

A Critique of the Data Capture Methods used in Ordnance Identification - COTEC Arena Trial.

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I. Abstract

This report critiques the data capture methods used during the COTEC arena trial to support post-detonation ordnance identification. The trial context and CW1 outcome were used to assess how fragmentation capture, velocity measurement, blast pressure recording, and residue analysis contributed to discrimination between candidate munitions, and where uncertainty was introduced by trial architecture rather than by physical limitations. The principal finding is that standard methods can enable correct identification, but the defensibility of conclusions is constrained when instrumentation lacks traceable geometry, robust mounting, and redundancy. Strawboards were assessed as the most established fragmentation witness medium due to standardised specification and strong recovery utility, but their effectiveness depends on medium condition control and accurate arc alignment consistent with ITOP practice. Velocity foils were evaluated as scalable and low-burden but sensitive to time-zero uncertainty and closure interpretation without independent confirmation. Piezoelectric blast gauges provided high temporal resolution but were degraded by ringing, local reflections, and vulnerability to damage, making peak-based comparisons unreliable without additional arrays and validation. FTIR was assessed as a high-discrimination method for energetic family indication when sampling, blanks, and replicates are controlled, with confidence further improved through complementary analytical techniques. Across all methods, the key improvement requirement is system-level resilience: redundancy by radius and bearing, and independent cross-validation of critical parameters (e.g., velocity and blast) using additional measurement routes such as high-speed optical shock visualisation and optical fragment tracking. The report concludes that ordnance identification trials should be designed as an engineered measurement system

so that one-off firings yield convergent, defensible datasets even when individual channels fail.

II. Table of Contents

I. Abstract	2
III. Table of Figures	5
1. Introduction.....	6
2. Trial Context and Identification Outcome	6
3. Criteria used to Critique Methods.....	8
4. Fragment Capture using Strawboards.....	10
5. Fragment Velocity Capture	16
6. Blast Pressure Capture	20
7. Energetic Residue Indication	26
8. Cross-Method Integration and Weighting.....	28
9. The Use of Redundancy Within Data Capture Methods.....	29
10. Modelling as Validation Tools	30
11. Data Limitations and Dependence on Candidate Reference Datasets	31
12. Conclusion	32
13. References.....	35

III. Table of Figures

Figure Number	Description
1	Arena Trial Layout (as initially implemented)
2	Radar chart template for method critique criteria
3	Arena layout evolution: strawboard sector mitigation
4	Strawboard method radar charts
5	Arena layout evolution: high-speed camera
6	Velocity Foil Method Radar Chart
7	Arena layout evolution: Additional Array on Different Bearing (Opposite)
8	Arena layout evolution: Shock Front Tracking Using High Speed
9	Pressure evaluation method radar chart
10	FTIR method radar chart

1. Introduction

Ordnance identification after detonation is rarely achievable using a single measurement stream. Fragmentation, blast, and residue evidence are typically incomplete, sensitive to set-up geometry, and vulnerable to range-condition effects. Reliable identification depends on capturing multiple independent datasets and weighting them by fidelity and discrimination value. This report critiques the data capture methods used during the COTEC arena trial: fragment capture using strawboards, fragment velocity estimation using velocity foils and a logic analyser, blast pressure capture using pressure gauges, and energetic residue indication using FTIR on residue associated with recovered fragments. Strengths, limitations, and practical improvements are assessed, with emphasis on traceability of geometry and timing, reduction of single points of failure, and the use of secondary measurement to validate key derived parameters.

2. Trial Context and Identification Outcome

The munition was not available for pre-trial inspection. The arena was prepared by teams covering pressure gauges, velocity foils, strawboards, and wiring. After set-up, personnel withdrew to the battery area, the munition was emplaced and fired, and post-event access was then used to recover fragments and document equipment condition.

