

Evaluation of a trial

by Joshua Ede

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A critical examination of the trial conducted on 15th of October 2024

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Abstract

The purpose of this report is to critically examine the process of conducting an energetic trial at Cranfield Ordnance Testing and Evaluation Centre (COTEC) on the 15th of October 2024. The trial was designed to collect data from an energetic event and subsequently this was analysed to provide evidence on the type of munition likely to have been detonated. It is not suggested that the data collected was of a poor quality or standard, but that it is possible to see where there might be errors and where possible alternative methodologies, and equipment may have yielded more accurate results. This report is the author's own analysis and judgements; however it should be acknowledged that the trial itself was conducted, supported and supervised by staff and students from the University of Wales Trinity St. David (UWTSD) and COTEC.

1.Introduction

On the 15th of October 2024 a trial was conducted at the COTEC range facility in Salisbury, Wiltshire. The purpose of the trial was to collect data from an unknown munition. This report will first describe the setup of the trial, whilst guiding the reader through the methodology and reasoning for the decisions made. A detailed description of the equipment used, its operation and limitations will then be provided. The data collected will then be shown. Following this there will be a discussion on possible issues from the data collection and finally alternative equipment and/or setups that could have been explored to potentially yield clearer more accurate results.

2.Trial setup

2.1 Overview

The trial arranged at COTEC was an arena trial, this is a recognised and approved method for testing munitions as outlined in NATO Standardisation Agreement (STANAG) 4170 and Allied Ordnance Publication (AOP) 7 [1], [2]. A detailed procedure for the appropriate setup and arrangement of arena trials is contained within and is listed as part of the quality assurance and guide followed by COTEC staff [3], [4]. The arena was constructed as per fig. 1 below.

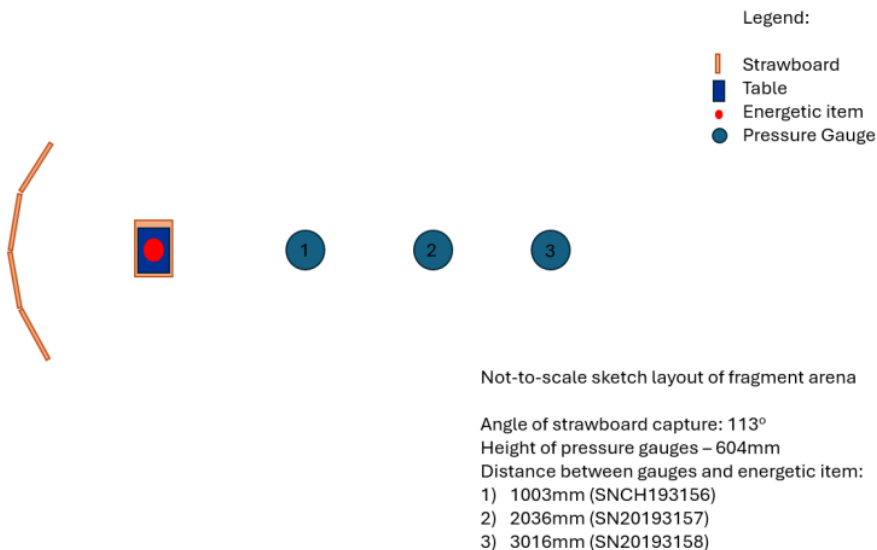


Figure 1: Arena trial layout.

The arena was built on a concrete trials pad, and prior to the arrival of the staff and students from UWTSD, stands and blocks had been positioned to aid in the speed and construction of the arena. This arrangement is visible in fig. 2. and was based on the prior experience and knowledge of COTEC staff. It should also be noted that the staff at COTEC, unlike the UWTSD students, were fully aware of the item being detonated and therefore were able to construct a safe and appropriate arena prior to the arrival of the students.



Figure 2: Students listen to a brief from the trials manager prior to helping setup the equipment for the trial. Note the partial construction of the arena i.e. the stands and the concrete blocks.

The items used for the construction of the arena were, strawboard, a wooden table and metal poles for mounting the gauges. The radius of the arena was 1500mm based on the position of the charge to the stands. This was effectively pre-determined as the stands had been positioned prior to the setup of the trial by UWTSD students. The primary instrumentation was three pressure gauges spaced according to fig 1. and velocity foils mounted on the front of the strawboard packs. The location of the velocity foils can be seen in fig 3.

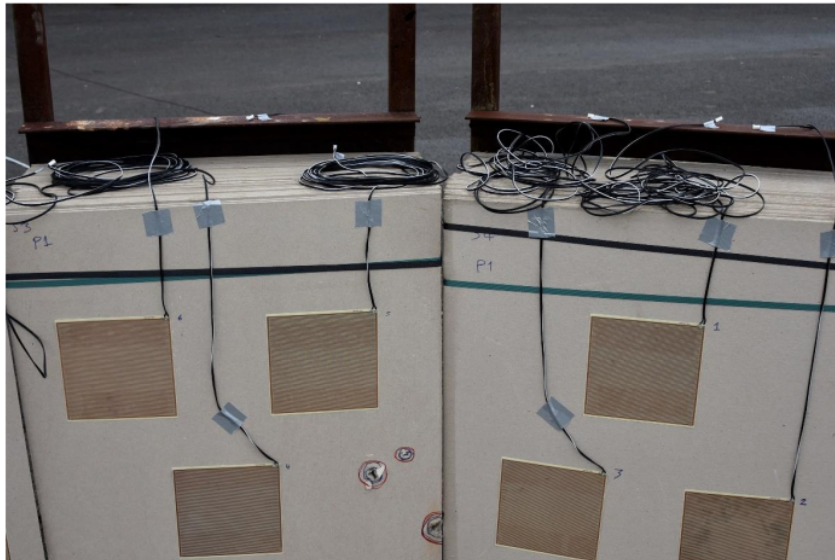


Figure 3: The positions of the velocity foils on the front of the strawboard packs.

2.1.1 Overview: Positioning

The blast gauges were measured into position using a tape measure and checked by using a laser range finder, see fig. 4. The blast gauges also had their serial numbers recorded, the SN values in fig 1., this ensured that distances for a given pressure could be attributed to a particular gauge during the results collection stage.



Figure 4: Distances of pressure gauges being checked with a laser range finder.

