University of Wales Trinity Saint David

Ordnance, Munitions and Explosives

Data Capture and Evaluation

ACDA6021

A Critique of the Data Capture Methods used in Ordnance Identification

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Abstract

An unknown munition was detonation at Cranfield Ordnance Test and Evaluation Centre. The aim of the test was to identify the munition through data analysis. The methods made us of pressure gauges, strawboard and velocity foils, and explosive residue analysis. It was found the data collection and test set-up was lacking in some areas, which impacted the analysis process. This critique considers the trial components and discusses its strengths and weaknesses, concluding with opportunities and risks (threats). It was found that changes ranging from easy and cost effective to expensive and slightly harder, could be made. This includes completing trial paperwork, additional gauges and complimenting attenuated total reflectance – Fourier transform infrared spectroscopy with Liquid Chromatography – Mass Spectrometry.

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1. Introduction

In October 2024, an arena trial took place at Cranfield Ordnance Test and Evaluation Centre (COTEC) with the aim being to evaluate the blast, fragmentation and explosive residue data from the detonation of an unknown munition. Through a series of analytical steps, it was determined the unknown munition was a RGD-5 grenade.

During the analysis it was noted there were limitations with the trial set-up and the data collected which restricted the possible analyses. This report considers the strengths, weaknesses, opportunities and threats of the trial through a simple SWOT analysis, shown in Table 1, using this process to propose alternative options to enhance the validity of the data. For ease of reading, the report will consider the different areas of analysis separately.

Table 1 SWOT analysis of the trial

SWOT Analysis	
Strengths	**Weakness**
Offset gauges	Limited trial paperwork
Lollipop style gauges reduce positioning error	Low number of velocity foils
Velocity foils are cost effective and simple to use	Single method of chemical analysis
Strawboard can allow velocity analysis - depth of penetration	No repeat gauges
Photographs	Poor arena set-up
	Velocity foils stop working if frag is lodged
	Foils not equidistant
	No ricochet trap
	No depth of penetration for the frag/strawboard provided
	Not clear if blast was air or surface burst
Opportunities	**Threats/Risks**
High speed video footage	Limited data
Several methods of chemical analysis	Poor data
Consider pencil gauges	Leading to incorrect conclusions
Extend strawboards to cover 180 degrees	Impact on future work/trials
Increase the number of velocity foils	Cost benefit analysis
Use ITOP 4-2-813	
Reduce trial cost - use MDF over strawboard	
Increase fragment capture - blastsax	

2 Methodology

2.1 Trial set-up and the arena

The arena was set up as shown in Figure 1. Three lollipop style gauges were placed at distances of 1.006 m, 2.026 m and 3.012 m from the charge, each slightly off-set from the gauge in front to reduce the effect of any shadowing. A fragmentation pole and a ricochet trap were used to reduce the risk of damage to the equipment. Four strawboards, each with three velocity foils were placed approximately 1.556 m from the charge.

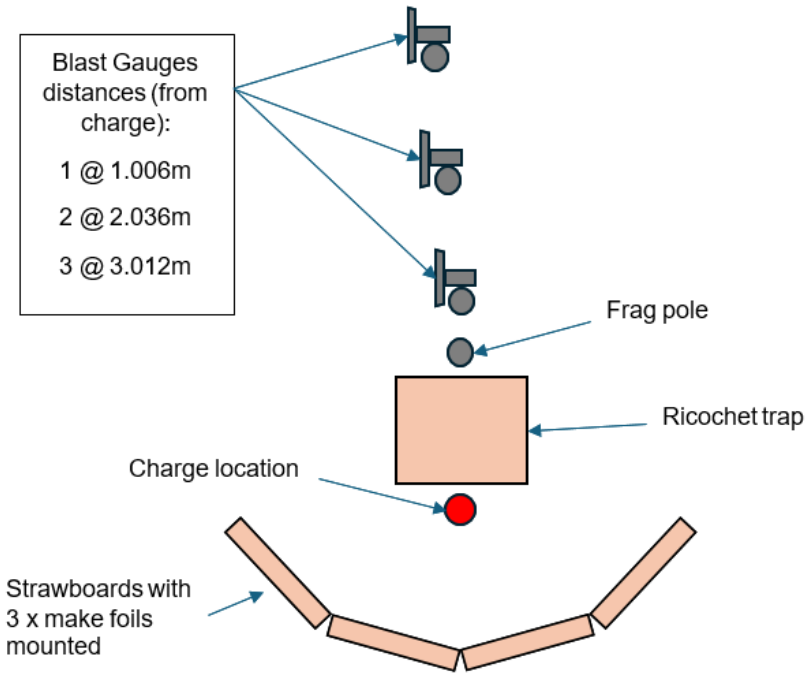

Figure 1 COTEC arena trial layout

2.2 Measurements and analysis

Measurements were taken of the distances of the foils to the charge, the height of the charge and the distance of the gauges from the charge.