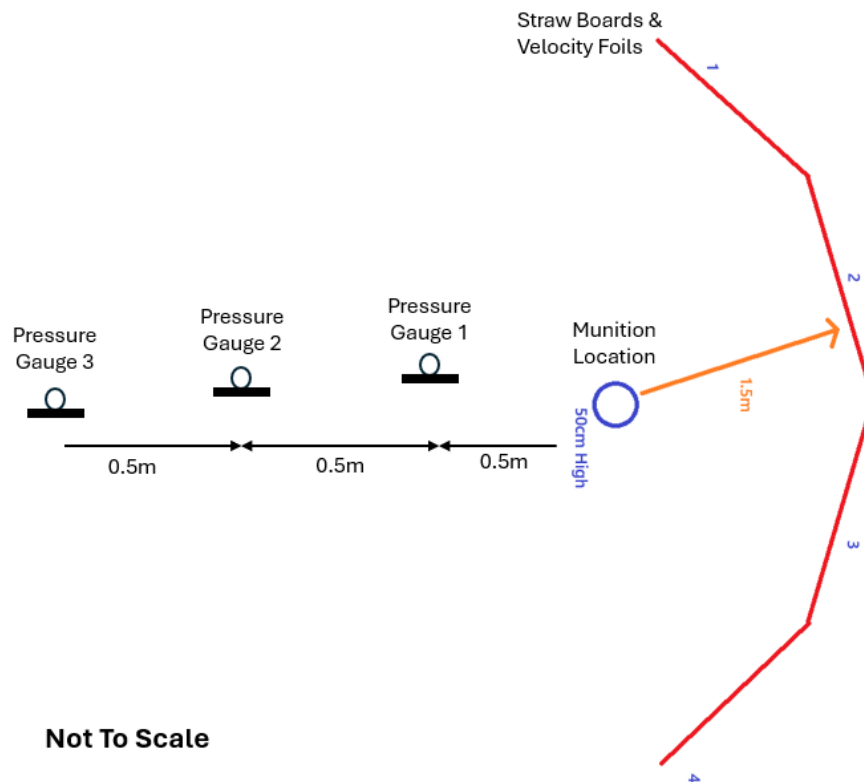


Figure 1 – Arena Trial Layout (as initially implemented)

The outcome was that the device was most consistent with a pipe bomb filled with PE-8 [1]. This decision was strongest where independent measurements converged. Fragmentation was natural, and the strike distribution supported a cylindrical casing detonated about the base. Recovered fragment statistics (mean mass and thickness) aligned closely with the pipe bomb candidate and disagreed with alternative candidates in the provided list. FTIR features were consistent with a nitramine signature (RDX) and indicated a plasticiser/binder component consistent with PE-8, while lacking features expected of aromatic TNT-based fills. Velocity foil results, restricted to first closures and

treated for timing uncertainty, provided supporting agreement within the uncertainty expected for a small dataset.

Event configuration affected interpretation. The device was an improvised, user-filled system and was not capped (confirmed by CW1 feedback). Reduced confinement and venting can shift energy partition, lowering fragment acceleration and altering local pressure response relative to idealised assumptions used in simplified blast calculators.

Overall, the arena set-up and the data capture methods enabled successful identification of the detonated munition; however, the trial also exposed avoidable sources of uncertainty and single points of failure, and significant improvement in capture fidelity and robustness would be achievable through changes to instrumentation layout, redundancy, and cross-validation.

3. Criteria used to Critique Methods

Each method is evaluated against measurement intent and discrimination value within the candidate set [2]:

- dominant uncertainty sources and bias mechanisms
- robustness to range conditions (wind, moisture, clutter)
- traceability of geometry
- calibration and timing
- redundancy and failure tolerance
- practical burden (set-up time, consumables, processing effort)

To support consistent comparison between data capture methods, radar charts are used to visualise relative performance against the critique criteria. Each radar chart scores the method against the same axes (as per Critique set) and is separated as follows: as implemented in the trial, post-mitigation (improved use of the same method), and alternative or augmented method.