The straw packs were positioned according to the stands, they were then numbered and recorded as shown in fig 5. below. The stand numbering goes from left to right, starting at stand 1 or S1, the packs are then numbered from back to front, with the front pack i.e. the one closest to the charge, being P1.

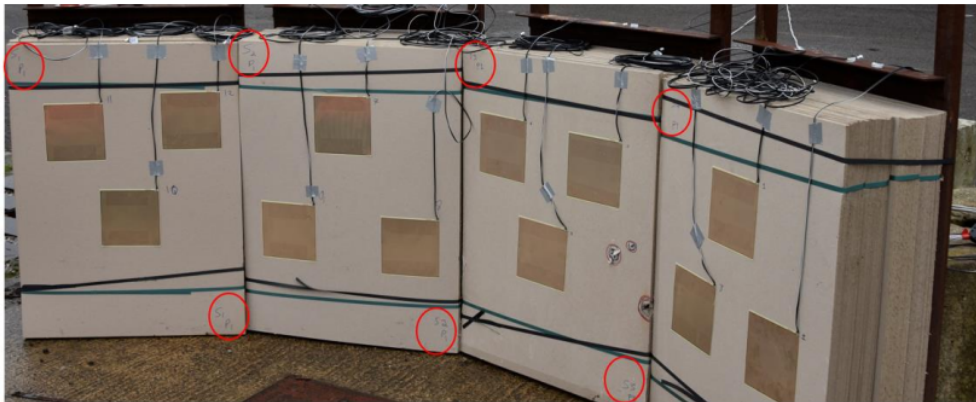


Figure 5: numbering of the strawboard packs highlighted in the red circles, full image contained in Annex A for clarity.

Each strawboard pack contained 10 boards and there were 4 packs to a stand. After mounting the strawboard packs to the stands, no further location measurements were taken to verify the position of the front of the pack relative to the explosive charge and no global navigation satellite system (GNSS) data was taken. It was argued that the time required for these extra steps was not worth it given the overall fidelity of the data being captured.

2.2 Equipment used

It is worth noting that all equipment was tested during the setup and that it was sufficiently calibrated before the detonation.

2.2.1 Blast gauges

The primary means for collecting the blast pressure from the detonation were three integrated electric piezoelectric (IEPE) gauges placed at known distances. IEPE gauges function by having a sensor containing a crystal that is susceptible to charge difference across its structure when a mechanical load is applied [5]. The charge generated across the crystal is proportional to the force applied and thus can be used to calculate the pressure witnessed by the gauge [5]. These changes in pressure are outputted as voltages in mV that can be recorded by a data logger. By taking multiple pressure measurements a profile for the wave can be generated as it passes over the gauge. This is why the pressure sensor is mounted perpendicular to the wave rather than head on to the wave front, see fig. 6. Each of the three gauges used during the trial was arranged in this manner at their respective distances, see fig. 1.

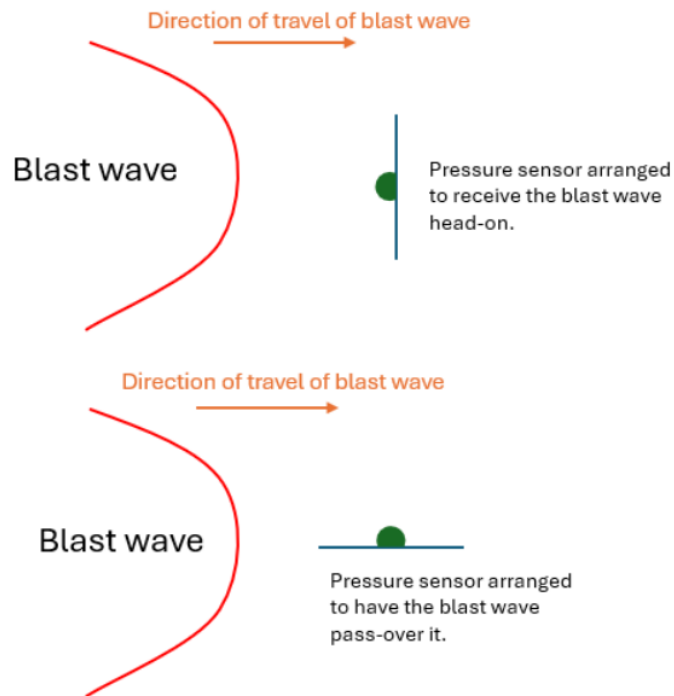


Figure 6: Diagram showing the arrangement of the pressure sensors relative to the blast wave, not to scale.

The ability for the gauge to measure a profile for the pressure relies on its response time. This is determined by how quickly the gauge is able to register an input and then turn this into a measurable output [6]. The response time for the gauges can be in the nanoseconds (μs), depending on their quality and calibration [5].

2.2.2 Velocity foils

The velocity foils used were make-foils. Make-foils work by having a thin track of copper separated into different paths across their surface. When something conductive, such as a metal fragment, contacts two or more of the paths then an electrical circuit is completed and a small charge is generated. This can be recorded and it provides a time of arrival (ToA) measurement for the fragment. If the distance between the foil and the fragment origin (the explosive) is known, then by recording the ToA for the fragment, a velocity can be worked out. This requires knowing the accurate position of the foil relative to the explosive [3].



Figure 7: Velocity 'make- foil' note the different copper paths that require connecting to generate a signal.

The foils can record multiple impacts across their surface, but there are no means of filtering out fragments that have had their trajectory altered or impeded in some way. This means that a single foil can be hit multiple times and that fragments ricocheting off the ground or an obstacle may also be recorded giving potentially erroneous results. To mitigate this, the velocity foils are setup in multiple locations around the arena to get a good spread of the fragments and time of arrival data.

