



Libby Mae Jones
2222538

Level 6 ACDA6021

Critique of Data Capture Methods Used

University of Wales Trinity Saint David
BEng Bachelor of Engineering Program, Ordnance, Munitions and
Explosives (Safety)

Academic Year: 2025 - 2026

Abstract

Effective identification of unknown ordnance, munitions and explosive (OME) items depends on the capture of reliable and interpretable data during explosive events. During the COTEC arena trial, witness strawboards, conductive foil strike timing systems, piezoelectric blast pressure gauges and post-blast Fourier Transform Infrared (FTIR) spectroscopy were employed to characterise blast behaviour, fragmentation characteristics, and explosive composition without direct visual inspection of the device. These systems provided the evidential basis for the identification conclusions drawn in Task One.

This report critically evaluates the data capture methodologies used during the trial, examining their operating principles, performance, limitations and susceptibility to environmental, physical and human factors. Issues such as incomplete fragmentation recovery, signal saturation, sensor vulnerability and residue contamination are discussed in the context of their impact on data confidence and interpretive uncertainty. The report also considers alternative and complementary technologies that could enhance future trials. Through this critique, the report demonstrates in-depth technical understanding of OME data capture systems and a critical appreciation of how methodological choices influence assessment of explosive performance and ordnance identification.

Table of Contents

Abstract	ii
List of Figures	iv
List of Tables	v
List of Equations	vi
List of Abbreviations	vii
1 Introduction	8
2 Technical Exposition	9
2.1 Blast Pressure Measurement	9
2.2 Fragmentation Capture and Recovery	9
2.3 Explosive Residue Analysis	9
2.4 Fragment Velocity Measurement	10
3 Case Analysis	11
3.1 Witness Strawboards & Fragment Recovery	11
3.1.1 Critical Limitations	12
3.2 Foil Strike Timing / Velocity Detection System	13
3.2.1 Critical Limitations	14
3.2.2 Recommendations	14
3.3 Piezoelectric Blast Pressure Gauges	16
3.3.1 Critical Limitations	16
3.3.2 Recommendations	18
3.4 FTIR Residue Analysis	19
3.4.1 Critical Limitations	20
3.4.2 Alternative and Complementary Methods	20
3.4.3 Recommendations	23
4 Discussion	24
5 Recommendations	25
6 Conclusion	26
References	27

List of Figures

Figure 1 COTEC Arena Trial Set-up..... 8

Figure 2 Mullen Test Method [4]..... 11

Figure 3 Example of Fragment Spatial Distribution, Captured by High-Speed Photogrammetry, Photron SA-X2 mono high speed cameras [10]. 13

Figure 4 A Diagram of the Mach Effect [8] 19

Figure 5 Deviation Between FTIR (- - -) and Ramen Spectroscopy (---) 21

List of Tables

Table 1 Comparison of Time of Arrival Devices (TOADs) [10] 15

Table 2 Comparison of Pressure Sensors [5] [6] [7]..... 17

Table 3 Comparison of Residue Analysis Methods [18] [19] [20] 22

List of Equations

3-1 13

List of Abbreviations

ATR	Attenuated Total Reflectance
COTEC	Cranfield Ordnance Test and Evaluation Centre
DSTL	Defence Science and Technology Laboratory
FTIR	Fourier Transform Infrared Spectroscopy
HMX	Tetraazacyclooctane
ITOP	International Test Operations Procedure
MDF	Medium-Density Fibreboard
MoD	Ministry of Defence (UK)
NATO	North Atlantic Treaty Organization
NEQ	Net Explosive Quantity
OME	Ordnance, Munitions and Explosives
PE8	Plastic Explosive No. 8
RDX	Triazinane
TNT	Trinitrotoluene
TOA	Time of Arrival
TOF	Time-of-Flight
UK	United Kingdom

1 Introduction

Effective identification of unknown ordnance, munitions and explosive (OME) items depends on the ability to capture reliable, meaningful and interpretable data during explosive events. During the COTEC arena trial seen in Figure 1, a range of data capture systems were used to characterise blast behaviour, fragmentation performance and explosive composition without direct visual identification of the device. Witness strawboards, conductive foil timing systems, piezoelectric blast pressure gauges and FTIR residue analysis collectively informed the conclusions reached in Task One regarding likely charge mass, casing behaviour and explosive type.

However, each method carries inherent strengths, limitations and assumptions that influence confidence and accuracy. This report critically evaluates the performance of these systems during the trial, considering measurement reliability, vulnerability to environmental and physical damage, human factors and interpretational uncertainty. It also explores potential alternative technologies and practical enhancements used within defence and industry that may improve future ordnance identification capability, aligning with the module aim of demonstrating both technical understanding and critical evaluation of OME data capture methods.



Figure 1 COTEC Arena Trial Set-up

2 Technical Exposition

The fundamental purpose of data capture during an explosive event is to translate a destructive chemical phenomenon into measurable, interpretable information that can describe the munition's behaviour, performance, and likely identity. Each measurement system at COTEC contributed to a different aspect of this understanding, collectively enabling assessment of explosive yield, casing behaviour, lethality potential and energetic composition.