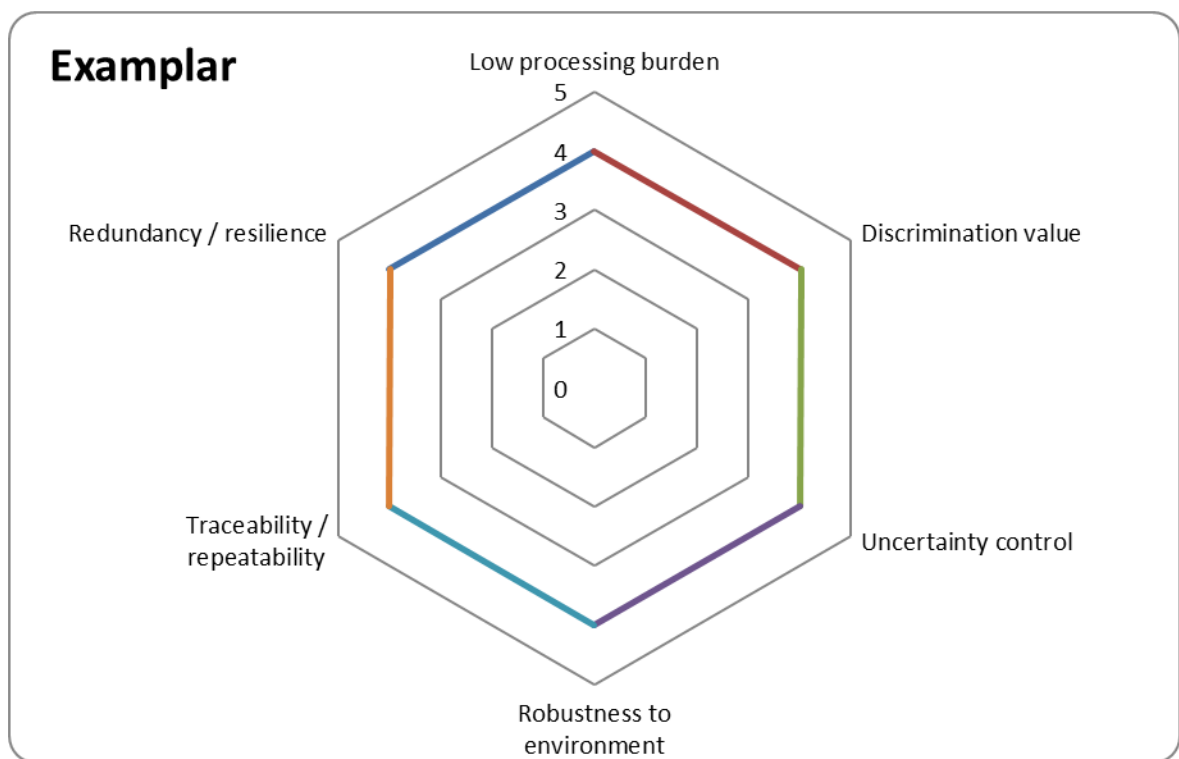


Figure 2 – Radar chart template for method critique criteria

4. Fragment Capture using Strawboards

4.1. Function and Why Strawboards are widely used

Strawboards are used as a standard witness and recovery medium in arena fragmentation trials because they provide fragment retention for physical recovery and a basis for comparing penetration behaviour when medium specification is controlled.

Arena fragmentation procedures rely on controlling the recovery medium and geometry. AOP-39 [3] provides the broader NATO context for munition test and evaluation approaches, within which ITOP-4-2-813 describes static testing of high explosive munitions to obtain fragmentation spatial distribution and supporting fragmentation statistics. Strawboard is identified as a recovery medium with defined characteristics. ITOP-4-2-813 specifies a strawboard thickness band of 3.50–3.85 mm, with a stated density of approximately $700 \text{ kg}\cdot\text{m}^{-3}$. This matters because penetration and retention behaviour depends on medium properties; without controlled witness specification, comparisons between trials become non-defensible.

There is no widely adopted direct substitute that provides the same combination of calibrated penetration behaviour, retention of fragments, scalability, and established reference practice [4]. Sustainable alternatives such as MDF have been examined in explosive testing contexts, but differences in density and failure mechanism change penetration and retention behaviour compared with strawboard. [4].

4.2. Value to Identification in This Trial

Strawboards produced the most discriminating dataset in this event because they enabled recovery of a fragment population suitable for statistical comparison against candidates. Fragment morphology, thickness, and mass distribution provided strong constraint.

4.3. What ITOP-4-2-813 Expects and Why Deviations Matter

ITOP-4-2-813 [5] includes controls intended to improve repeatability and data quality, including fair-weather conduct and recording meteorological conditions per detonation, and maintaining instrumentation in calibration. These controls matter for strawboards because moisture alters density and penetration response, increasing uncertainty for penetration-based inference and strike-density comparison.