2.2.3 Strawboard

The strawboard used in the construction of the arena can also be used as a means of recording data. If the density of the strawboard is known, along with its position then the depth of penetration of the fragments can also be used to calculate their velocity. In collecting the strawboard post-experiment the fragment location could be carefully recorded and this could be used to calculate how its velocity using the McMahon equation [7].

$$V_s = \frac{KP}{M^{\frac{1}{3}}\rho^{\frac{2}{3}}} + V_L \quad (1)$$

Table 1: Explanation of terms for equation 1

V_s	Strike Velocity (ms^{-1}).
K	Constant for a given fragment shape and fragment capture material
P	Penetration depth (mm).
M	Mass of the fragment (g).
ρ	density of the fragment (g/m^3)
V_L	Limiting velocity (ms^{-1})

2.2.4 Data logger / logic analyser

Although it does not measure the blast event directly, a data logger or logic analyser was also used to collect the different measurements and convert them to useable data to output on specialist software. The cables and linkages between the data logger, computers and instrumentation were all carefully recorded and noted prior to the detonation. All of the equipment was also tested to ensure continuity between the different systems and that the outputs were within the expected range.

2.2.5 Fourier Transform Infrared spectroscopy (FTIR)

Although the FTIR was not set out during the arena trial, it was used to get more data from the fragments following the detonation. Spectroscopy requires exciting the energy of an atom or molecule. The *spectra* produced from this excitation can either be related to the emission, or the absorption, of energy and can therefore indicate the structure of the substance being studied [8]. Infrared spectroscopy uses the interaction between bonds and infrared radiation to determine functional groups within molecules [9]. By collecting residue from the fragments in the trial, through dissolving in acetone, it was possible to also collect spectra for the explosive that could be compared against a reference library.

2.2.6 Initiating the detonation

The detonation was initiated using a high voltage detonator, with breakwire around the munition to provide another means of confirming the detonation. As the wire breaks it breaks a circuit letting the system know that the detonation has occurred. The auto trigger for the pressure gauges was set to function at 30mV, which equates to 3.5 kPa of pressure, before this the initiating system was continually recording and overwriting the data. The system is able to retrieve 10% , roughly 40ms, of data prior to the triggering and then records for a set period after the initiation. This is so that it is possible to be sure that the instrumentation is capturing information from the detonation event and there can be a reliable time zero for the data. The firing signal was done using a Reynolds firing pack.

3. Results

3.1 Pressure

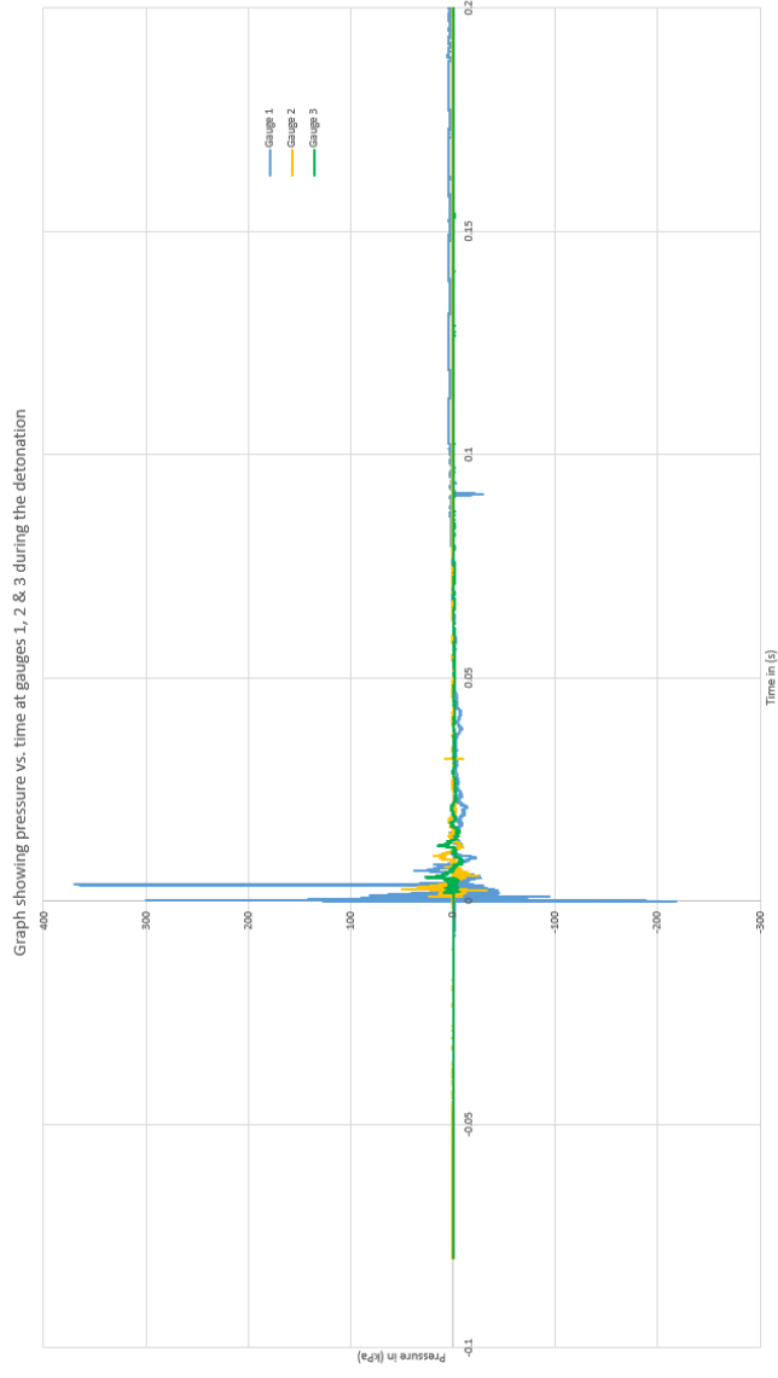


Figure 8: Graph showing the different pressures recorded by the 3 gauges during the detonation.