2.1 Blast Pressure Measurement

Blast pressure gauges are essential for characterising the intensity and nature of the detonation. Peak overpressure, reflected pressure and waveform shape provided insights into whether the event represented a high-order detonation or a lower energy deflagration. When referenced against established blast scaling such as Kinney-Graham, measured pressures enable estimation of effective TNT equivalent mass, allowing comparison across different given explosive types. In ordnance identification, blast pressure therefore informs both the likely explosive quantity and the detonation efficiency of the device [1] [2].

2.2 Fragmentation Capture and Recovery

Fragmentation data are critical to understanding casing behaviour and lethality potential. Straw witness boards and post-blast fragment recovery reveal fragment count, size, distribution, morphology and deformation characteristics. These features indicate whether a casing was designed to fragment in a controlled manner, like military ordnance, or failed through ductile rupture typical of improvised devices. Fragment patterning also allows assessment of directional blast behaviour and casing geometry, providing strong indicators of munition form and structural design [3].

2.3 Explosive Residue Analysis

Chemical residue analysis, such as FTIR spectroscopy, enables the direct identification of the energetic material used within the device. Since many

ordnance types share similar fragmentation or blast signatures, chemical characterisation provides a decisive discriminatory capability, matching spectral absorption peaks to chemical bond structures Residue analysis therefore links physical performance to material chemistry [4].

2.4 Fragment Velocity Measurement

Velocity measurement provides an indication of fragment lethality and structural break-up dynamics. Time-of-arrival foil systems allow estimation of fragment speed, which is a key determinant of casing energy transfer efficiency and wounding potential. High, consistent velocities typically indicate engineered fragmentation, whereas lower and more irregular velocities are characteristic of improvised, uncontrolled casing failure. Velocity data also support validation of blast-derived yield estimates by providing an independent kinetic performance indicator. Although data from Task One wasn't indicative of these insights [5].

3 Case Analysis

3.1 Witness Strawboards & Fragment Recovery

Witness strawboards are one of the most widely used and established methods for capturing physical fragmentation during arena trials. Constructed as layered strawboard stacks, they act as sacrificial capture media, providing a means of embedding fragments while absorbing their kinetic energy. In the COTEC trial, twelve-panel strawboards were used to intercept fragments across a defined 118° sector, enabling the collection, measurement and analysis of recovered casing debris following detonation [6].

In the UK, strawboard is the preferred standard material for capturing fragments in explosive testing. It is officially recognised in NATO's (ITOP) 4-2-813 procedure and offers a reliable historical baseline, dating to the 1970s, for measuring fragment velocity and energy absorption [7] [6]. The UK Ministry of Defence enforces strict quality standards (via Defence Standards, e.g., DEF STAN 93-59) [8], specifying thickness, grammage, and bursting strength (tested via Mullen method, Figure 2) to ensure consistency and effective fragment recovery [6].

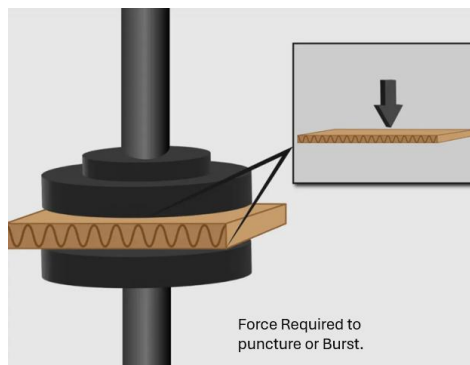


Figure 2 Mullen Test Method [9]

Though it likely originated as a convenient option (sometimes called "chipboard" or "millboard"), strawboard remains the benchmark for assessing performance in high-pressure events. However, its high cost, limited supply, and recycling challenges have spurred research into cheaper, more uniform alternatives like medium-density fibreboard (MDF) [6].

3.1.1 Critical Limitations

A key limitation of the strawboard witness packs is their restricted capture sector (the 118° arc used at COTEC), which excludes fragments outside the defined field and introduces bias from any directional asymmetry in warhead fragmentation or its orientation at detonation. This partial coverage, combined with the inability to capture escaping fragments and limited direct quantification of velocity or kinetic energy (without supplementary systems), means the data provides valuable but incomplete insights, rendering extrapolated fragment totals as estimates rather than definitive values.

Manual fragment recovery introduces further uncertainty. Human operators must physically extract fragments from the strawboard packs, an inherently subjective process prone to bias from human factors. Smaller fragments may be overlooked or lost in higher strike areas, fragments lodged deep within the board structure may remain undetected. In Task one, although 90 fragments were recovered, the foils and visible perforations clearly indicated that the true fragment count was significantly higher. This demonstrates a key limitation: witness boards under-represent total fragmentation, particularly at fine mass scales. These limitations present risk of false interpretation if data are not critically assessed.

