



Emalie Halifax

A Critique of the Data Capture Methods used in Ordnance
Identification

University of Wales Trinity Saint David
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Abstract

This report critically evaluates the data capture methods used during a fragmentation trial to identify an unknown munition. Established techniques were evaluated including Integrated Electronics Piezoelectric (IEPE) pressure sensors, calibrated strawboards, velocity foils, and Fourier Transform Infrared Spectroscopy (FTIR).

The evaluation revealed significant discrepancies between theoretical models and observed results. Blast pressure data was compromised by fragmentation and reflection interference, while fragmentation data was hindered by mathematical ambiguity and manual capture methods. Chemical sampling was further limited by inadequate sample preparation and identified the need for robust protocols and confirmatory analysis.

Alternative methods including Photonic Doppler Velocimetry (PDV), high-speed imaging and Raman Spectroscopy were recommended as ways to address technical limitations to ensure reliable and accurate datasets in unpredictable environments.

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1 Introduction

In the Ordnance, Munition, and Explosives (OME) industry, data is essential to ensure safety, validate operational effectiveness, enable forensic capabilities and ensure compliance with defence regulations. By adopting systematic methods to obtain accurate and reliable data [1] it provides the evidence base for design validation, accident prevention and post-event investigation.

Within the design stage of munition development, data is captured to validate theoretical models and ensure munitions meet performance and safety requirements. This is often conducted in a trial environment which enables the data to be collected in controlled conditions. While trials are typically performed with known munitions, the ability to identify unknown munitions post-blast is essential for forensic purposes, especially with the use Improvised Explosive Devices (IEDs) by terrorist groups [2]. Capturing detailed, reliable datasets in these hazardous environments can be hindered by technical limitations which need to be overcome.

A fragmentation trial was conducted during which fragmentation, blast and chemical data was collected to aid a group of students identify an unknown munition using pre-given information of potential systems. This report aims to critically evaluate the data capture methods employed during the trial whilst demonstrating a fundamental understanding of those methods.

2 Analytical Concepts for OME identification

Blast pressure, fragmentation, and chemical data can provide insightful information to aid the identification of munitions and to determine performance.

Overpressure, impulse, and shockwave propagation data can aid in determining explosive yield and distinguish between high-order detonation and low-order deflagration. By comparing measured overpressure and impulse against theoretical models such as Hopkinsin-Cranz scaling and Kingery-Bulmash curves, the explosive mass and type can be estimated [3].

Fragmentation patterns can reveal casing material and design intentions, specifically size, mass and velocity distribution of fragments which can indicate whether the munition was anti-personnel, anti-armour or improvised. The recovery of fragments, via arena trials or forensically, can indicate the presence of pre-formed fragmentation or natural casing rupture.

Chemical analysis can identify explosive residue and chemical compounds which support the identification of explosive devices. Trace impurities and stabilisers can provide manufacturing signatures useful for characterising munitions.

3 Overview of Trial Methodology

The trial took place at the Cranfield Ordnance Test and Evaluation Centre (COTEC), in accordance with ITOP-4-3-813 – Static Testing of High-Explosive Munitions for Obtaining Fragment Spatial Distributions. Incident Blast Pressure, Fragmentation and Chemical analysis data was collected to support the analysis required to identify the unknown munition.

3.1 Blast Pressure Collection Methodology

To measure the incident blast pressure, Integrated Electronics Piezoelectric (IEPE) pressure sensors were used. IEPE sensors measure dynamic pressure resulting from turbulence, cavitation, blast, ballistic and engine dynamics [4]. Piezoelectric gauges incorporate crystalline quartz sensors [4] that produce an electrical charge when under load. IEPE sensors contain integrated electronic circuits that convert the charge into a voltage signal given as mV per unit of pressure [5].

IEPE sensors require power due to their integrated amplifiers, a standard two-wire cable is suitable to power the sensor and transmit the voltage signal, without the need for additional specialist cabling.

During the trial, IEPE sensors were positioned within pressure gauges as illustrated in Figure 3-1 and clamped to supports as shown in Figure 3-2. Bayonet Neill-Concelman (BNC) cables provided power and sent data to the Data

Acquisition System. Steel I-beams and sandbags were used to protect the cables from damage.