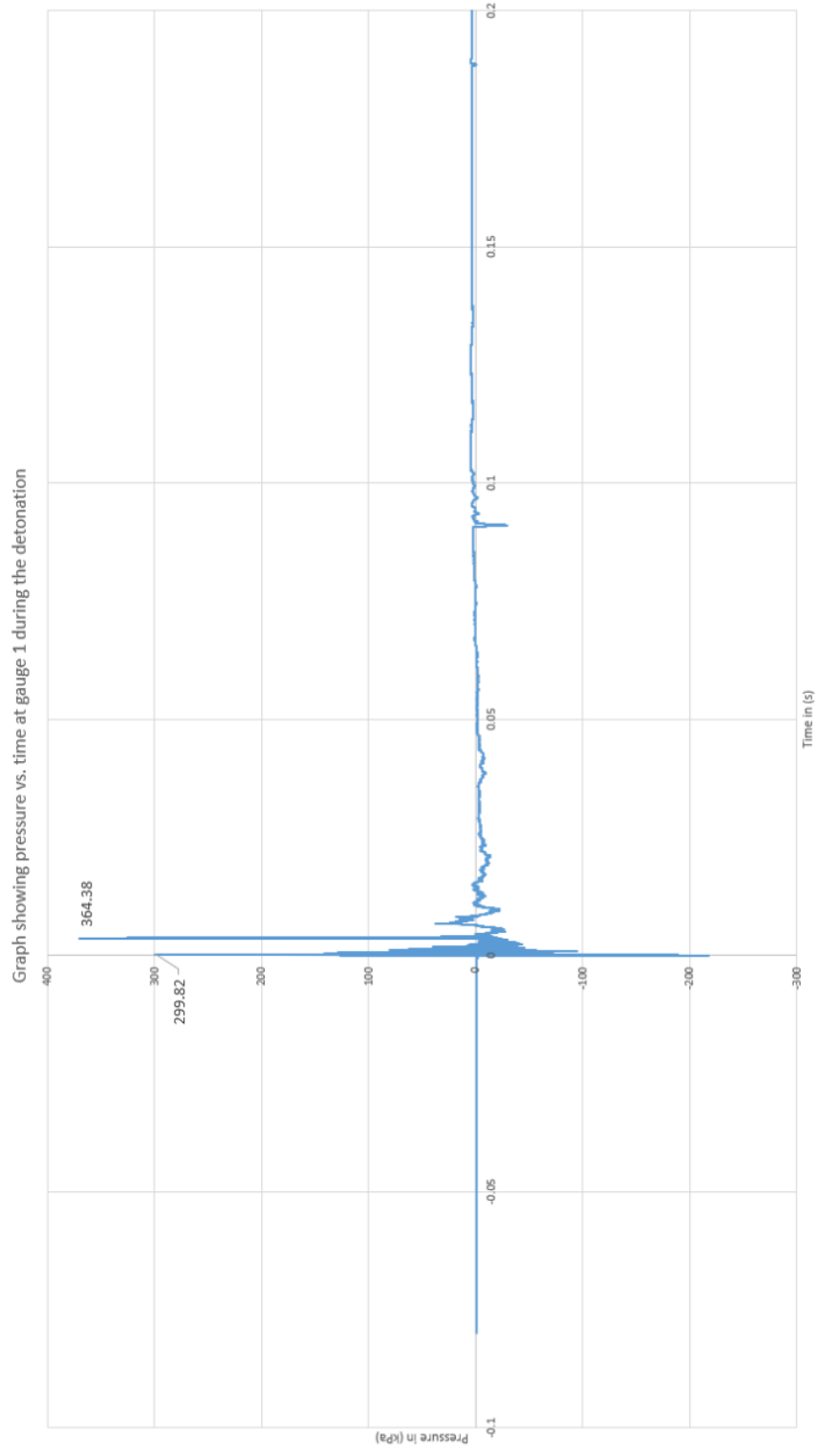


Figure 9: Graph showing the pressure at gauge 1 during the detonation with peak overpressure and reflected overpressure marked.