A number of enhancements and alternative approaches exist within industry to address these shortcomings. A full ring arena or extended arc coverage would enable closer approximation to 360° collection. Automated or semi-automated recovery systems, such as metallic fragment capture gels or other soft recovery medium, reducing human extraction dependence and improve recovery of fine fragments [10] [3]. Magnetic sweeping can support recovery where ferrous or other ferromagnetic casings are expected [11]. High-speed photogrammetry (Figure 3), and calibrated imaging can provide spatially resolvable impact mapping, fragment estimation and validated strike fields [12] [13]. The use of NATO standard witness materials can improve reproducibility and comparability across trials.

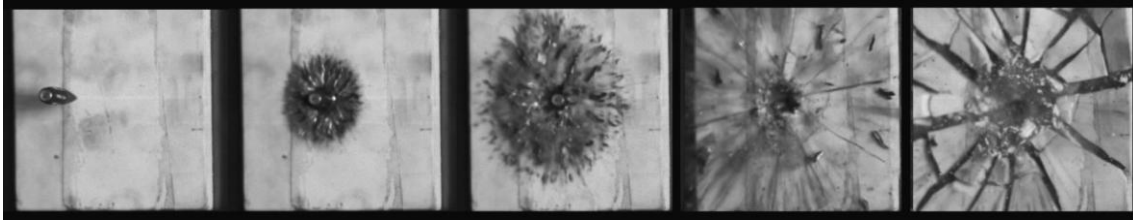


Figure 3 Example of Fragment Spatial Distribution, Captured by High-Speed Photogrammetry, Photron SA-X2 mono high speed cameras [14].

Finally, integrating sensors, such as fibre-optic, piezoelectric, ionisation, or conductive wire systems, are commonly combined with strawboards to improve strike timing accuracy and reduce undetected impacts, though each adds cost and deployment considerations (detailed in Table 1 Comparison of Time of Arrival Devices (TOADs)Table 1).

In summary, strawboards remain a practical and essential tool for fragmentation capture, but function as sampling devices rather than complete systems. Their results require careful interpretation, awareness of biases, and integration with complementary sensors.

3.2 Foil Strike Timing / Velocity Detection System

The foil strike timing system is used to estimate fragment velocity by measuring the time taken for fragments to travel from the detonation point to the witness foils. This is fundamentally a time-of-flight (TOF) method, using the relationship:

$$\text{Fragment Velocity} = \text{Distance to Foil} \div \text{Recorded Strike Time} \quad 3-1$$

At COTEC, each strawboard panel consisted of three copper make foils. Configured as open circuits, when a conductive fragment perforated/ penetrated a foil, the circuit closed, generating a digital pulse. These foils fed into a multi-cable junction box, where each foil occupied an individual input channel. The outputs were logged via a logic analyser, which timestamped strike events to microsecond precision. This provided quantitative arrival timings that could be converted into approximate fragment velocities.

This method is popular because it is:

- robust in harsh explosive environments
- relatively low cost
- simple to deploy

3.2.1 Critical Limitations

Despite its practicality, the method has notable constraints. Multiple fragments striking within microseconds cause signal saturation, meaning only a single strike may be recorded despite many perforations. Other fragments may fail to register entirely if they are non-conductive, graze the foil, or perforate without producing a clean electrical bridge. Timing noise, cabling interference and environmental disturbances could add further error [15].

The method also assumes straight-line travel and constant acceleration. Fragments tumble, collide, and experience varying drag. The foil itself represents a broad target, so the “measured distance” is only an estimate. These geometric and aerodynamic uncertainties mean TOF represents a best approximation rather than a precise ballistic velocity. This was clearly reflected in the dataset where velocities varied widely (300-800m/s⁻¹), indicating methodological limitation as much as physical behaviour.

3.2.2 Recommendations

When viewed against the alternatives in Table 1, the conductive foil system represents a practical compromise between reliability, cost, and ease of integration. It avoids the high-voltage moisture sensitivity of ionisation pins, the fragility and light-control issues of fibre-optic sensors, and the false-failure risk of bare copper wire systems, while remaining simpler and cheaper than piezoelectric pins. However, its known limitations from Table 1 were clearly demonstrated in this trial: saturation during simultaneous hits, and under-reporting in dense fragment fields, explains the discrepancy between visible perforations and logged events. Although PDV/LDV offers far superior scientific accuracy, its cost, complexity, and alignment demands limit practicality for routine arena work. Overall, foils remain appropriate for arena trials, but future

improvements should consider pairing them with fibre-optic or Doppler systems to enhance timing resolution while retaining robustness.