ITOP-4-2-813 also prefers repeated firings of the same item type (minimum three, five preferred) to allow fragmentation data to be averaged and reduce sensitivity to shot-to-shot variability. Where only one firing is available, strawboard-derived statistics can remain strong for identification, but they are less robust for estimating whole-population behaviour and the strawboard coverage should be as large as possible.

4.4. Complete Spherical Break-Up Correction

ITOP-4-2-813 [5] treats recovery as incomplete and relates recovered sample data to complete spherical break-up by applying area-ratio correction factors across polar zones. A polar zone is defined by angular bounds in the horizontal plane measured from

the munition axis (nose direction defined as 0°) and a notional sphere of radius R centred at the munition centre of gravity.

For a polar zone bounded by θ_{i-1} and θ_i , the area of the complete annular zone on a sphere of radius R is:

$$A_{s,i} = 2\pi R^2 (\cos \theta_{i-1} - \cos \theta_i)$$

The corresponding area represented by the measured test-arena recovery zone for that polar sector is $A_{t,i}$, computed from the documented strawboard arc geometry (radius, angular coverage, and pack alignment). The ITOP correction factor for the zone is then:

$$f_i = \frac{A_{s,i}}{A_{t,i}}$$

This factor scales the recovered sample in that zone to the estimated total for complete spherical break-up. If the measured recovered fragment mass in the zone is w_i and the recovered fragment count is n_i , then the estimated total mass and count represented by that zone are:

$$W_i = w_i \cdot f_i N_i = n_i \cdot f_i$$

Summing across all k zones provides the estimated total fragment mass and total fragment count for the munition:

$$W_T = \sum_{i=1}^k W_i = \sum_{i=1}^k (w_i f_i) N_T = \sum_{i=1}^k N_i = \sum_{i=1}^k (n_i f_i)$$

These relationships are only valid if $A_{t,i}$ is correct. If packs are misaligned or the arc is not maintained, then $A_{t,i}$ is wrong and the correction factor f_i can systematically bias the scaled result (and may amplify error). In this trial, the strawboard arc was noted as imperfectly aligned. As a result, the spherical break-up correction is less defensible for whole-population spatial distribution estimates, however, the raw recovered fragment population remains valid for identification and comparative down-selection because it is based on measured fragment properties rather than geometric scaling.

4.5.Improvements and Controls

Strawboard fidelity is governed by witness condition control, geometry traceability, recovery discipline, and (where feasible) repeat firings. Strawboards should be protected from precipitation and stored covered, exposure time should be recorded, and any wetting should be declared as a limitation on penetration-based inference. Pack positions and headings should be recorded in a single coordinate system, so recovery zones are auditable. Pre- and post-event photography supports later reconstruction of pack condition and strike distribution. Increasing sector coverage reduces sampling bias and improves fragment population statistics.