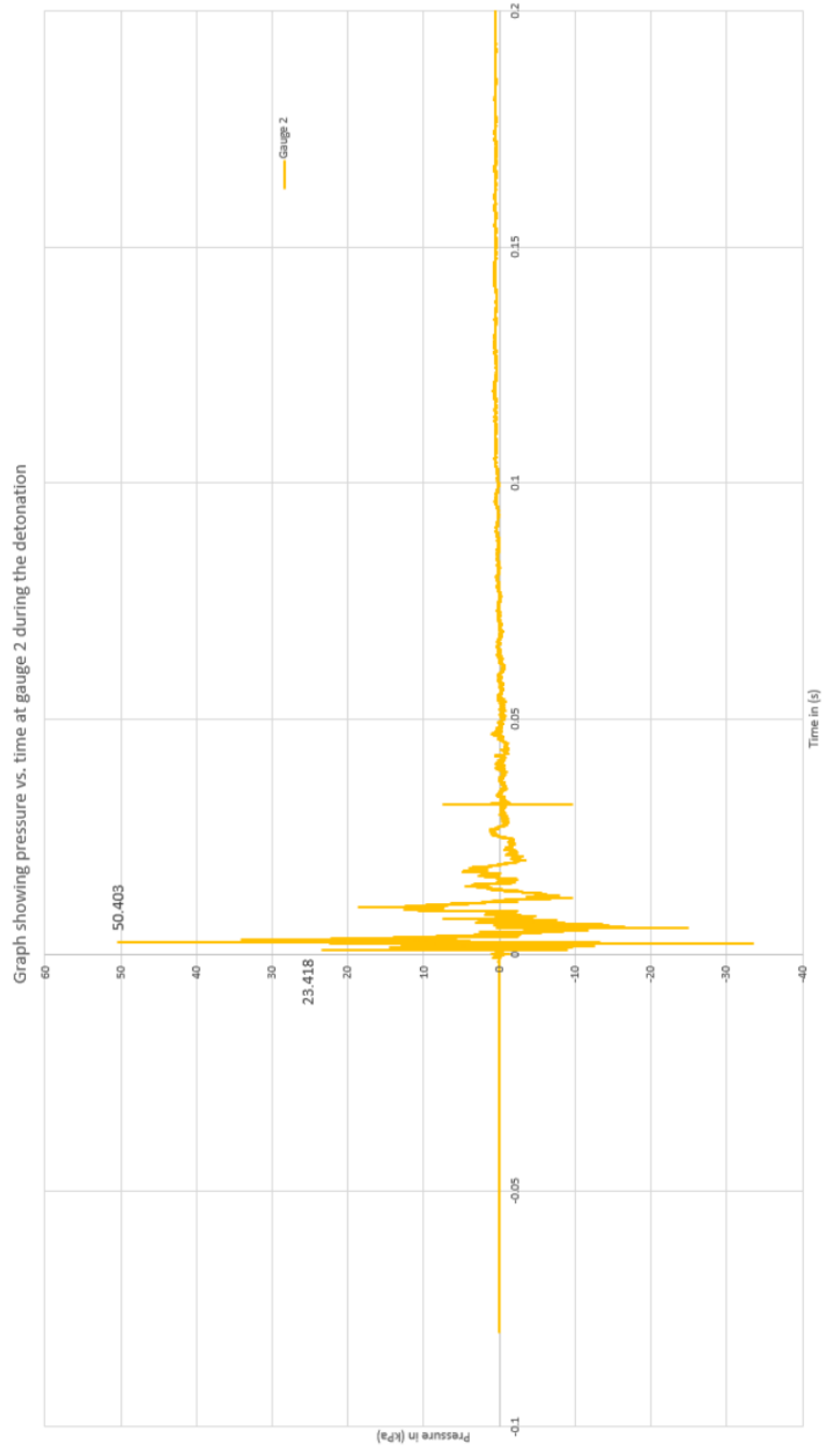


Figure 10: Graph showing the pressure at gauge 2 during the detonation with peak overpressure and reflected overpressure marked.

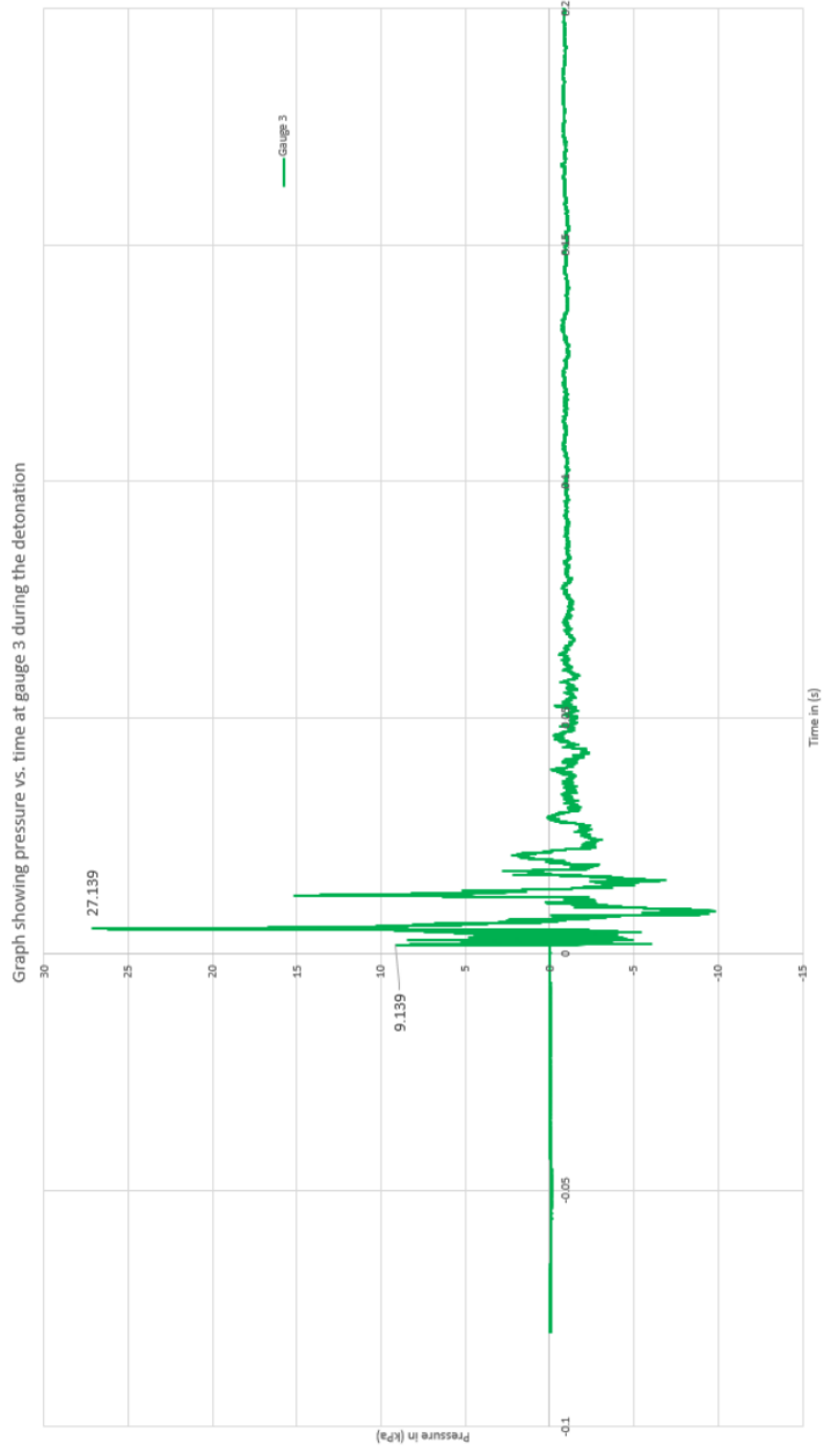


Figure 11: Graph showing the pressure at gauge 3 during the detonation with peak overpressure and reflected overpressure marked.

3.2 Fragment analysis

Table 2: Table showing the impact velocities recorded during the detonation

Stand Number	Stand 1				Stand 2				Stand 3				Stand 4			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Foil Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Velocity in ms ⁻¹	1423.99	1394.79	1395.85	1342.56	n/a	730.16	1432.57	1339.85	1305.44	1360.51	465.86	341.30				

Table 3: Fragment analysis results from the detonation.

Fragment Analysis Results	
Material	Steel
Number of fragments	138
Mass of all fragments	154g
Average mass of fragments	1.116g
Average fragment area	28.05mm ²
Average fragment thickness	1.24mm



Figure 12: Fragmentation collected from the COTEC arena trial with a ruler included for scale.