Table 1 Comparison of Time of Arrival Devices (TOADs) [16]

System	Principle of Operation	Advantages	Limitations
Ionisation Pins	Detect arrival of ionised shock front / plasma ahead of fragment	Simple design, Reasonably cheap, Early event detection	Highly moisture sensitive Requires >100V supply, Performance dependent on environmental conditions
Piezoelectric Pins	Fragment impact generates pressure signal in piezo crystal	Very reliable , Good temporal accuracy, Robust physical hardware	More expensive, Requires shielded cabling, Still single-point measurement
Bare Copper Wire Break Sensors	Fragment severs wire, breaking electrical circuit	Extremely cheap, Simple setup	Easily damaged before the event, Requires insulation removal, Prone to non-detections and false failures
Fibre Optic Break Sensors	Detects interruption of light transmission in fibre	Very cheap, Immune to electrical noise, Lightweight and flexible	Requires strict control of ambient light. Fragile under blast debris. Can be difficult to align
Conductive Foils (COTEC System)	Fragment bridges interleaved conductive layers creating a signal	Proven and reliable, Well-suited to fragment-dense environments, Integrates well with logic analysers	Saturation during simultaneous strikes, Misses partial / grazing hits, Provides arrival time, not exact trajectory
Heterodyne / Photon Doppler Velocimetry (PDV / LDV)	Uses laser Doppler shift to directly measure velocity	Extremely precise, Direct velocity measurement, High scientific credibility	Expensive, Requires specialist setup and expertise, Sensitive to alignment and optical access

3.3 Piezoelectric Blast Pressure Gauges

Piezoelectric blast pressure gauges were used to quantify the dynamic blast environment generated by the unknown munition. These sensors exploit the piezoelectric effect, producing an electrical charge under rapid mechanical loading, making them suitable for recording short-duration, high-frequency blast events. They measure overpressure above atmospheric level and record both incident and reflected pressures, providing evidence of detonation strength and behaviour [17].

Gauges were positioned at 2.075m and 3.09m opposite the 118° arena sector and staggered to avoid mutual interference, allowing pressure decay with distance to be assessed and enabling comparison with Kinney Graham predictions. Gauge 2 recorded a clear high-order shock front with a strong positive phase, confirming detonation rather than low-order burn.

3.3.1 Critical Limitations

Gauge 1 was destroyed by fragment impact, highlighting instrumentation vulnerability and the need for redundancy and protection. Analysis relied on Gauges 2 and 3, which provided clear, usable data.

The trial used piezoelectric sensors for their excellence in capturing high-frequency blast transients. Table 2 compares relevant pressure sensor types.

Table 2 Comparison of Pressure Sensors [17] [18] [19]

System	Principle of Operation	Advantages	Limitations
piezoresistive pressure sensor	use a strain gauge made from a conductive material that changes its electrical resistance when it is stretched. The strain gauge can be attached to a diaphragm that recognises a change in resistance when the sensor element is deformed. The change in resistance is converted to an output signal	Earliest type of pressure sensor, are critical devices in a variety of control and automobile applications, robust with good resistance to shock, vibration, and dynamic pressure changes, suitable fore a wide range of pressure measurements.	Not suitable due to limitations in precision and speed of capture, outdated technology. Well-suited to low-pressure applications, down to around 2 kPa.
Piezoelectric Pressure Sensor	Robustness and low power, made of rigid materials, which can be natural crystals such as quartz or specially formulated ceramics meaning, they can be used in a range of very harsh environments.	Piezoelectric elements can be very small with an extremely fast response to changes in pressure. Some devices can measure rise times in the order of 1 millionth of a second.	piezoelectric sensors is that they can only be used for dynamic pressure measurement.
Integrated Circuit Piezo Electric/Integrated Electronics, Piezo Electric	Amplifier for piezoelectric material integrated into the sensor itself. Reduces the inherent noise on the signal to an absolute minimum, provides a low-impedance output signal, which is less susceptible to signal degradation.	Ease of use and elimination of operator error.	Integrated amplifier also inherently limits the temperature range of the sensor

The comparative assessment of pressure sensing technologies showed that piezoresistive sensors, while historically important, lack the temporal precision and responsiveness required for short-duration blast shock events, making them unsuitable for arena trials. In contrast, piezoelectric sensors, particularly ICP/IEPE variants, are optimised for highly dynamic environments due to their extremely fast rise-time capability, robustness, and strong resistance to vibration and mechanical loading. These characteristics explain why the COTEC gauges captured detailed waveform structure, including oscillations, ringing and double-peaked behaviour; rather than representing error, these signals reflect genuine blast complexity caused by fragment interaction, ground coupling and structural reflections.

At close stand-off distances, interaction between the incident blast wave and ground-reflected wave can generate a Mach stem, seen in Figure 4, where the reflected and incident shocks merge to form a reinforced vertical shock front. This Mach effect increases local overpressure and impulse beyond free-field predictions, particularly at low sensor heights. As a result, measured peak pressures may exceed idealised Kinney-Graham scaling, not due to increased charge yield but due to constructive shock interaction. Recognition of Mach stem formation is essential to avoid overestimation of explosive performance when interpreting near-ground pressure data [20]. Although environmental conditions, alignment sensitivity and cable vulnerability can influence clarity, the trial data demonstrated that piezoelectric gauges still provide reliable, decision-quality outputs suitable for yield estimation and blast characterisation. Overall, the available evidence supports that ICP-type piezoelectric gauges represent the most appropriate and operationally credible choice for high-order blast measurement in arena testing.