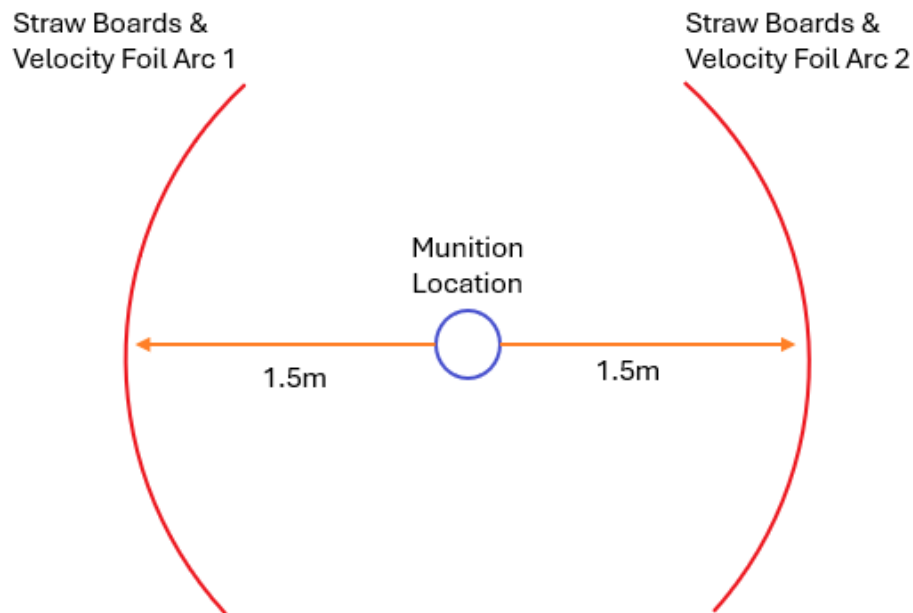
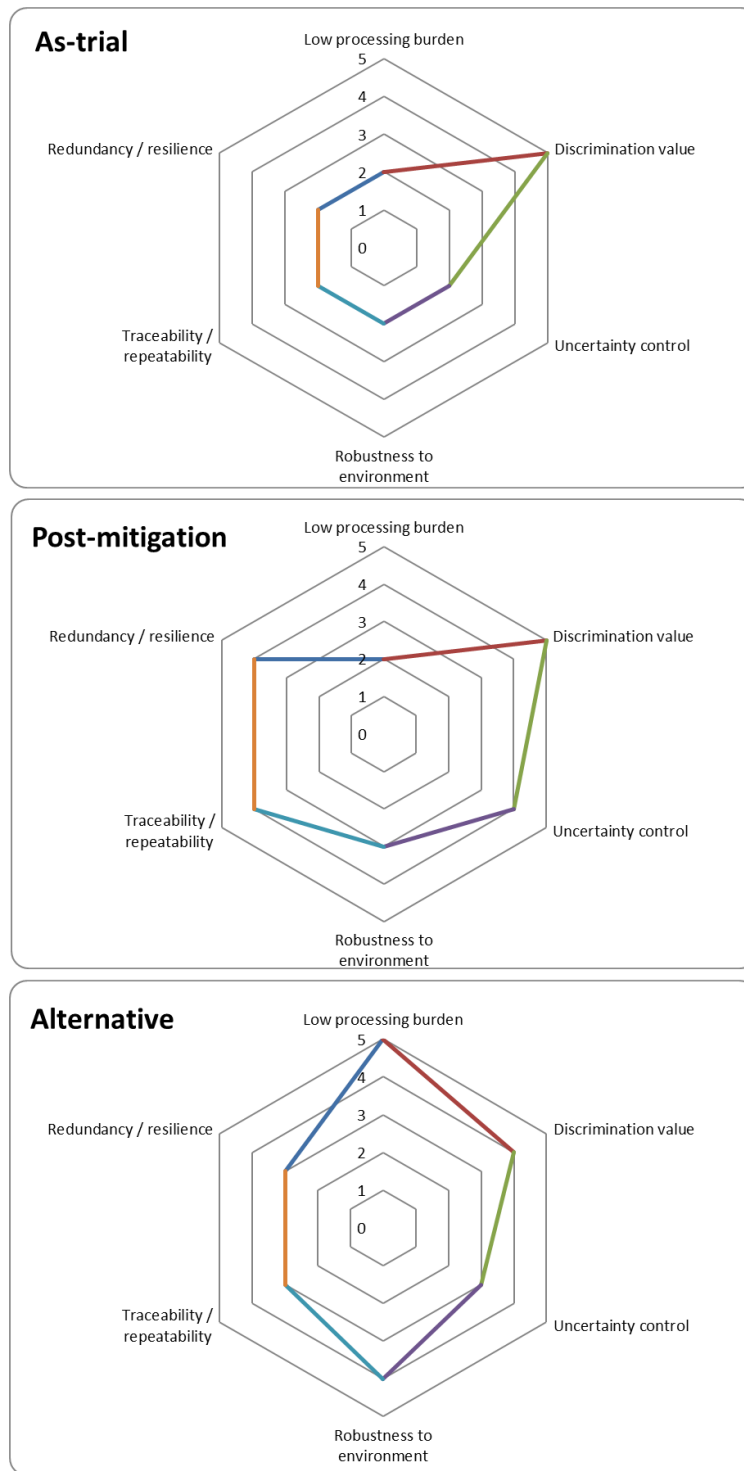


Figure 3 – Arena layout evolution: strawboard sector mitigation

4.6. Alternatives and Process Simplification (recovery-only)

Where strawboards are used only to recover fragments (and penetration depth is not required), alternative recovery methods can reduce labour and improve recovery completeness. A practical option is a water-filled Intermediate Bulk Container fitted (IBC) with an external perforated witness sheet to record impact locations. Fragments are recovered by draining the IBC and collecting fragments from the base. This approach is only suitable where the objective is fragment recovery and strike mapping, because the water medium does not provide a directly comparable penetration-depth basis for kinetic energy and velocity.