3.3 Fourier Transform Infrared (FTIR) results

PerkinElmer Spectrum IR 10.7.2

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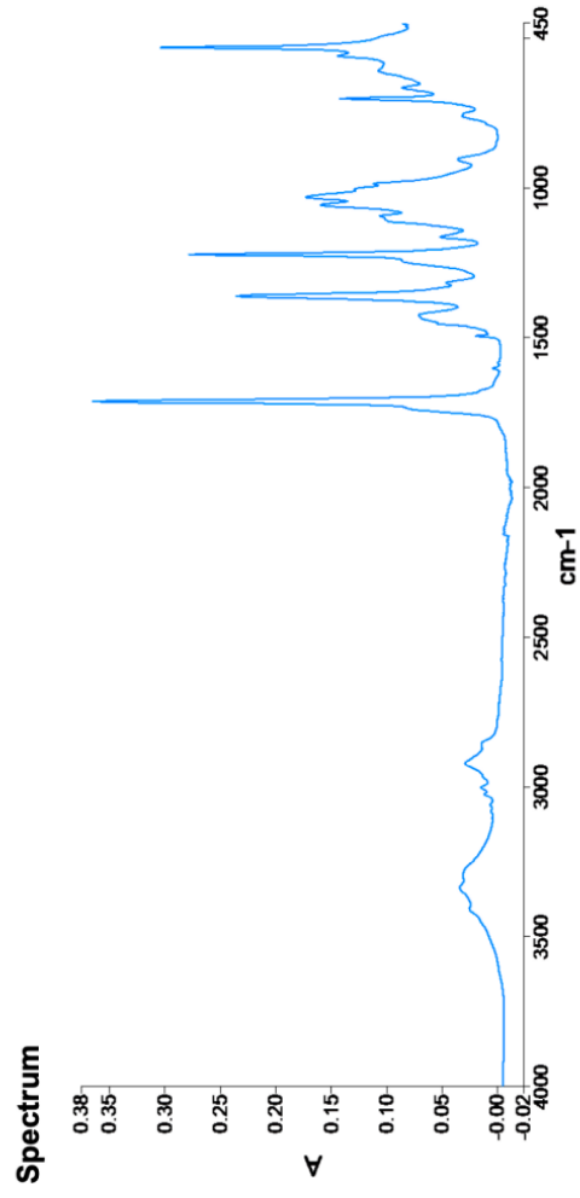


Figure 13: FTIR spectra recovered from the residue found on the fragments recovered on 15th October from the COTEC trial.

4. Discussion

The results from the trial did allow the author to make a reasonable estimation of the likely munition that had been detonated. However, they also highlighted some weaknesses in the data collected and these will be outlined here, along with the general recommendation to always record all the data required.

4.1 Meteorological data

The question for the trial was to ascertain which munition had been detonated based on its energetic output, the fragmentation created and an analysis of the explosive that it contained. In order to turn the trial outputs into data to answer the overall question they were substituted into equations, such as the ones below [10] [11].

$$\frac{P_s}{P_a} = \left(\frac{808 \left(1 + \left(\frac{Z}{4.5}\right)^2\right)}{\sqrt{1 + \left(\frac{Z}{0.048}\right)^2} \times \sqrt{1 + \left(\frac{Z}{0.32}\right)^2} \times \sqrt{1 + \left(\frac{Z}{1.35}\right)^2}} \right) \quad (1)$$

One of the parameters for this equation is ambient pressure P_a . Unfortunately, ambient pressure is not a static value and can be altered by changes in altitude, humidity and temperature [12]. None of these were measured prior to the detonation. Furthermore, changes in ambient pressure effect the air density which effects the velocity of fragmentation [3] as can be seen from equation 2 [13].

$$V_s = V_0 \exp\left(\frac{-C_d \times \rho_{air} \times A \times S}{2m}\right) \quad (2)$$

The COTEC trial site is at an elevation of 164 metres above sea level, see fig. 14., which effects the pressure, even if only in a small way and was not factored into the results when trying to analyse which munition was detonated.



Figure 14: Elevation of COTEC range taken from

The weather on the day of the trial was cold, wet and overcast see figs. 2 and 4. In the analysis it was noted that the average fragmentation velocity, provided in full in table 1, is lower than expected. It is not known if the weather at the trial site accounts for the discrepancy, but because it was not recorded prior to the detonation its effects cannot be accurately determined making the analysis potentially inaccurate.

Table 4: Table showing the expected fragment velocity for some of the munitions examined vs. the actual velocity recorded, note larger munitions had already been ruled out due to other data collected.

Munition	Expected velocity (ms^{-1}) (2dp)	Actual velocity (average) (ms^{-1}) (2dp)
M-67	1721.18	1374.45
RGD-5	1543.44	
Pipe bomb	1766.51	

4.2 Location data

During section 2 it was noted that several of the pieces of equipment only had relative locations recorded. The strawboard stands were positioned, but not geolocated using a GNSS system, similarly the strawboard packs were only set relative to the charge and whilst the pressure gauges were measured and checked, this was done prior to the placement of the munition so it is unclear where they were exactly being placed relative to. This means that the pressure gauges may not quite be in the locations outlined in fig 1. Furthermore, they were not checked after the detonation to see if they had moved.

The location data also effects the fragmentation collection. If accurate locations for the positioning of the strawboards, and subsequent collection of the fragmentation, had been taken this could have been used as another means of calculating the velocity of the fragmentation, based on their depth of penetration [7]. It could have also provided further data on fragment distribution, which may have highlighted features such as the 'beam angle' of the munition. The beam angle is the angle at which fragments break off the original munition casing [13].

4.3 Blast gauges

The blast gauges were used to measure the pressure at different points in the arena. The profiles suggest issues in the data collection.

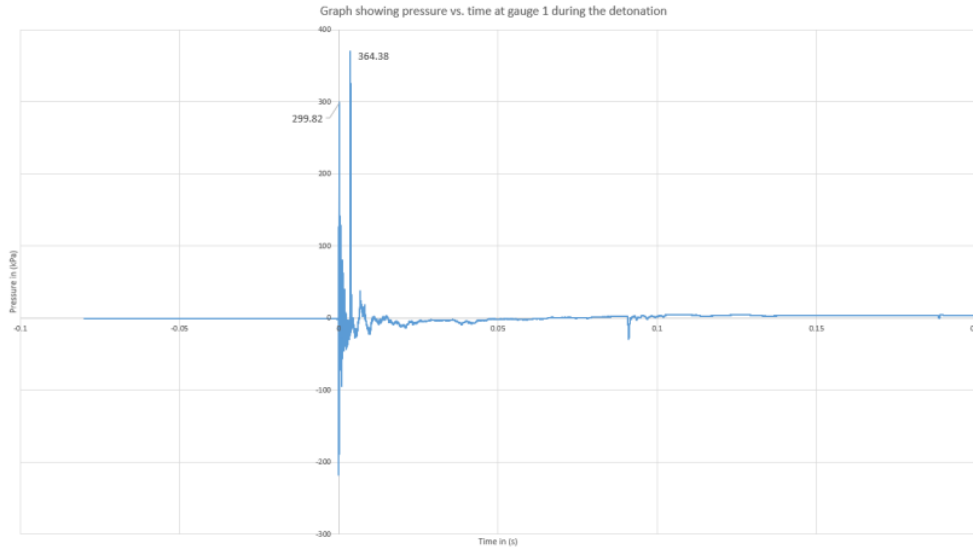


Figure 15: Pressure data from gauge 1 at 1.003m.