3.3.2 Recommendations

Future trials should strengthen resilience and reduce uncertainty by incorporating redundant gauge networks to avoid single-point failure, protective baffling to improve survivability without distorting measurements, and stand-off mounting arrangements to minimise excessive ground-reflection coupling [21].

Supplementing physical instrumentation with computational blast modelling would support interpretation, while low-parallax high-brightness imaging rig (LP HBI) could visually verify shock structure and reflection behaviour. Despite the loss of Gauge 1, Gauges 2 and 3 provided credible, high-quality data, reinforcing both the value of piezoelectric systems and the importance of improved protection and redundancy in future testing [22].

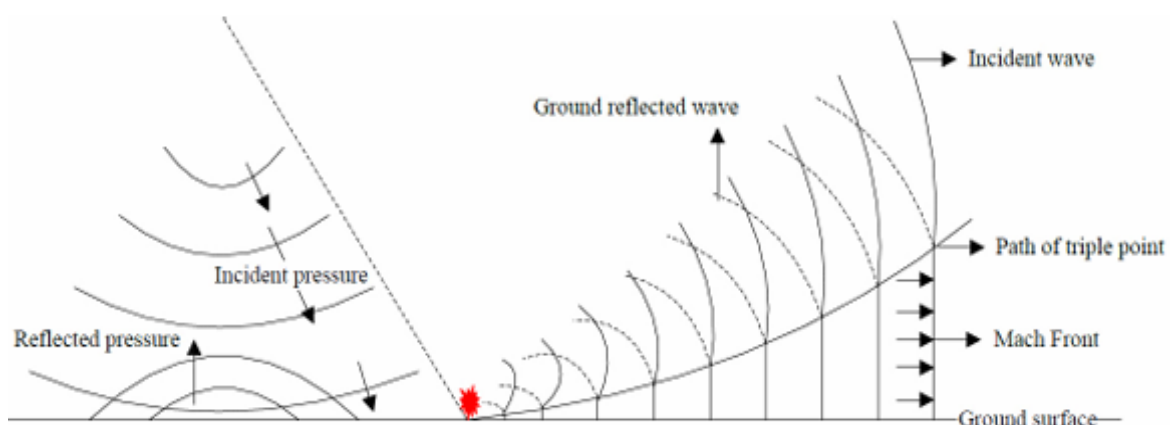


Figure 4 A Diagram of the Mach Effect [23]

3.4 FTIR Residue Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is a technique that detects absorption of the infrared spectrum of absorption and emission of molecules in solid, liquid, or gaseous phase, recovered from residue swabbing at the arena trial. Every chemical bond vibrates at characteristic frequencies; therefore, the absorption peaks act as a molecular “fingerprint”. By comparing these peaks to validated reference libraries or chemical bond structures. The term Fourier-transform has been used because this process requires a mathematical process termed Fourier transform to convert the raw data into the actual spectrum. Leading to the identification of the explosive residue [24].

FTIR is particularly powerful because it provides direct chemical identification. Different explosive families (such as nitramines, TNT-based aromatics, and nitrate esters), exhibit distinct vibrational spectra, allowing analysts to link specific

absorption peaks to functional groups. For example, nitramines display characteristic N–N, C–N and N–O vibrational modes, while TNT shows aromatic C=C and nitro-ring signals. This direct correspondence between spectral features and molecular structure means FTIR conclusions are grounded in chemistry, significantly increasing confidence in explosive identification.

When properly applied, FTIR produces repeatable results that can be cross-referenced against established literature and explosive spectral databases. As a non-destructive technique, it allows repeat analysis without consuming the sample. For these reasons, FTIR is widely used by defence laboratories and forensic units as a primary tool for explosive identification.

3.4.1 Critical Limitations

FTIR is a powerful but not infallible tool and must be interpreted critically. Swab sampling introduces variability, as residue recovery depends on surface coverage, residue concentration and operator technique, with additional variation introduced during swab retrieval and handling in the post-blast environment. Inconsistent recovery, handling errors or partial transfer of residues can result in weak or incomplete spectra. Contamination from environmental dust, oils or range materials may further obscure or distort key spectral features. Interpretation therefore relies on analyst expertise; while software supports spectral matching, professional judgement is required to distinguish genuine energetic signatures from noise or overlapping environmental compounds. In line with DSTL guidance, FTIR provides valid and credible identification data only when supported by disciplined sampling, contamination control, calibration and experienced analysts, demonstrating that data reliability depends as much on human factors and methodology as on instrumentation.