**Figure 4 – Strawboard method radar charts**

Strawboards remain the most established recovery medium for arena fragmentation trials because their specification is standardised and they support penetration and retention interpretation when used as intended [5]. Alternatives can simplify recovery for recovery-only use cases, but do not replace calibrated penetration-depth utility. Strawboard effectiveness depends on accurate geometry, controlled witness condition, and sufficient sector coverage to reduce sampling bias.

5. Fragment Velocity Capture

5.1.Measurement Purpose

Velocity foils estimate time-of-flight by recording circuit state-change when a conductive fragment interacts with a foil circuit. They provide a multi-channel method for estimating fragment arrival times at known standoff distances. In this trial, interpretation was restricted to first state-changes because subsequent state-changes cannot be confidently assigned to separate fragments without independent confirmation [6].

Two circuit principles are commonly used: Break foils use a normally closed circuit, impact opens the circuit and produces a measurable loss of continuity (signal drop). Make foils use a normally open circuit, impact closes the circuit and produces a measurable continuity event (signal rise) for the duration of contact. The trial configuration employed a state-change approach consistent with the “make” principle, where the first closure was treated as the only defensible timing datum [7].

5.2.Strengths

Foils are low cost, scalable, and quick to process. They can provide useful timing data even in harsh environments and can be deployed across multiple sectors to increase coverage.

5.3.Limitations

The method is vulnerable to delayed closures and time-zero uncertainty (break wire), and low coverage of foils increases sensitivity of any mean value to a small number of problematic channels. In addition, uncapped improvised devices can produce genuinely lower fragment velocities due to energy loss through venting, so low velocities require both measurement and physics interpretation. Foils are also vulnerable to shorting due to wet weather.

5.4.Improvements

Foil fidelity depends primarily on time-zero traceability and channel redundancy. Increased amounts of foils should be used at different bearings to reduce sensitivity to outliers. Post-event foil inspection photography supports plausibility assessment of first closures. Insulation mediums can be used to stop the effect of wet weather.

5.5. Secondary redundancy and validation using high-speed video

High-speed video can provide an independent time-of-arrival measurement for selected foil sectors. This provides redundancy if a foil channel fails and provides validation where delayed closure is suspected [8].