The data is very noisy, meaning it is difficult to be able to see a clear curve that is expected from a blast wave, see fig. 16.

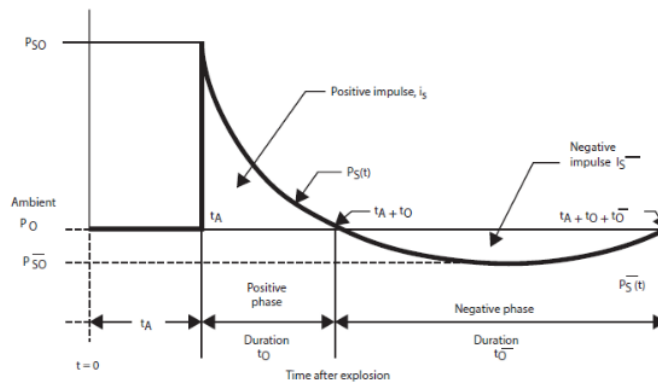


Figure 16: Typical Friedlander curve with a sharp peak, positive phase and negative phase taken from [14].

This is perhaps to be expected as the pressure is dynamic, meaning that the gauge is having to take multiple readings over a very short time. It is therefore likely that the gauge has been calibrated so small changes will be seen in the results. As mentioned in section 2, the pressure gauges have a response time, a delay in turning an input into an output, this may be very fast but is still going to create jumps in the results. It is possible to smooth the data and make the curve appear more characteristic of the Friedlander, but in so doing the peaks are also 'smoothed' reducing the accuracy of peak overpressure and peak reflected pressure. Considering the importance of these two results for the investigation of the

munition the author decided to leave the pressure data unmodified, but recognises that this makes the data difficult to interpret.

The results for pressure gauge 2 show there is a point with a simultaneous peak and trough see fig. 17. It is not known what has caused this, but it is suggested that it could be due to something impacting the gauge and so that the whole mount moves away from the blast while at the same time recording a relatively high pressure. As the locations of the gauges were not measured again following the trial it is not known whether this is an accurate understanding of why this result occurred, but it is a possible theory.

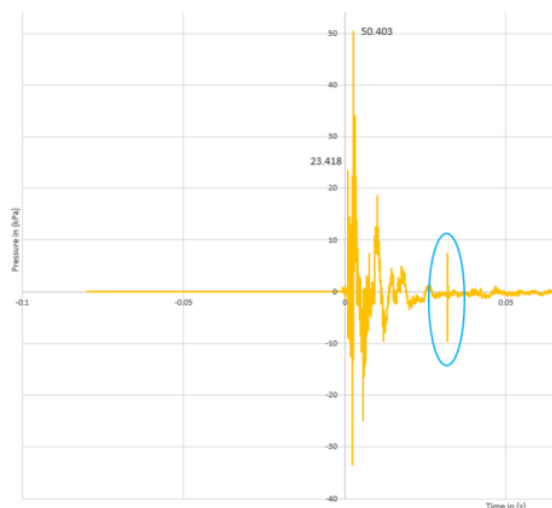


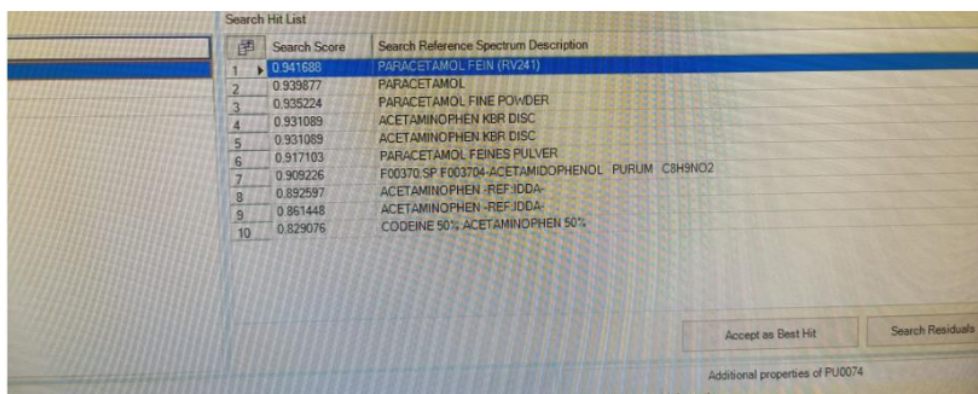
Figure 17: Pressure profile at gauge 2 showing simultaneous peak and trough, circled in blue.

Other factors also effect the pressure results including the ground shock, the phenomenon of the shock wave being passed through the earth following the detonation. It was thought that this effect was minimised due to the mounting of the gauges, but it cannot be said with certainty that this was fully accounted for.

4.4. Fragment analysis and FTIR

The presence of unknown metals and the overall mass of the fragments collected suggests that there may be pieces of previous munitions that were collected by mistake. This particularly effects the FTIR results as it is unknown whether the samples used from the fragments were from this munition. It may have been a previous device, but the acetone solvent used for the preparation of the samples may have dissolved or otherwise filtered out the other explosive before testing.

The FTIR results do appear fairly conclusive, however, to fully verify the findings of the analysis a check should be done of the spectrum against a library containing a number of explosive spectra. Furthermore, it is possible when doing that analysis to get a computer to calculate the percentage difference between a sample and a reference.