3.4.2 Alternative and Complementary Methods

Table 3 Demonstrates several alternative analytical techniques. Raman spectroscopy provides vibrational chemical information comparable to FTIR, seen in Figure 5, but is particularly effective for identifying crystalline energetic materials and is largely unaffected by water because it probes changes in

molecular polarizability rather than dipole moment [4]. Its main limitation is the potential for fluorescence, which can obscure weaker Raman signals. Gas Chromatography-Mass Spectrometry (GC-MS) provides extremely high chemical specificity and can identify plasticisers, stabilisers and binders but is destructive and laboratory-intensive [25]. Gas Chromatography-Mass Spectrometry combine the benefits of high selectivity and high sensitivity, producing precise results for samples.

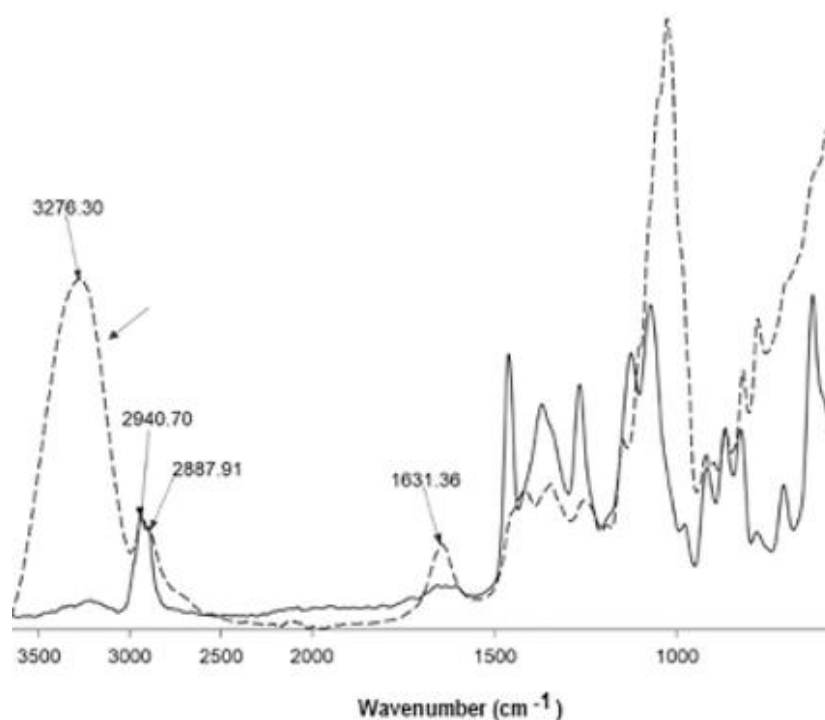


Figure 5 Deviation Between FTIR (- - -) and Raman Spectroscopy (---) [26]

Table 3 Comparison of Residue Analysis Methods [27] [4] [25]

System	Principle of Operation	Advantages	Limitations
FTIR Spectroscopy	Measures absorbance, transmittance, or reflectance of infrared light at frequencies corresponding to molecular vibrational modes. Sensitive to changes in dipole moment. Uses a Fourier transform to convert the raw interferogram into a usable spectrum.	Strong signals for hetero-nuclear functional groups and polar bonds. Not affected by fluorescence. Provides clear functional-group information. Applicable to solids, liquids and gases.	Requires controlled sample thickness, uniformity and dilution to avoid saturation. Water strongly absorbs IR and can interfere with spectra. Surface contact (ATR) can be challenging on rough or irregular samples.
Raman Spectroscopy	Inelastic scattering of monochromatic light, where incident photons interact with molecular vibrations and are re-emitted at shifted frequencies. Sensitive to changes in molecular polarizability.	Minimal sample preparation required. Works well on crystalline materials. Largely unaffected by water. Can be coupled with microscopy for spatially resolved analysis.	Fluorescence from the sample or substrate can obscure Raman signals. Weaker scattering intensity compared to IR absorption. Materials produce very low Raman response.
Optical Emission Spectroscopy (OES)	High-voltage electrical discharge (arc or spark) heats a metallic sample to thousands of degrees, vaporising surface atoms. Excited atoms emit element-specific optical lines. A spectrometer separates these wavelengths, and detectors measure their intensities to determine elemental composition.	Highly accurate elemental analysis of metals. Fast, repeatable, and suitable for alloy verification.	Destructive: requires vaporising part of the sample. Limited to conductive/metallic materials.
Gas Chromatography-Mass Spectrometry	Detailed chemical profiling. Combines gas chromatography separation with a quadrupole and a high-resolution time-of-flight (TOF) mass analyser. but not a direct swab-analysis technique for post-blast residues. Used after FTIR/Raman if you needed deeper compositional insight into organic additives.	Can distinguish compounds with nearly identical nominal masses. Extremely high mass accuracy and resolving power.	Destructive analytical technique. Requires laboratory instrumentation and skilled operators. More expensive and maintenance-intensive