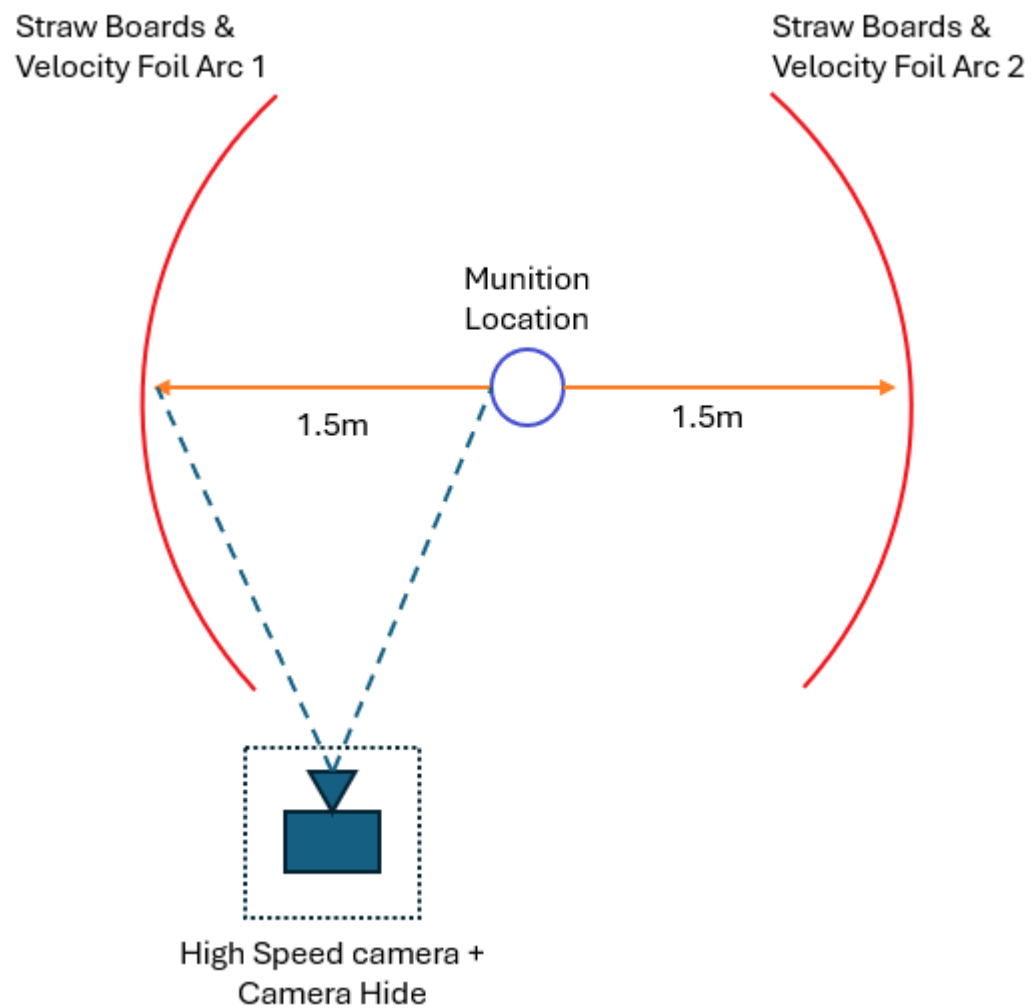


Figure 5 – Arena layout evolution: high-speed camera

5.6. Alternatives and Process Simplification

Where delayed closure is a dominant uncertainty, optical timing or a break wire grid (ensures break closer to point of initiation) can be used to reduce time delay and thus assumed calculations, or as augmentation. A mixed approach remains efficient, foils provide scalable coverage and optical timing on selected sectors provides validation without full arena optical coverage.