Data was collected on the blast over pressure; fragmentation velocity and chemical analysis performed on explosive residues post-trial using attenuated total reflectance – Fourier transform infrared spectroscopy (ATR-FTIR).

3 Evaluation

3.1 Pressure Data Collection – The Trial

Three lollipop style gauges were used in this trial – aligned as shown in Figure 1. A photo of the gauges from the day is shown in Figure 2. These gauges have a thin cross-sectional area, reducing the chance of a fragmentation hit, and thus reducing the likelihood of any damage. They make use of piezoelectric transducers which are incredibly stable and does not suffer from natural aging, therefore the gauges, when looked after, will last for a long time. The shape of these is such that they are less affected by elevation in relation to the blast wave. Care must be taken to keep the faces aligned with the blast wave during set up, as misalignment will result in waves being generated from any leading edge, consequently affecting the pressure measurement [1]. This effect can be reduced by using gauges that have a sensor on either side of the disc. Additionally, if the gauges are aligned face-on to the flow they become more susceptible to damage [2].

Figure 2 Lollipop style gauges - photo taken at the trial

An obvious flaw with the pressure data is that no trigger time was recorded. The time of arrival at the gauges is therefore unknown. It is possible to calculate the time difference between gauge one and two, and gauge two and three, but this data is not complete and is of limited use.

3.2 Pressure Data Collection – Recommendations

A major disadvantage of only using three pressure gauges is that there is no redundancy built into the system should any one develop a fault. It is recommended that at least six gauges should be used – two at each distance to reduce the likelihood of losing data. Depending upon the positioning of the gauges, each pair should provide almost identical pressure results, and any

fault would become immediately obvious during processing. During analysis of the pressure data, a late time peak was noted for the gauge at 1.006 m. The cause of this may have been a faulty gauge, reflected wave or perhaps a Mach stem formation. Additional gauges would have helped analyse the cause. High speed camera footage can be used to track the blast wave propagation as the distortion will be clearly visible. Coupling this with a large zebra board, or known markers on the ground, it is possible to calculate the velocity of the wave and potentially observe any Mach stem formation. Footage from this trial could have helped confirm the cause of the additional peak noted in the first gauge. Any zebra boards or markers must be carefully placed to avoid reflections early on in the event.

The height the charge was placed at for the trial leaves a lot of ambiguity over whether the blast was a surface or an air burst – and this directly impacted the analysis. Peak pressure and time of arrival of the wave differs for each type of burst. This could impact the outcome of the analysis depending upon how it is processed. Furthermore, the Mach stem formation associated with air bursts could affect the readings on the pressure gauges. Once the munition had been determined, it was then possible to consider any Mach stem effects looking at the scaled height of triple point [3]. See effects for determination of any Mach stem effects. For the purposes of this exercise, nothing critical would have been given away by specifying the nature of the burst. For trials in the workplace, Mach stem formation may need to be given consideration when considering arena layout.

It is noted from photos taken on the day, that gauge cables had some protection using U-shaped steel channels – shown in Figure 3. It is felt this could have been enhanced using sandbags at joins, or where cables are exposed on the ground. A recent trial which the author attended resulted in broken cables from fragmentation. While repair is not a difficult task, it is easy to reduce the risk of damage and therefore steps should be taken to apply protection where possible.

Figure 3 Arena set-up with potentially exposed cable visible

Depending on the nature of the trial, alternative gauges can be used. Pencil gauges are commonly used when the direction of the propagating wave is known and can be used to measure the Mach stem [4] [5]. They are also known to be more sensitive to misalignment from the charge and should aligned incident to the to the blast wave for accurate measurement – basic set-up is shown in Figure 4 [6]. It is for these reasons pencil gauges would not be recommended for this trial and the author agrees with the choice of lollipop gauges.

Figure 4 Pencil gauge alignment [5]

3.3 Fragmentation Data Collection – The Trial

For the trial, four strawboards each with three small velocity foils were used to collect data on the fragmentation from the munition. Velocity foils, shown in Figure 5, consist of two thinly spaced metallic sheets, connected to a power supply and a data logger. When a fragment impacts and pierces a foil, the circuit between them is completed by the metal fragment. At this point a signal

is generated and logged. If the distance from the charge is known and the time at which the signal was generated, the average velocity of the fragment can be calculated [7]. They are simple and easy to use. They require no calibration and are cheap. However, if a fragment becomes stuck in a foil, this renders it useless, and no further data is collected.