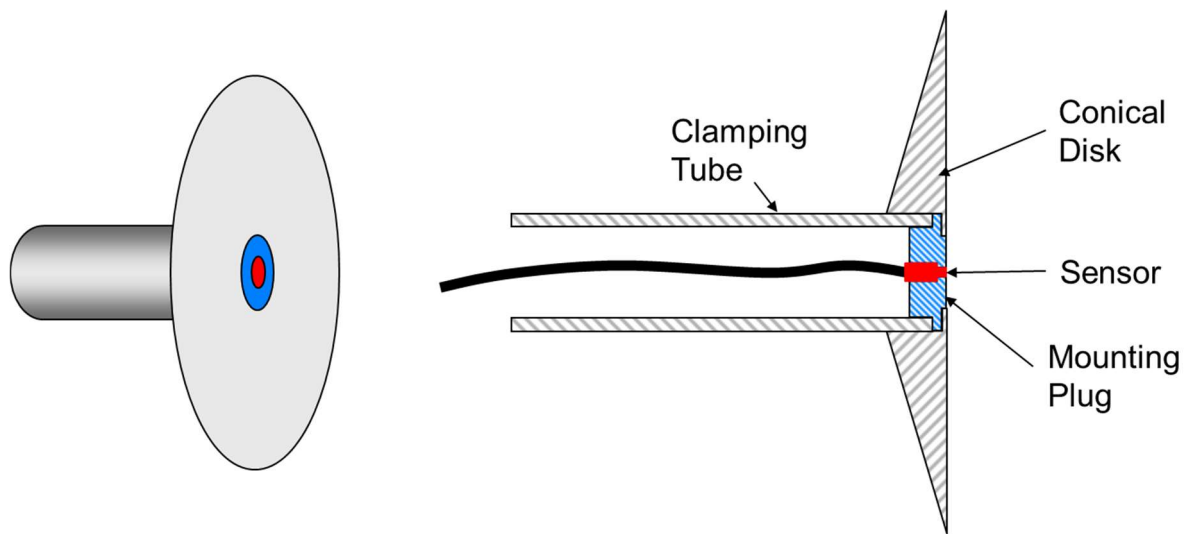


Figure 3-1 - Schematic of Blast Pressure Sensor Positioned in Gauge

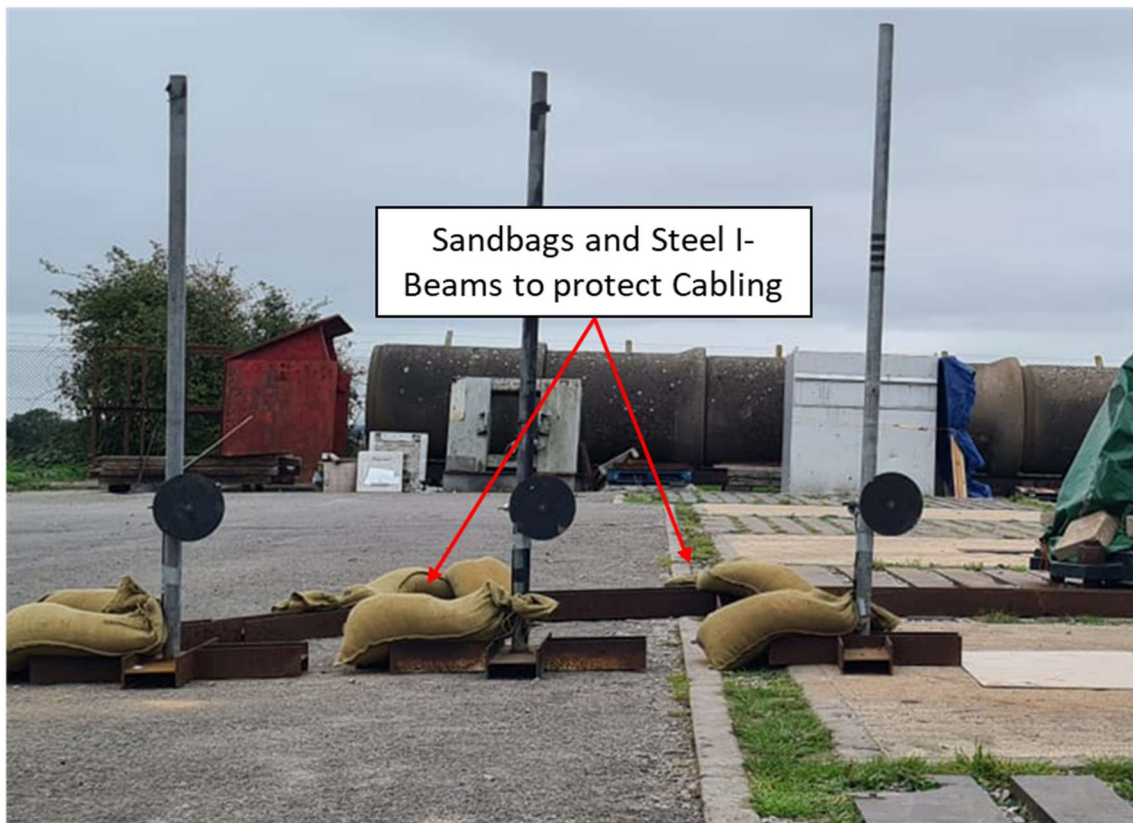
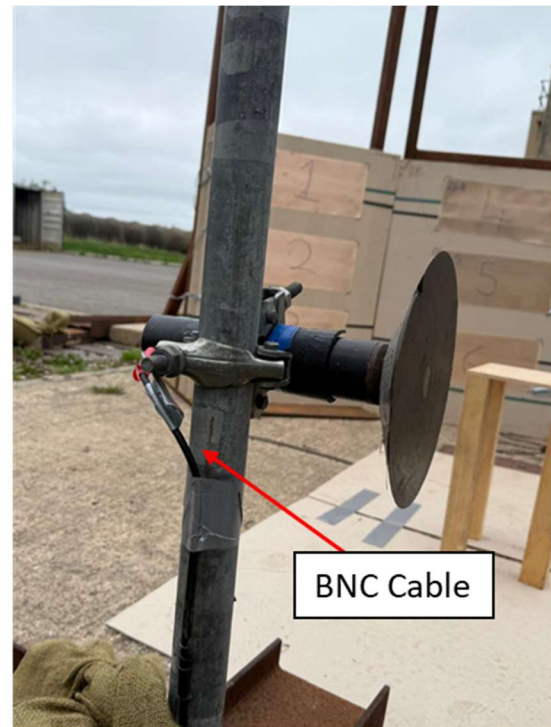
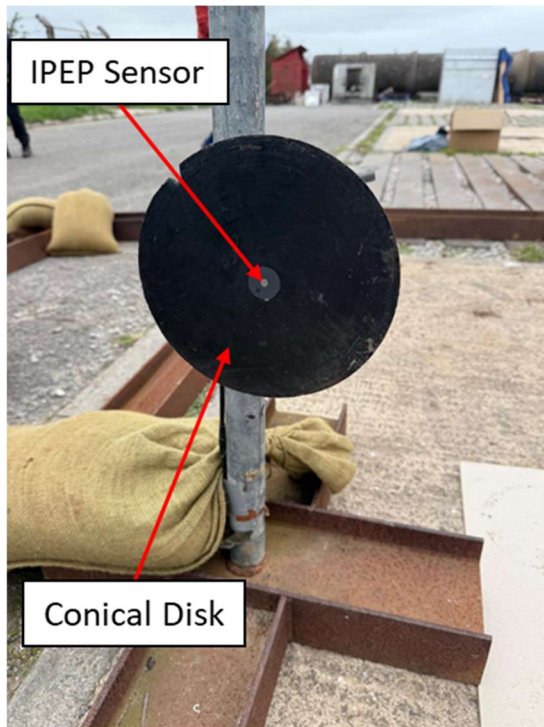


Figure 3-2 - Blast Pressure Gauges Clamped to Support Beams

3.2 Fragmentation Data Collection Methodology

3.2.1 Physical Fragmentation Collection

Physical Fragmentation from a detonated munition can provide detailed information on its design, size and intended use. Calibrated cardboard strawboards were used to collect the fragments during the trial. Four panels with forty individual sheets were positioned in a 113° arc attached to steel supports around the munition as shown in Figure 3-3. Depending on fragment velocity and explosive power from the munition, fragmentation would become embedded in different panel layers. The number of fragments per panel, their position on the boards and penetration depth can then be analysed.