3.4.3 Recommendations

For repeat experimentation, a combined FTIR and Raman spectroscopy approach is recommended, supported by targeted OES on recovered fragments. FTIR should remain the primary screening tool due to its strong sensitivity to nitramine functional groups and extensive reference databases. Raman spectroscopy would complement this by overcoming FTIR limitations associated with water interference and surface roughness, while enabling spatially resolved analysis of crystalline residues. OES should be applied selectively to fragment materials to characterise casing composition and manufacturing signatures. This multi-technique approach reduces single-method bias, improves chemical and material discrimination,

4 Discussion

This study demonstrates that no single data capture method is sufficient for confident OME identification; rather, reliability emerges from the convergence of complementary datasets. At COTEC, blast pressure, fragmentation behaviour, fragment velocity and chemical residue analysis each addressed different aspects of munition performance, but each was also constrained by environmental effects, device vulnerability, limitations and human factors. Piezoelectric pressure gauges provided high-fidelity dynamic blast data, yet were sensitive to fragment strike and ground coupling. Strawboard witness packs yielded valuable insight into casing failure mode but under-represented fine fragmentation and were limited by sector coverage and manual recovery bias. Foil timing systems offered objective arrival data, though saturation and geometric assumptions reduced velocity precision. FTIR provided the strongest discriminatory evidence through direct chemical identification, but its reliability depended heavily on disciplined sampling and detailed interpretation.

Critically, these limitations did not invalidate the trial outcomes; instead, they framed the uncertainty bounds within which conclusions were drawn. The trial highlights the practical reality that explosive testing operates under safety, NEQ and resource constraints, requiring informed judgement rather than idealised measurement. Confidence was therefore derived not from any single metric, but from consistent trends across independent methods, demonstrating the value of integrated, critically assessed data capture in OME analysis.

5 Recommendations

Future trials should prioritise improving data resilience and interpretive confidence rather than maximising instrumentation complexity. For blast measurement, piezoelectric (ICP/IEPE) gauges should remain the primary sensors, but deployed with increased redundancy, selective splinter shielding and refined stand-off mounting to reduce single-point failure and excessive ground-reflection coupling. Computational blast modelling should be routinely integrated to contextualise measured waveforms and support yield estimation.

Fragmentation capture would benefit from extended angular coverage where practicable and partial automation of recovery, such as soft capture media or magnetic sweeps, to reduce human bias and improve fine-fragment recovery. Conductive foil timing systems should continue to be used for robustness and cost efficiency, but paired with higher-resolution methods.

For chemical identification, FTIR should remain the primary screening tool due to its sensitivity to chemical groupings and extensive reference libraries, but be complemented by Raman spectroscopy to mitigate water interference and improve spatial resolution. Targeted Optical Emission Spectroscopy on recovered fragments would further strengthen casing material attribution. Collectively, this layered approach reduces single-method bias, improves uncertainty.

6 Conclusion

This report has critically evaluated the data capture methods used during the COTEC arena trial to support ordnance, munition and explosive (OME) identification. By examining blast pressure measurement, fragmentation capture, velocity estimation and chemical residue analysis, the study demonstrates how each technique contributes distinct insight into explosive performance while simultaneously introducing methodological limitations and uncertainty. The findings show that no individual system is sufficient in isolation; rather, confidence in identification is achieved through the convergence of multiple, independently derived datasets.

Piezoelectric blast pressure gauges provided reliable characterisation of detonation behaviour and yield when appropriately protected and interpreted, while witness strawboards and foil timing systems offered practical insight into casing failure and fragment characteristics. FTIR residue analysis proved the most decisive method due to its direct chemical discrimination, though its reliability remained dependent on disciplined sampling and interpretation. Throughout, the trial highlighted the influence of safety constraints, environmental effects and human factors on data quality.

Ultimately, the work reinforces that effective OME identification depends not on idealised measurement, but on informed integration of imperfect data within realistic operational constraints. The methods employed at COTEC, when critically applied, provided credible, defensible and decision-relevant outcomes consistent with current defence practice.

References

- [1] G. F. K. a. K. J. Grayham, Explosive Shocks in Air (Second Edition), China Lake California : Springer Verlag Berlin Heidelberg New York in 1985 , 2014.
- [2] T. M. Klapotke, Chemistry of high-energy Materials, Boston, Berlin: Meta Systems Publishing , 2022.
- [3] P. Y. J. L. C. T. S. F. Y. D. Xuanyi An, “Dynamic Fracture and Fragmentation Characteristics of Metal Cylinder and Rings Subjected to Internal Explosive Loading,” Materials (Basel), Beijing, 2020.
- [4] Gatway Analytics , “Comparison of Raman and FTIR Spectroscopy: Comparison of Raman and FTIR Spectroscopy:,” Gatway Analytics , 7 12 2021. [Online]. Available: <https://gatewayanalytical.com/comparison-of-raman-and-ftir-spectroscopy-advantages-and-limitations/>. [Accessed 28 12 2025].
- [5] GICHD, Geneva,, “Explosive Weapon Effects,” GICHD, Geneva,, Turkey, Syria , 2017.
- [6] T. R. L. B. S. B.-R. B. T. R. H. a. R. C. James Read, “Quantification of fragmentation capture materials and an assessment of the viability of,” Cranfield Forensic Institute, Cranfield University, Defence Academy of the United Kingdom, , Shrivenham, 2023.
- [7] US Military Specs/Standards/Handbooks, “NATO ITOP-4.2.813 Revision A,” US Military Specs/Standards/Handbooks, 2014.
- [8] Gov.uk, “DEFSTAN 93-59,” Uk Ministry of Defence Standards, London, 2005.
- [9] CMIC, “What are the Mullen Burst Test and Edge Crush Test For Corrugated Packaging,” CMIC, 2025.

