intensity values when integrated over the full frame image. This would not, necessarily be picked up by the light meter alone.

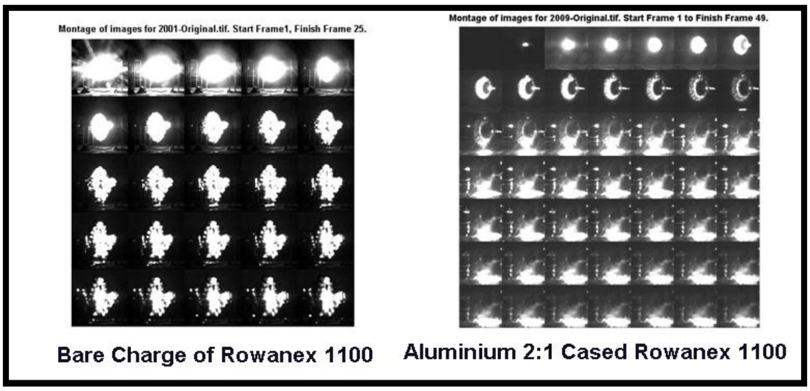

Figure 6 – Typical Camera output showing ground effects following Aluminium case interaction with the arena floor.

Figure 7, below, shows typical output from the camera data. Direct camera readings were used to define the edge of the fireball/products to assess Fireball edge velocity. This showed close comparison between the aluminised explosive whilst the initial velocity regime for Rowanex 1100 demonstrated a 50% reduction in velocity. The intensity data was analysed using a camera generated .tif file which could be assessed using standard image processing sub-routines within the MATLAB software programme. This is an automated process allowing investigation of several hundred frames of data. At present this integrates data regardless of edge effects.

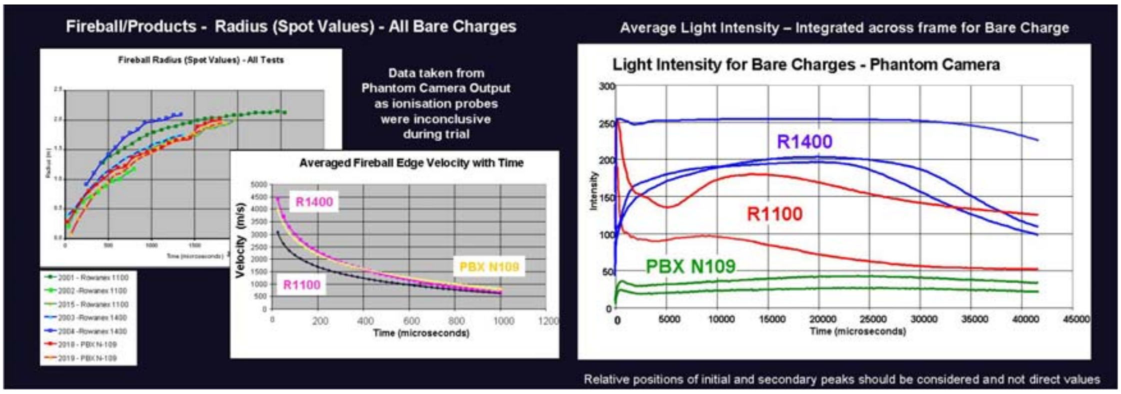

Figure 7- Typical Output from Camera Data

Work is ongoing to refine both of these process and increase the automated elements of the MATLAB process. This can be seen below in Figure 8. This ongoing package of work has examined the definition of a pseudo-streak record of the fireball record. This is automatically positioned about the detonation point and the vertical pixel grouping about this point, for each frame, is then built up into a new photographic record. This measures both upper and lower boundaries of the image and defines overall width for each frame/time combination. This will allow interpretation of the fireball/products growth during the initial stage.

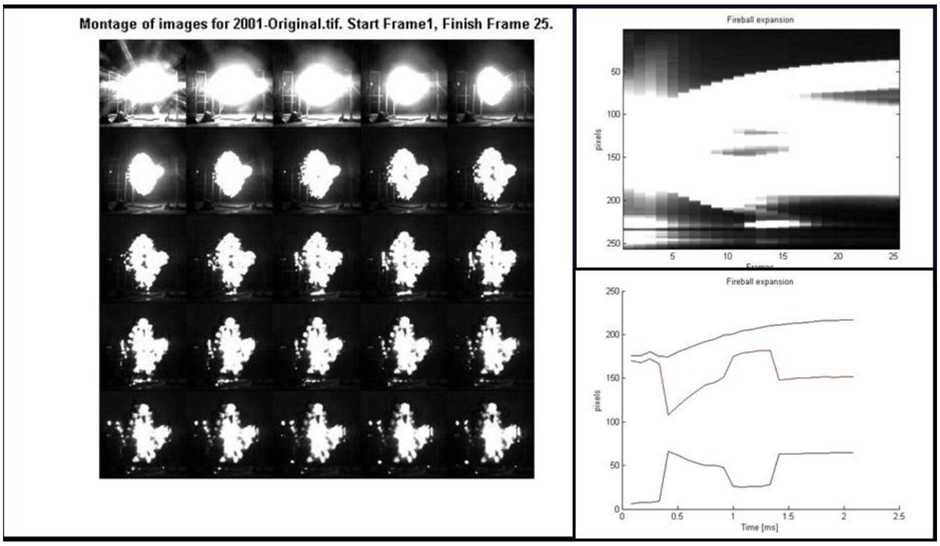

Figure 8 – Automated tracking of Fireball Products using MATLAB.

With regard to intensity assessment work is also underway in assessing techniques to automatically define a sgregated area of interest within the frame and use this boundary for intensity data only. This will reduce the effects of ground flash and other strikes around the arena.

Summary and Conclusions

A set of experiments has been performed to measure case effects for four different systems. The results show that, as well as the mass of the case, case effects depend on charge type and case material. The results have been used to develop case effects algorithms, by fitting generalised forms of the Fano and Fisher curves. It is found that the Fisher form consistently gives a better fit to the data.

Further work will enhance the data at the high mass ratio end of the charges for both RX 1100 and RX 1400. Steel encasement on PBX N109 will also be examined in greater detail. This work, scheduled for test in March 2006 and completion by July 2006 should allow Fisher type algorithms to be fitted a more accurately and expand the current IM Materials dataset.

A flexible trials vehicle has been defined for Blast Analysis testing. The design allows consideration of case mass: explosive mass ratios up to 10:1 - in a variety of materials whilst retaining manual handling. This reduces test time and minimises test costs. This should aid future tests and automatically increase materials database.

The trials arena, offers duplicate independent instrumentation whilst remaining compact in size. Complimentary diagnostics allow the team to examine in greater detail all aspects of the trial. Visual data has enabled detailed use of Post trial analytical tools – such as Matlab image processing – to vastly automate the data output.

Acknowledgements

This work would not have been possible without the dedication and support of a wide range of personnel both within BAE SYSTEMS (Shrivenham, Glascoed, FEF Chorley, Ridsdale Trials Facility and the Lethal Mechanisms group at Chorley), FGE and the UK government. Particular thanks go to Jim Dunnet of FGE for his analytical skills and to Geoff Wanstall for his support in setting up the experiment.