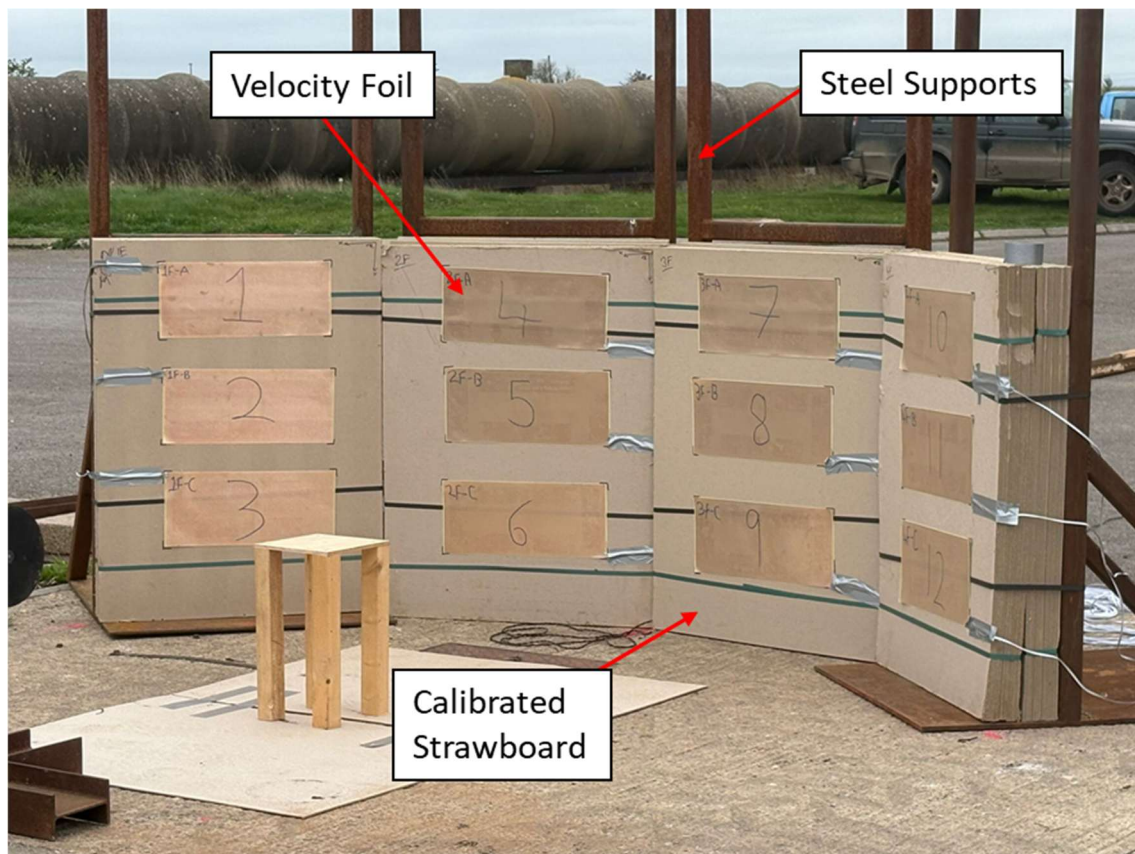


Figure 3-3 - Velocity Foils Mounted onto Calibrated Strawboards

3.2.2 Fragmentation Velocity

Measurement of fragmentation velocity is key to identifying and assessing the performance of munitions, providing critical insight into the explosive energy and

potential chemical composition. During the trial, velocity foils were the primary method of data collection for fragmentation velocity.

Make Foils were mounted onto strawboards (Figure 3-3) and connected to a logic analyser. These foils consisted of an open circuit with a 1mm gap, which, when a metallic component strikes the foils, it closes the circuit and a signal change is registered on the logic analyser. When the component leaves the foils, the circuit reopens, enabling additional strikes to be recorded. During the trial, a start signal (T_0) was initiated by a break wire around the munition, allowing timestamps to be recorded for each strike. This method permitted capture of multiple fragmentation pieces, allowing the potential of a more comprehensive dataset than traditional break foils.

3.3 Chemical Sampling

Chemical analysis was conducted post-trial by Fourier Transform Infrared Spectroscopy (FTIR). FTIR is an essential analytical technique used for material analysis of organic components [6], including identification of explosive compositions. It operates by producing a molecular fingerprint of a sample, which can be used as a confirmatory test [7]. Samples can take the form of liquids, solutions, pastes, powders, films, fibres and gases [6].

Samples were produced from the fragmentation and environmental samples were collected pre- and post-detonation. After preparation, the trial samples were subjected to Infrared Radiation (IR) which interacted with atomic vibrations of the molecules present, producing specific transmittance and/or absorption of energy relating to the sample. This data can be presented in tabular or graphical form as shown in Figure 3-4 and Table 3-1.

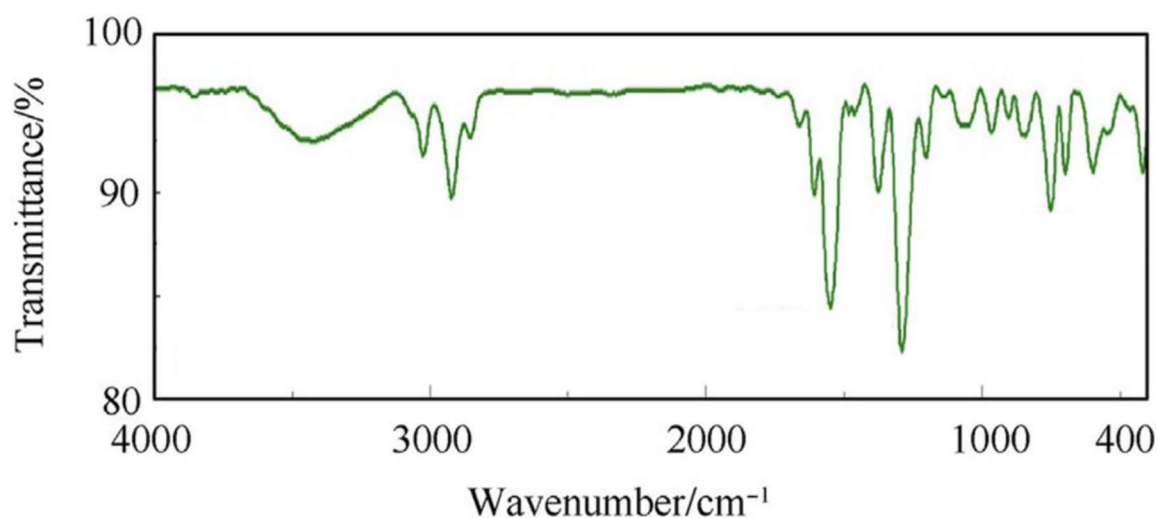


Figure 3-4 - Example of FTIR Transmittance Graph

Table 3-1 - Example of Vibration Frequencies Produced from FTIR

Experimental vibrational frequencies [cm^{-1}]	Description of the normal modes of vibration	Comments
3075	CH stretch (s)	Strong
3066	CH stretch (a)	Strong
3001	Plasticizer	Weak
2930	Plasticizer	Weak
1738	Plasticizer	Weak
1593	NO stretch	Strong
1574	NO stretch	Strong
1533	NO stretch	Strong
1460	H-C-N bend (a)	Strong
1434	H-C-N bend (a)	Strong overlap
1390	C-N stretch	Strong
1351	C-N stretch	Strong
1312	N-N stretch	Strong broad
1269	C-N stretch	Very strong
1233	C-N stretch	strong Overlap
1218	C-N stretch	Strong overlap
1040	C-N stretch	Strong
924	O-N-O bend	Strong broad overlap
882	N-N-O bend	Medium
843	N-N-O bend	Medium
783	N-N-O bend	Strong
753	Ring distortion	Medium
604	Chair type ring distortion	Medium overlap
590	Ring distortion at carbon atoms	Medium overlap
461	Ring distortion	Weak
410	Ring distortion	Weak

4 Critical Evaluation of Data Capture Methods

4.1 Blast Pressure Critical Evaluation

Accurate blast pressure measurements require an understanding of blast mechanics and what can cause interference. An ideal blast wave will produce a sudden increase of positive pressure with a period of steady decline followed by a period of negative pressure as demonstrated in Figure 4-1. In real environments, deviations from ideal blast pressure waves are probable. If not accounted for they could impact interpretation of results and reduce data reliability. Based on the trial blast pressure results, Figure 4-2, it is clear that insufficient precautionary measures were taken to mitigate potential interferences. With adjustments, it is likely that data quality could be improved.