- [10] T. S. P. F. M. D J Carr, "The use of gelatine in wound ballistics research," research. Int J Legal Med, Swindon, 2018.
- [11] Picatinny Arsenal , "Testing Manual Fragmentaion Testing Procedures," Picatinny Arsenal , Dover, New Jersey , 1950.
- [12] X.-w. C. Zhi-yong Yin, "Numerical study on the dynamic fracture of explosively driven cylindrical Shells," KeAi Defence Technology , Beijing, 2022.
- [13] ,. P. D. A. H. I. L. R. T. I.G. CULLIS, "Numerical simulation of the natural fragmentation of explosively loaded thick walled cyliners," QinetiQ, Kent, UK, 2014.
- [14] SLOW MO, "PGC LTD," SLOW MO, [Online]. Available: <https://slowmo.co.uk/case-studies/ballistics-munitions/pgc-ltd/>. [Accessed 20 12 2025].
- [15] The University of Sheffield , "The Negative Phase of the Blast Load.," White Rose Research Online, 2014. [Online]. Available: <https://eprints.whiterose.ac.uk/id/eprint/78295/8/Rigby%20et%20al.%20-%202014%20-%20The%20Negative%20Phase%20of%20the%20Blast%20Load.pdf>. [Accessed 14 11 2025].
- [16] s.-l. L. O.-y. K. H.-S. C. J.-H. L. Joung-Man Park, "Comparison of nondestructive microfailure evaluation of fiber-optic Bragg grating and acoustic emission piezoelectric sensors using fragmentation test," in *Composites Part A: Applied Science and Manufacturing*, Delaware, University of Delaware, 2003, pp. Pages 203-216.
- [17] Hol Ykell Technology, "Advantages & Disadvantages of Piezoresistive Pressure Sensors," Hol Ykell Technology, 11th August 2023. [Online].

Available: <https://www.holykell.com/Advantages-Disadvantages-of-Piezoresistive-Pressure-Sensors.html>. [Accessed 2nd January 2026].

[18] Avnet ABACUS, "Pressure Sensors: The Design Engineers Guide," Avnet ABACUS, [Online]. Available: <https://my.avnet.com/abacus/solutions/technologies/sensors/pressure-sensors/core-technologies/capacitive-vs-piezoresistive-vs-piezoelectric/>. [Accessed 27 12 2025].

[19] The Modal Shop An AMPHENOL COMPANY, "ICP vs Charge Mode Sensors and Instrumentation," The Modal Shop An AMPHENOL COMPANY, [Online]. Available: <https://www.modalshop.com/calibration/learn/accelerometers/icp-charge-sensors>. [Accessed 27 12 2025].

[20] atomic archive.com , "The Mach Stem," atomic archive.com , 2024. [Online]. Available: <https://www.atomicarchive.com/science/effects/mach-stem.html>. [Accessed 28 11 2025].

[21] G. c. M. Walter V.Medenica, "Blast Shields Testing," NASA, Huntsville, 1968.

[22] M. M. B. B. E. H. R. A. B. V. M. B. S. a. J. M. D. Kevin L McNesby, "Imaging Detonations of Explosives," ARL US Army Research Laboratory , Livermore, CA, 2015.

[23] I.-T. Wang, "Numerical simulation and experimental validation," Iau-Teh Wang , Kaohsiung , 2014.

[24] A. Sapkota, "22 types of Spectroscopy with Definition, Principles, Steps, uses," Microb notes, 12 August 2022. [Online]. Available: <https://microbenotes.com/types-of-spectroscopy/>. [Accessed 19 12 2025].

[25] Agilent, "Gas Chromatography/ Mass Spectrometry," Agilent , [Online]. Available: <https://www.agilent.com/en/product/gas-chromatography-mass>

spectrometry-gc-ms/gcms-fundamentals/gcms-instrument-types.
[Accessed 28 12 2025].

[26] Vasosarema, "FTIR Spectroscopy Vs Ramen at Richard Travis Blog,"
[Online]. Available: <https://vamosarema.com/>. [Accessed 18 12 2025].

[27] AZO Materials , "What is Optical Emission Spectroscopy (OES)," AZO
Materials , [Online]. Available:
<https://www.azom.com/article.aspx?ArticleID=15632>. [Accessed 03 01
2026].

[28] M. H. Keshhavarz, Energetic Compounds, Berlin, Boston : Deutsche
Nationalbibliothek, 2020.