	Search Score	Search Reference Spectrum Description
1	0.941688	PARACETAMOL FEIN (RV241)
2	0.939877	PARACETAMOL
3	0.935224	PARACETAMOL FINE POWDER
4	0.931089	ACETAMINOPHEN KBR DISC
5	0.931089	ACETAMINOPHEN KBR DISC
6	0.917103	PARACETAMOL FEINES PULVER
7	0.909226	F00370 SP F003704-ACETAMIDOPHENOL PURUM C8H9NO2
8	0.892597	ACETAMINOPHEN - REF ID: A
9	0.861448	ACETAMINOPHEN - REF ID: A
10	0.829076	CODEINE 50% ACETAMINOPHEN 50%

Accept as Best Hit Search Residuals

Additional properties of PU0074

Figure 18: Photo of a sample being cross-referenced with an appropriate library, percentage match likelihood shown.

5. Recommendations and future work

The overall recommendation from the discussion above is to simply better record all the different parameters of the trial setup, such as meteorological and locational data. However, there are also some developments in the instrumentation that could yield benefits in improving accuracy in the future.

5.1. Fibre-optic pressure gauges

One area where there has been considerable development in recent years is the quality of fibre-optic cables [15]. It is now possible to use these along with a diaphragm, to create an interferometer to measure pressure changes [15] [16]. The interferometer measures the difference in emitted and reflected light from a moving surface. It is possible using this technique to measure very small very rapid movements and then by referencing the original emitted light, a distance can be calculated which tells an observer how far that surface has travelled in a given time. Using this technique it is possible to construct pressure sensors that measure the effect of the wave on a thin diaphragm and then work out the pressure of the wave causing the diaphragm to fluctuate [16] [15]. The advantage this has is that each sensor can be very small, meaning that multiples can be used for a number of locations and

the response time of the sensor is very rapid, far higher than piezoelectric sensors which would possibly reduce the noise seen in the results in section 4 [15].

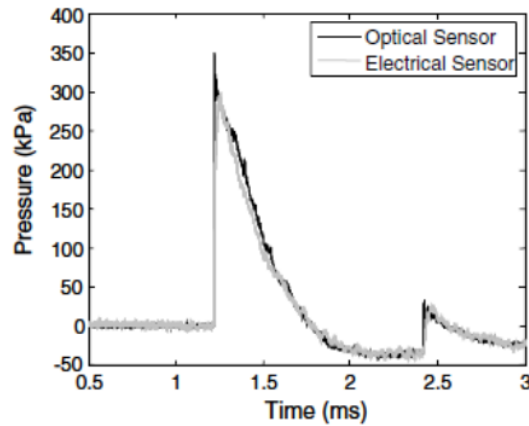


Figure 19: Optical sensor plot shown in black, note its similarity to the Friedlander curve profile, taken from [15].

5.2. HetV

HetV essentially uses similar technology to the fibre optic gauges to measure the change in distance to a surface. In explosive trials this can be useful for tracking the velocity of the metal casing of the munition of interest [17]. As the metal case expands the distance between the emitted and reflected light shortens and this can be measured to give a velocity [18]. The advantage that HetV has over velocity foils is that it can be mounted much closer to the device and that multiple signals can be taken along a surface recording the expansion of a case in time [18].

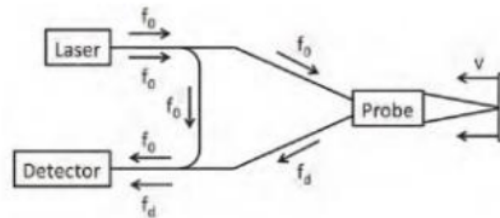


Figure 20: HetV setup with the probe near to the surface of interest and the laser and detector setup to emit and record light [18].

5.3 Radar doppler velocimetry

Another variation on the previous two instrumentation techniques is radar doppler velocimetry. Instead of using light to generate the signal this technique employs radar [19]. One of the advantages of this technique is the ability to track group of fragments, at the point of separation from the munition, across the radar measurement window and into a target [20]. This allows for multiple fragments to have their velocity measured, but also to filter out those that might have had their trajectory altered prior to hitting the target.

Radar doppler velocimetry also has a significant advantage in not relying on optical feedback for measuring the fragment velocities. This is important because other products of an explosion are high amounts of light and smoke, both of which obscure the ability of instrumentation to take measurements immediately at the point of detonation [3]. By relying on radar as opposed to light, the fragments can be tracked closer to the point of detonation [20].

6. Conclusion

This report has critically assessed the methodology and outputs from the trial undertaken on 15th October 2024. It is argued that although the data gathered allowed the author to fulfil the research requirement, i.e. to reasonably present which munition was likely to have been detonated, the data could have been stronger and clearer if further data had been recorded at the time of the trial. It is also argued that future work may wish to consider using alternative technologies to better measure important characteristics in the detonation event such as fragment velocity. `

References

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Annex A



Figure 21: Larger version of fig 5, showing the numbered packs and stands more clearly in the red circles.

Evaluation of a trial

GRADEMARK REPORT

FINAL GRADE

85 / 100

GENERAL COMMENTS

Hi Josh,

There is very little fault to find on this submission. As such, I am not deliberating too much on the feedback, other than to list your scores against the criteria for a 1:1 degree from what I have read. This is a difficult subject so extremely well done. Bodes well for the Major Project.

1. Exceptional engagement with an extensive range of relevant and credible literature, informed by the latest research. High-level referencing skills consistently and professionally applied. Exceptionally coherent and detailed knowledge and systematic understanding of the principles and theories of the subject, well-informed by current research and scholarship. 8/10

2. A critical, sophisticated and nuanced awareness of the ambiguities and limitations of knowledge. Exceptional critical thinking, analysis, synthesis and evaluation based on judiciously selected evidence. Ability to investigate contradictory or incomplete information and make strong, persuasive, arguments and sophisticated, nuanced, judgements. 18/20

3. Evidence of independent thought and ability to 'see beyond the question', suggesting an outstanding grasp of the broader field and wider concepts. Exceptional levels of application and deployment skills in unpredictable, practical contexts, drawing skilfully on the latest research within the discipline. 25/30

4. Can identify complex problems and propose sophisticated solutions. Assimilation and development of cutting edge processes and techniques.
Can communicate with an exceptionally high level of professionalism.
Work is exceptionally coherent, very fluent and is presented professionally. 25/30

5. Can work exceptionally well and professionally within a team, showing advanced leadership skills. Demonstrates exceptional graduate employment skills and an appetite for further development.
9/10

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