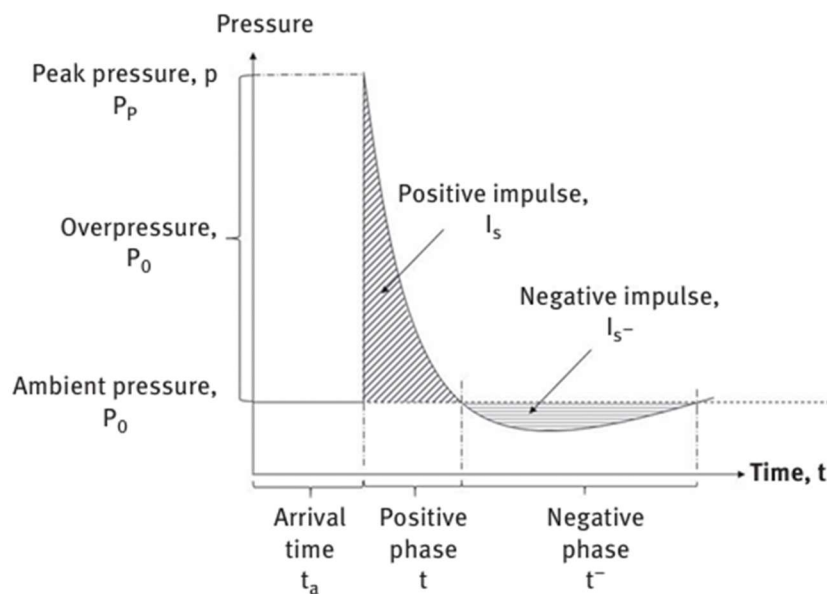


Figure 4-1 - Ideal Blast Wave [8]

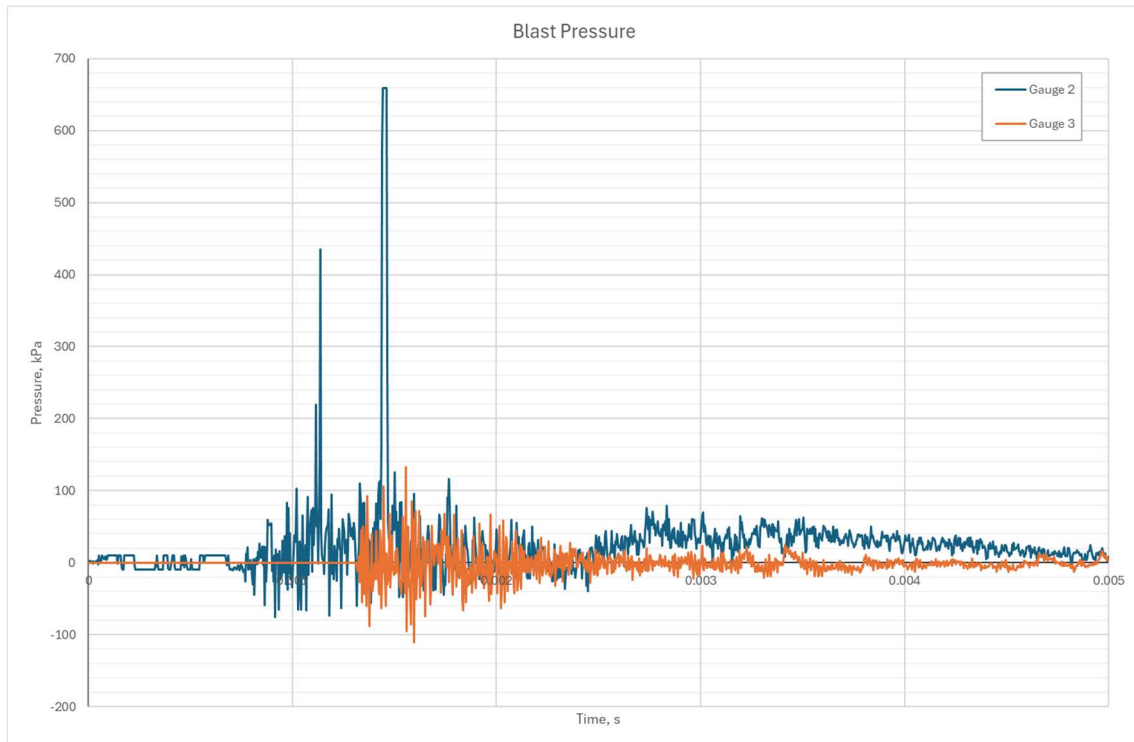


Figure 4-2 - Blast Pressure Results from COTEC Trial

Fragmentation has the potential to travel at considerable velocities, with sufficient momentum, they may travel faster than the blast wave, producing disturbances on the pressure gauges before the wave's arrival [9]. Fragmentation can also potentially impact or damage equipment, causing additional interference in the results or rendering them unusable. Precautions were taken to ensure the cabling was positioned on the opposite side of the support beams from the munition. Exposed wires on the ground were covered by steel I-beams and sandbags, however, the gauges were not as protected. This is demonstrated in Figure 4-3 where a pressure gauge was catastrophically damaged by fragmentation, rendering its data unusable. Placing gauges behind a protective barrier while keeping the diaphragm free, would have protected vulnerable components.



Figure 4-3 - Gauge One Fragmentation Damage from Trial

Reflective waves can impact blast pressure measurements, making interpreting the true incident wave difficult. Blast waves reflect off any solid object or surface in their path, particularly if originating above ground. Reflected waves propagate faster than incident waves since they pass through air which is already moving at high velocity caused by the original wave. A reflective wave can eventually merge with the incident wave, forming a combined wave known as the Mach Stem [10] as shown in Figure 4-4. Pressure recorded from a Mach Stem can be twice that of the original incident wave [8]. Without additional equipment, it can be difficult to interpret when this has occurred.