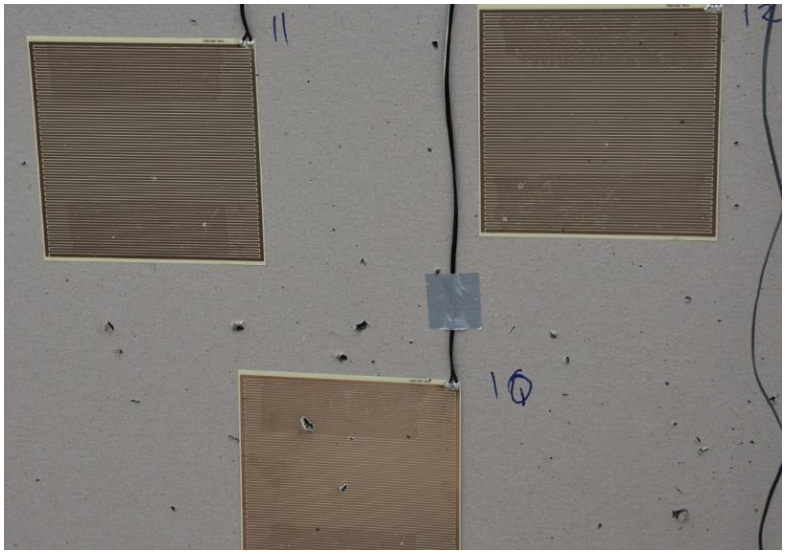

Figure 5 Velocity foils (post-trial)

3.4 Fragmentation Data Collection – Recommendations

To improve the data collected for fragmentation velocity analysis, it is recommended other techniques are used included. High speed cameras with a zebra board allow a contactless method of calculating the velocity of fragments. This method can be used to track individual fragments due to the rapid processing by the cameras [7]. The zebra board has black and white lines at known separations which then allow the footage to be processed frame by frame. If we know the time it took a fragment to travel between two points on the zebra board, the velocity is simple to calculate. High speed cameras are expensive to purchase but can provide invaluable and reliable data. They do need to be positioned and protected to prevent any damage from trials.

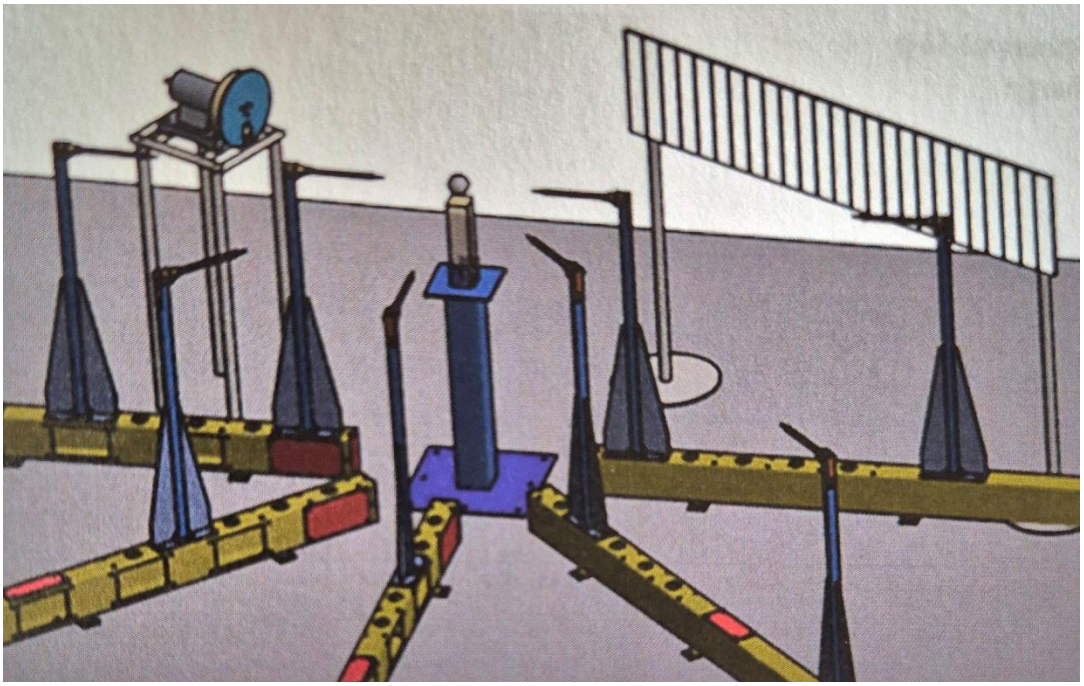

Figure 6 Potential arena set-up with gauges, high speed camera and a zebra board [8]