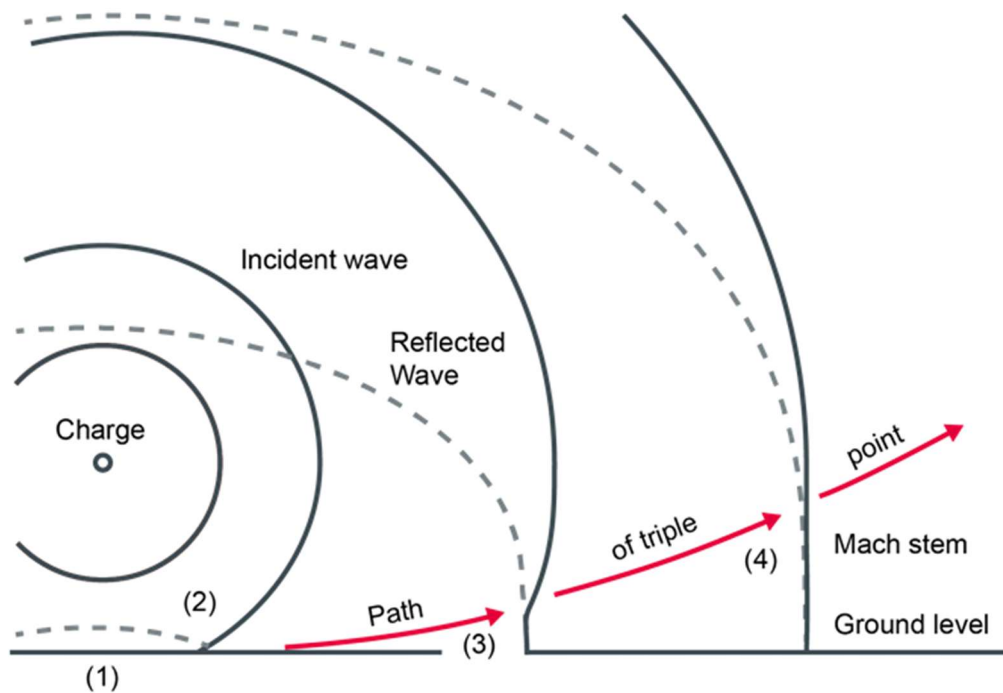


Figure 4-4 - Production of a Mach Stem [11]

To reduce the impact of reflective waves, the trial should be conducted in an environment with minimal obstacles for the incident wave to interact with. Soft materials situated beneath the munition's stand and gauges can limit ground reflections and shock. A singular piece of strawboard was positioned under the munition stand to mitigate this effect (Figure 4-5), however, additional pieces would have further minimised the effects.

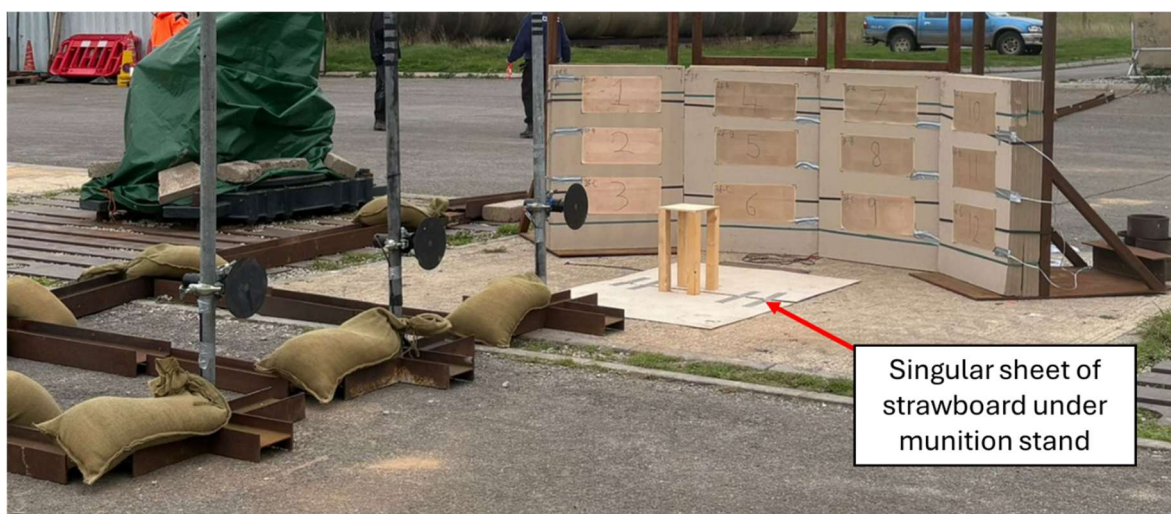


Figure 4-5 - Trial Set Up Highlighting Strawboard Under Munition Stand

The shape of the munition can impact blast measurements as spherical and cylindrical charges have different blast mechanics, illustrated in Figure 4-6. To provide a better understanding of pressure waves, and to aid identification of interferences and reflections, multiple arrays of pressure gauges are typically employed. Depending on the requirement of a trial and size of munition, different configurations can be used [12, 13] – ideally a minimum of three arrays with three gauges as illustrated in Figure 4-7. This trial had one array with three gauges, reduced to two gauges due to a fragment strike. This limited the dataset and prevented suitable information from being collated. Additional arrays would have provided redundancy, while increasing the potential for more data to be collected.

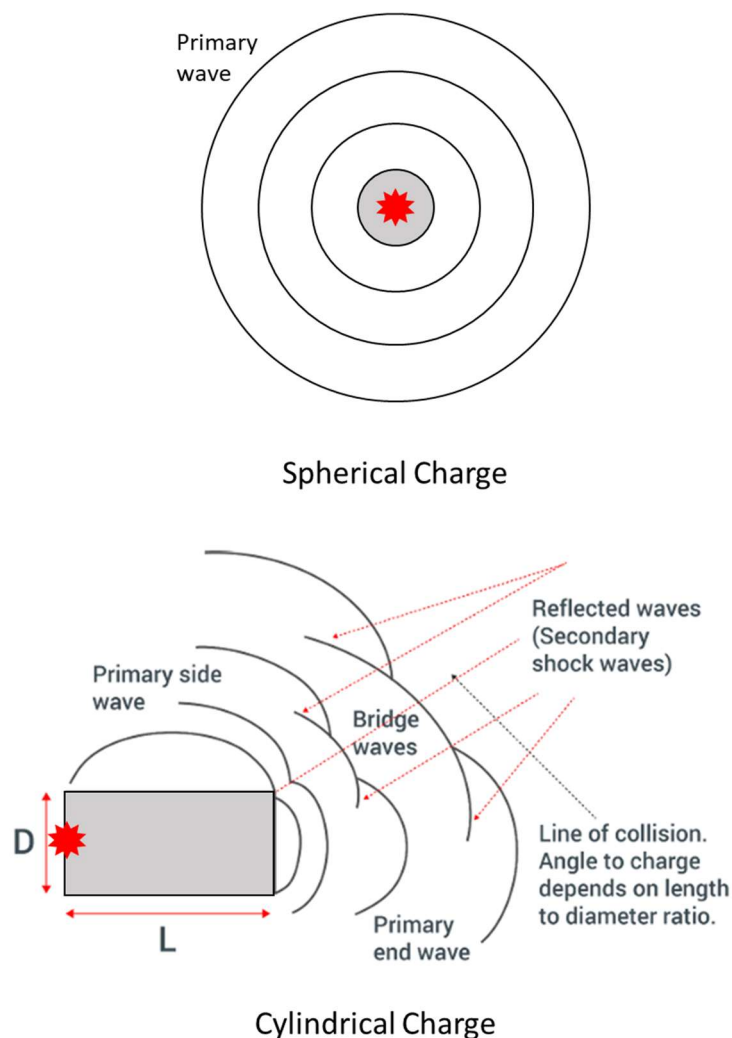


Figure 4-6 - Comparison of Spherical and Cylindrical Charge Blast Waves

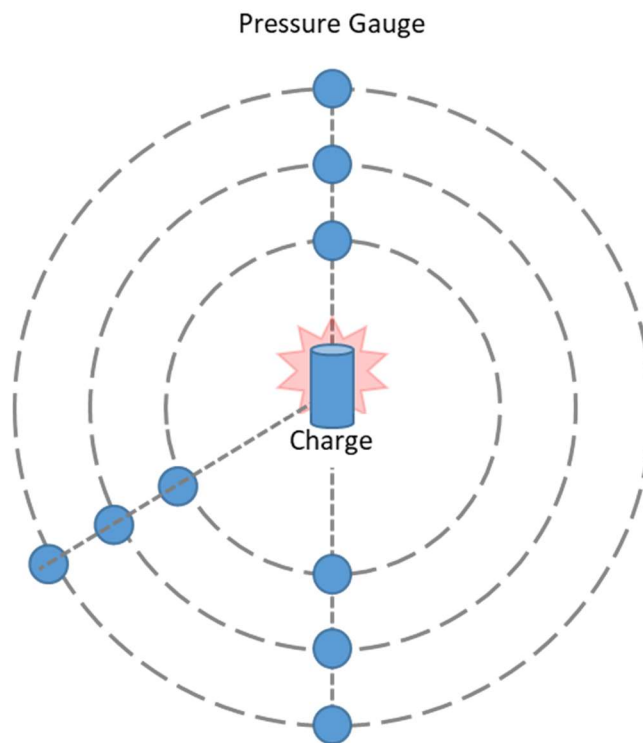


Figure 4-7 - Typical Blast Pressure Gauge Array

4.2 Fragmentation Data Capture Critical Evaluation

4.2.1 Physical Fragmentation Evaluation

Accurate collection of fragmentation was essential to identifying the munitions casing. Primarily, its mass, size and whether it was designed to have natural or preformed fragmentation.

While strawboards are typically used for analysing penetration depth [14], they are also an effective means of capturing fragmentation for further analysis, however, this relies on fragments being physically retrieved from the boards by hand. This can introduce an element of human error in both retrieval and positional data recording.

The manual picking of fragments can be assisted via the use of tools such as pliers, which were used in this trial, or magnets which mean smaller pieces can be collected [15], allowing for a more accurate dataset.

If trials are conducted in a contaminated environment, as was the case with the COTEC trial, it becomes necessary to limit fragment collection to the strawboards to avoid cross contamination with previous trials.

While sufficient fragmentation was collected to provide a usable dataset, a lack of co-ordination and consistency between the groups meant that no data regarding the number of fragments per panel was recorded. This would have provided further insight into the casing design and fragment dispersion. Closer collaboration in fragment retrieval would have increased the accuracy and thoroughness of the dataset.

Strawboards have seen use in fragmentation trials since 1960 [14] and are well established as an effective collection method. Initially, these boards were easily sourced and affordable [14] but due to recent economic and geopolitical supply issues, this is no longer viable. Alternative sustainable and economical materials are starting to be considered. A 2024 paper by James Read et al [14] explored alternative options demonstrating the key characteristics shown in Table 4-1. The highest performing material for penetration depth was 6mm Medium-Density Fibreboard (MDF) as measured against NATO guidelines for witness capture methods. The market availability of MDF makes it both economically attractive and environmentally sustainable as a replacement. While further testing is required to determine the versatility of the material during explosive trials, it highlights the need for modernisation and continuous assessment of methodology and materials.

Table 4-1 - Key Characteristics of Fragmentation Witness Capture Materials

<i>Characteristic</i>	<i>Description</i>
<i>Handling</i>	Options must be able to be handled by two people, and to retain structural integrity when handled while partially saturated.
<i>Density</i>	The density of the material should not affect the physical characteristics of the impacted fragmentation.
<i>Flammability</i>	The risk of fire should be minimised when containing hot fragments.
<i>Calibration</i>	The materials should be calibrated to assess correlation between depth of penetration and impact velocity.
<i>Cost</i>	The materials should not be prohibitively expensive.
<i>Availability</i>	The materials should be readily available.

4.2.2 Fragmentation Velocity Evaluation

Velocity foils are a simple, cost-effective means to determine fragmentation velocity, however, its ability to produce reliable measurements depends on several assumptions and instrumentation choices.

The make foils used in the trial are capable of registering multiple strikes, unlike break foils which are single use, enabling more data to be collected per foil. The materials are inexpensive and the connected logic analyser offers precise timings, if configured correctly. This presents an attractive methodology for experimental or supplementary measurements where budget and set-up constraints are significant.

There are, however, limitations with the technique. The foils only detect conductive fragments over the threshold size of 1mm. Any non-metallic or very small fragments will not trigger the foils, adding an element of bias in favour of

larger metallic fragments. This undermines the representativeness of the recorded velocity distribution.

There is also an element of mathematical ambiguity which effects the results. Fragments disperse in multiple directions and the distance travelled before striking the foils varies with angle and position. Without knowing the exact trajectory of each fragment, the assumption of a fixed path length introduces inaccuracy in velocity calculations. The method therefore risks producing lower estimates rather than accurate measurements.

Efficient placement of the foils is essential to ensuring reliable data collection. Fragment spatial distributions will differ between munitions and to determine fragment velocity, it needs to be ensured that the fragments will strike the foils.

Foils are susceptible to distortion from fragmentation, this can cause them to short circuit, preventing additional strikes from being detected. When analysing the recorded times, only the fastest strikes can be deemed reliable, limiting the dataset. This is evident in the trial results. Figure 4-8 shows the physical strikes from three foils that were positioned on panel two. It shows there are significantly more strikes than what the logic analyser detected.