The use of strawboards can allow analysis of the fragmentation distribution and energy absorption providing data is collected on the mass and size of each piece of fragmentation, and the depth to which it penetrated [9]. Extracting fragmentation manually is already time consuming and limited by the ability of those conducting the trial to spot all pieces – becoming increasing more difficult as the fragments become smaller. Adding in the additional task of weighing and measuring each fragment adds a considerable amount of time to the trial but again may provide insightful information.

A sandbag type item, called 'BlastSax', has been developed which is highly effective in collecting fragmentation from explosions [10]. These could be used to collect a vast amount of the fragments – but bearing in mind the time and effort that would be required to extract each piece from the bags. Velocity foils could still be attached to front face of the bags.

In addition to the above techniques, improvements could be made to methods used on the day. The data collected suggests some of the fragments ricocheted before impacting the foils. These registered a much lower velocity than direct hit fragments. To reduce the likelihood of ricochet hits, placing a ricochet trap in front of the strawboards will help to capture some of these pieces. A limited number of velocity foils were used. When looking at trial photographs, it is clear the number of fragments which hit the strawboards is much higher than number which impacted the foils. An example is provided in Figure 7. Vastly increasing the number of foils used would provide a larger data set and more accurate results.

Figure 7 Post-trial strawboards and velocity foils

The strawboard set-up on the day should have extended 180 degrees around the munition [11]. Reciprocal fragmentation effects can be assumed to be the same as that captured by the strawboard, but this was not possible in this case as the strawboard appears to be much less than 180 degrees. Potentially useful data points are therefore missing from the trial analysis from the areas where there is 'missing' strawboard.

The use of strawboard and velocity foils for this trial was not a poor choice, there simply was not enough in the arena to provide an accurate and reliable set of results.

3.5 Explosive residue analysis – The Trial

ATR-FTIR was used as the sole method for identifying the explosive in the suspect munition. This was done by soaking fragments in acetone or isopropyl alcohol and analysing the resulting spectra by comparing with known spectra for the suspect munitions. The isopropyl alcohol did not produce any usable results. The spectrum from the acetone analysis had a limited number of usable results. This is likely due to a high concentration of acetone with a very low concentration of explosive residue – the exact situation where FTIR is not the perfect choice.

3.6 Explosive residue analysis – Recommendations

FTIR is a quick and relatively cost-effective technique that can be used as a confirmatory test to backup other analysis where clear and complete data has been collected. Relying on FTIR analysis without any other molecular analysis is limiting the reliability of the results, especially if

those performing the test do not have access to a library of spectra. In this instance it is highly recommended that other techniques as used alongside FTIR analysis. There are numerous techniques which could be used for trace analysis, as such only two will be discussed here.

Liquid chromatography-mass spectrometry (LC-MS) combines two processes (liquid chromatography and mass spectrometry) to separate compound mixtures in a liquid phase and provide direct mass measurements. This process is capable of providing data on the molecular weight, structure, identity, and purity of compounds – as well as being able to quantify the compound. It is a quantitative and qualitative technique [12]. This is far beyond the capabilities of FTIR but does have some drawbacks. LC-MS equipment is much larger than FTIR equipment and requires a constant supply of diluent and buffers. It would be completely impractical to take this out to the arena; therefore, samples would have to be returned to the laboratory for analysis.

A technique already in use away from laboratories, is Ion Mobility Spectroscopy (IMS). This analyses compounds by separating and then identifying ions within the sample, based on their speed through an inert gas, under the influence of an electric field. Larger ions travel slower than smaller ions. Although portable and relatively sensitive the process is prone to false positives where samples are contaminated. [13], [14]

Given the numerous trace residue techniques available, it is recommended that a choice is made based on the exact need of the test. There would be little point in choosing to use a process which requires equipment with a large footprint and multiple additional components if in-field testing is necessary. Likewise, there is no need to compromise on a portable but less sensitive technique if returning samples to the laboratory is perfectly acceptable. Equally, consideration must be given to any excitation method in these processes. Subjecting a sample of explosive to an energy source could have unintended consequences.