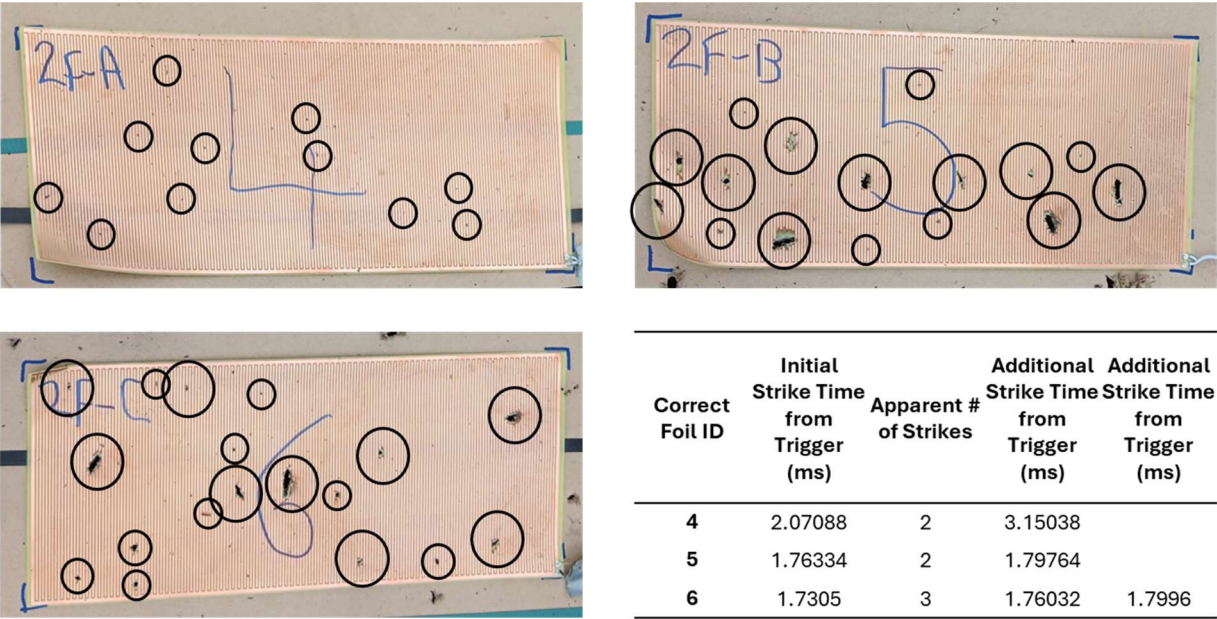


Figure 4-8 - Strikes Present on Panel 2 Velocity Foils with Detected Strike Times

The reliance on a break wire as the trigger for T_0 introduces an element of uncertainty as the wire may break at different times relative to actual fragment release, offsetting all subsequent measurements.

If any assumptions underpinning the use of foils are false, detection efficiency decreases significantly. For example, ceramic or oxidised fragments may pass undetected and fragments could bypass the foils entirely, if incorrectly placed.

Make foils susceptibility to distortion can impact their ability to record multiple strikes. Reducing the size and increasing the number of foils would help mitigate this by adding an element of redundancy. Smaller foils would also enable more accurate velocity calculations as time strikes can be allocated to more precise distance measurements. Positioning foils precisely would support additional analysis based on fragmentation spatial patterns, as discussed in the trial laboratory report [16].

4.3 FTIR Critical Evaluation

FTIR is an accurate and repeatable process making it a reliable technique for positive identification of organic compounds. While it is a confirmatory test, the results can be compared to known samples, often in a database or analysed manually by identifying key functional groups at specific frequencies [6]. FTIR offers precise measurements with a sample rate of seconds due to all frequencies being measured simultaneously [7]. Internal calibration ensures increased sensitivity compared to dispersive techniques minimising interference [7].

As a non-destructive test [7], samples can be obtained by swabbing areas of interest. During the trial, environmental swabs were obtained before and after detonation, however they were not prepared correctly with an appropriate solution meaning only samples from the physical fragmentation were analysed. A wider spread of samples would enable any potential contaminations to be ruled out. As the fragmentation was metallic, they could not be used in their original form and had to be dissolved in acetone to produce a solution. The acetone contamination had to be removed before analysis to determine the explosive composition.

5 Potential Alternative Methodologies

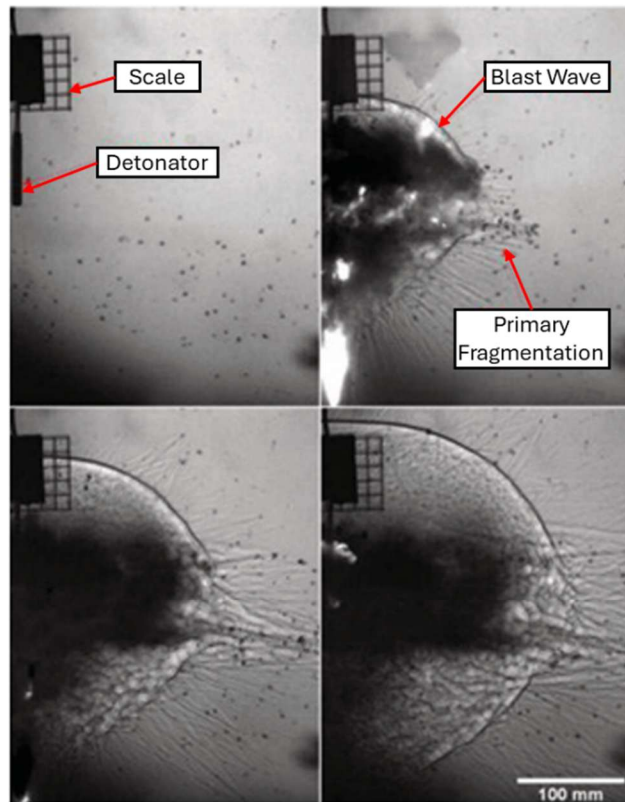
Whilst the collection methods used during the trial enabled sufficient data to identify the unknown munition, the reliability and accuracy of the dataset could be improved with the employment of alternative methodologies.

5.1 Advanced Imaging

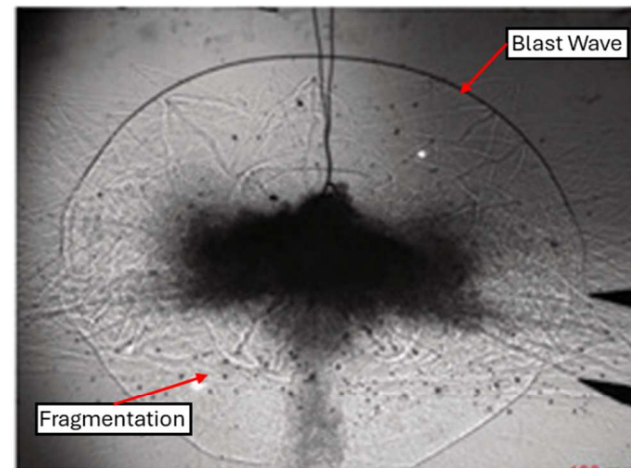
Although this trial was conducted with a limited number of resources, employing advanced imaging techniques would enable a greater understanding of the blast wave and fragmentation velocity.

Advanced imaging techniques such as shadowgraphy or Schlieren imaging combined with high-speed photography can provide additional information, such as the radial expansion of blast waves and the velocity of fragmentations [17] as demonstrated in Figure 5-1. High-speed photography requires a sufficient view of the test area to be in frame in order to capture wave propagation. This should be captured in the highest possible resolution to ensure high quality images for post-processing [17].

Using high-speed cameras in conjunction with blast pressure sensors can help identify propagation of incident and reflected waves and record the time each wave reaches the gauges. This would pin-point the corresponding pressure from the blast results, allowing the relevant results to be visualised without interference. This can also aid identification of a Mach Stem as demonstrated in Figure 5-2 [13].



(a)



(b)

Figure 5-1 - (a) Image Sequence of Blast Wave Propagation and (b) Blast Wave during Advanced Explosives Processing Research Group (AXPRO) High-Speed Imaging and Shadowgraph Experiment [17]

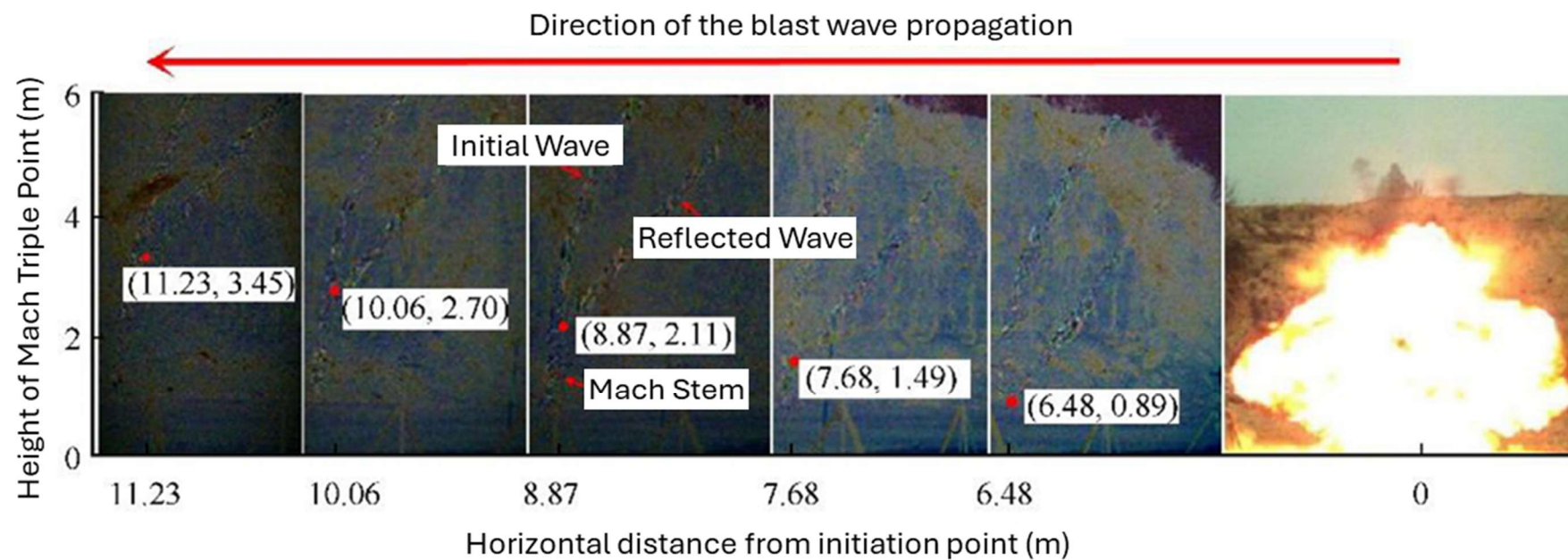


Figure 5-2 - Propagation of a Blast Wave Captured by a High-Speed Camera, Highlighting Mach Stem Propagation [13]

5.2 Fragmentation – Photonic Doppler Velocimetry (PDV)

Photonic Doppler Velocimetry (PDV), also known as Heterodyne Velocimetry (HetV), is a non-contact technique that uses laser light and the Doppler effect to precisely measure extremely high velocities, such as those occurring during explosive fragmentation [18]. The core concept relies on mixing laser light reflected from a moving surface with un-shifted laser light to create a measurable electrical signal called a beat frequency [18, 19]. It works on the following principle:

1. Laser light, typically 1550nm fibre laser and single mode fibres [18], is delivered to the trial location and to a specialised probe, with an original frequency of f_o .
2. The probe directs light onto a moving surface, which is reflected and scattered changing the f_o to the Doppler shifted frequency, f_d .
3. The collected Doppler shifted light, is transported back to a detector via fibre, and mixed with a portion of the original un-shifted light to generate a beat signal, with a beat frequency, f_b , which equates to the absolute difference between f_o and f_d .
4. Fast Fourier Transform is applied to create a spectrogram and to identify all beat frequencies. The velocity is proportional to f_b and the laser wavelength, λ_o , as shown in equation 5-1 [18].

$$v = \left(\frac{\lambda_o}{2}\right) f_b \quad 5-1$$

While this method enables the observation of multiple discrete velocities simultaneously and mitigates several of the limitations of velocity foils, in comparison it is a more expensive method.

5.3 FTIR – Ramen Spectroscopy

As previously discussed, FTIR can only identify organic compounds. The COTEC trial used an organic compound and was therefore detectable by FTIR Spectroscopy, however, for inorganic or metallic compounds an alternative

identification method would have been required such as Raman Spectroscopy [20].

While it is similar to IR Spectroscopy, Raman Spectroscopy relies on the inelastic Raman scattering effects of molecules, requiring intense light sources and complex optics, making it preferable when FTIR spectroscopy is inconclusive. An added benefit is that it can be conducted without the need for sample preparation [8] allowing it to be used within the trial environment itself rather than a laboratory. This would have benefited the COTEC trial, as samples were discarded due to inadequate preparation.

6 Conclusion

This report has critically evaluated the data capture methods employed during the COTEC fragmentation trial, identifying discrepancies between theoretical models and observed results. Although IEPE sensors, velocity foils and FTIR analysis enabled the identification of the unknown munition, the trial highlighted limitations in data reliability and accuracy.

Blast pressure measurements were compromised by fragmentation damage and reflection interference, while fragmentation data exhibited mathematical ambiguity and inadequate chemical sampling preparation highlighted the need for robust protocols and confirmatory testing.

To mitigate these shortfalls, the adoption of advanced technologies would improve data reliability. PDV and high-speed imaging could enhance precision in fragmentation velocity and blast wave analysis. Raman Spectroscopy could offer a more versatile chemical analysis method that reduces contamination risks compared to FTIR.

Overall, the findings demonstrate that while traditional methods provide a foundation for fragmentation trials, their limitations in high-hazardous environments require the integration of modern alternatives and rigorous protective measures.

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