3.7 Paperwork and Best Practice Comments

It is standard practice when preparing for and setting up a trial to complete a trial plan. This details every aspect of the trail, including but not limited to equipment, procedures, arena layout, personnel required from start to finish, customer requests, timescales, data to be collected and standards (if any) to be followed. A key weakness with this trial is the only documentation that was provided was a simple sketch of the arena layout which while useful, was lacking in detail. There is no log sheet from the trial day – this ensures each require step for set up has been completed, equipment positions and serial numbers are recorded, weather conditions may be noted depending on the test, to name but a few. This is basic best practice technique, ensuring complete traceability and repeatability. There is no information on any observations made during

the test – having not attended the test day it is not clear if any additional observations could have been made. However, from experience the author is aware observations can be made of any obvious residues and the colour of these and the colour of any smoke seen during the test.

Photographs were taken on the day before and after the test. The author would have taken different images, however this may simply be down to personal preference and so there will be no critique of this point.

Unfortunately, there was only one test item so there was no possibility of repeat tests. While best practice indicates that there should always be repeat tests to validate the results, this is simply not always possible in the Ordnance, Munitions and Explosive Industry. Having said that, by utilising multiple gauges, having additional foils and including techniques outlined about such as the high-speed videography, the risk is somewhat mitigated as one set of data should back up another without ambiguity.

4 Discussion

The methods and procedures used for this trial were not particularly poor. It is the pre and post-trial paperwork where this the most room for improvement. Having said that, it is the small improvements in the set-up and data collection techniques that would have made the greatest difference to the validity and reliability of the trial and the results.

Admittedly, several of the suggestions made require a cost benefit analysis. If performing FTIR analysis is good enough, then why spend a considerable amount of money on expensive equipment which will need regular servicing and maintenance.

Poor trial set-up, data collection technique and limited analysis is not a good way to conduct a trial and will impact the reputation of the company. Scientific analysis and trials, when undertaken, must be conducted to the highest standard, there is no justification why testing should not be rigorous if meaningful and reliable conclusions are to be made.

While not referred to during the critique, a standard exists for fragmentation trials – International Test Operations Procedure (ITOP) 4-2-813 [11]. It is perhaps beyond the scope of this trial, but it is highly recommended that where standards exist, they are in the very least referred to for guidance, and good justification must be provided for not following these if deviations are to be made. Adherence to standards allows direct comparisons between different tests at different sites and provides a great deal of confidence in the process and results obtained.

One final note –subject matter expert (SME) guidance throughout trials will help reduce mistakes and will also provide a sanity check on the trial set-up. The benefits of this should not be underestimated.

5 Conclusion

Incorporating the suggestions (opportunities) made above will massively reduce the risks (threats) to the trial by producing more extensive and better-quality data. For the benefit of a learning exercise, this trial was acceptable. Strengths and weaknesses have been discussed at length, and the impact of the weaknesses on the analysis noted.

Best practice is best learned at the start of one's career in arena trials and therefore this trial should be seen as an exercise in learning a lot from very little, rather than as a template for performing future trials.

The overall aim of identifying the munition in the trial was achieved despite the limitations noted in the arena set-up and data capture methods. The data collected allowed a process of elimination to be followed which would not change had there been additional equipment utilised, but confidence in the process and results would have been higher.

In conclusion, as a bare minimum, it is recommended that trial paperwork is completed as this has no cost implications and would at least ensure the validity and reproducibility of the test if needed. The remainder of the suggestions would need consideration with respect to their benefit to the trail in question.

6 Summary of Recommendations

This critique put forward recommendations to improve the data capture techniques used on the trial test day at COTEC. These are summarised below.

- Use a second set of pressure gauges
- Extend strawboards to 180 degrees
- Increase the number of velocity foils
- Ricochet traps in front of strawboards
- Use high speed video footage
- Consider alternative methods of fragmentation collection such as BlastSax
- Additional methods for trace residue analysis such as LC-MS
- Protect any exposed cables in the arena
- Follow established standards such as ITOP 4-2-813
- Complete all trial paperwork
- SME guidance

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7 Appendix 1 – Mach stem effects

Using the following formula after the munition had been identified, it is possible to calculate if a Mach stem effect would be noted from the blast.

$$\frac{Height\ of\ burst\ above\ ground}{\sqrt[3]{Charge\ mass\ (kg)}}$$

Equation 1 Mach stem effect [3]

If this value is <10 then a Mach wave will form.

If this value is > 10 than a Mach wave will not form.

For the identified munition – RDG-5 grenade:

Height of burst – 0.3m

Charge mass – 0.046kg

Therefore:

$$\frac{0.3}{0.358} = 0.837$$

A Mach stem would form from this blast at the given height and the conclusion that this test should have been analysed as an air burst can be drawn. It would be interesting to repeat the analysis with this knowledge and compare the accuracy of the results.