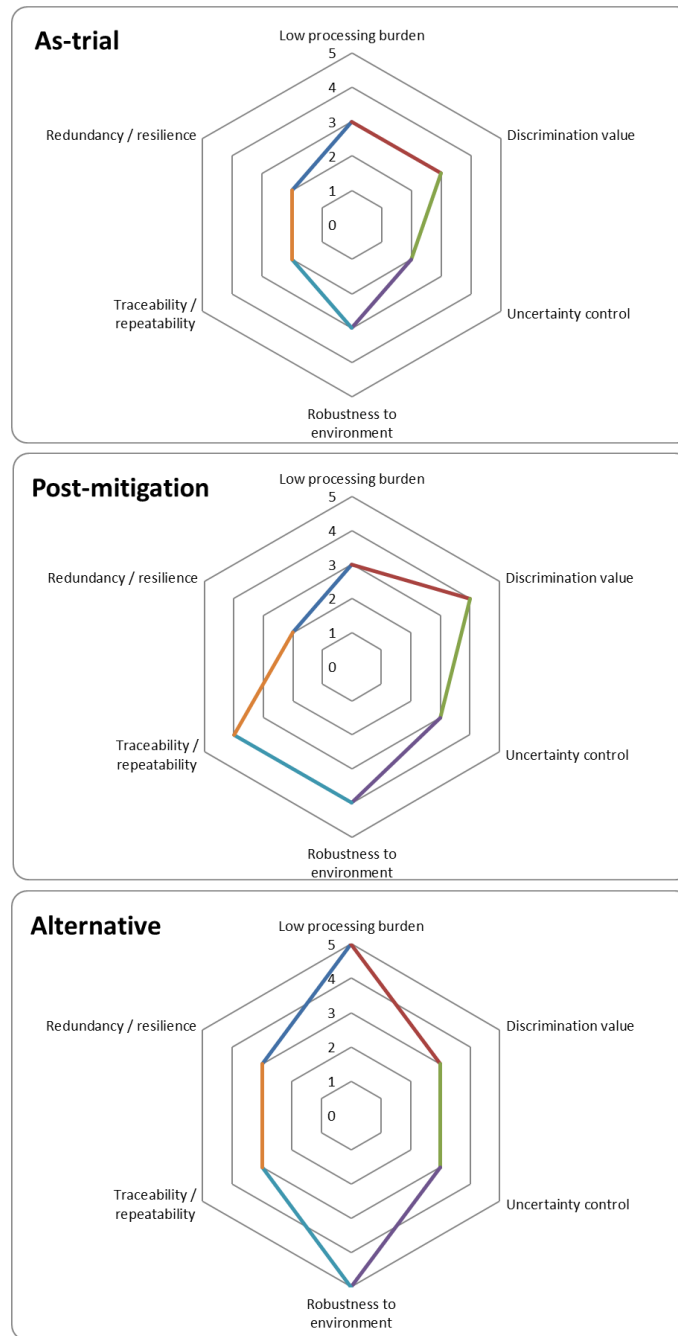


Figure 6 – Velocity Foil Method Radar Chart

Velocity foils provide scalable arrival-time capture at low burden but only reach full potential when time-zero is traceable and channel redundancy is sufficient to stabilise derived values. Foils are best used as a high-coverage velocity measurement method.

6. Blast Pressure Capture

6.1.Measurement Purpose

Pressure gauges measure overpressure time history at known standoff. In principle, incident peak overpressure, arrival time, and impulse support scaled-distance comparisons [9]. The trial used piezoelectric blast gauges, which generate an electrical signal when a pressure pulse applies stress to a piezoelectric crystal. The gauge output is recorded as a voltage (or conditioned voltage) and must then be converted into pressure using the gauge calibration sensitivity/conversion constant (e.g., $\text{Pa}\cdot\text{V}^{-1}$), typically applied during post-processing so that peak incident and reflected overpressures can be compared on an absolute basis. This instrumentation provides high temporal resolution suitable for short-duration blast events, but it is sensitive to mounting and local structural vibration. In this trial, the pressure dataset had reduced discrimination value due to ringing and complex local wavefield effects [6].

6.2.Strengths

Pressure gauges provide a waveform rather than a single value. When geometry and mounting are controlled, incident and reflected components can be separated and compared across arrays. Arrival-time scaling provides a consistency check independent of peak magnitude. Piezoelectric gauges are well suited to capturing fast transient pressures due to their bandwidth and response time.

6.3.Limitations

Mounting resonance, ringing, and local reflections can produce multiple local maxima and ambiguous peak assignment. Piezoelectric gauges can also capture structural vibration through the mounting path, which can appear as spurious peaks or oscillations in the trace if the stand, ground coupling, or fixings resonate. Sensors and cables remain vulnerable to fragment hazard. Under these conditions, matching a single peak to a calculator is sensitive to peak selection and can drive false positives.

6.4.Improvements

Multiple gauges should be used on different bearings to support arrival-time checks and averaging across pressure peaks. Shielding can reduce fragment loss risk (with light effects on the wave as it impacts the gauge), this reduces single-point failure and improves the likelihood of retaining a usable trace at the closest standoffs. Gauge stands should be mounted on a flat, stable plane with vibration damping to reduce ringing, and damping material should be applied at the gauge-to-stand interface to reduce mechanical coupling.

A practical alternative or augmentation is the use of diaphragm gauges [10], which are commonly used in explosive testing to measure blast impulse through permanent deformation. A simple diaphragm gauge uses a thin, annealed copper diaphragm clamped in a steel flange; the blast wave loads the diaphragm and produces a permanent central deflection. Post-test measurement of this deflection provides an integrated impulse metric. Diaphragm gauges are robust and reproducible and can survive

environments that may damage or saturate electronic gauges. When instrumented with strain gauges, diaphragm gauges can also provide time-dependent deformation data, offering an active pressure/impulse record while retaining the durability of a passive witness. Diaphragm gauges therefore provide a useful cross-check where electronic pressure traces are degraded by ringing or where survivability is a dominant concern.

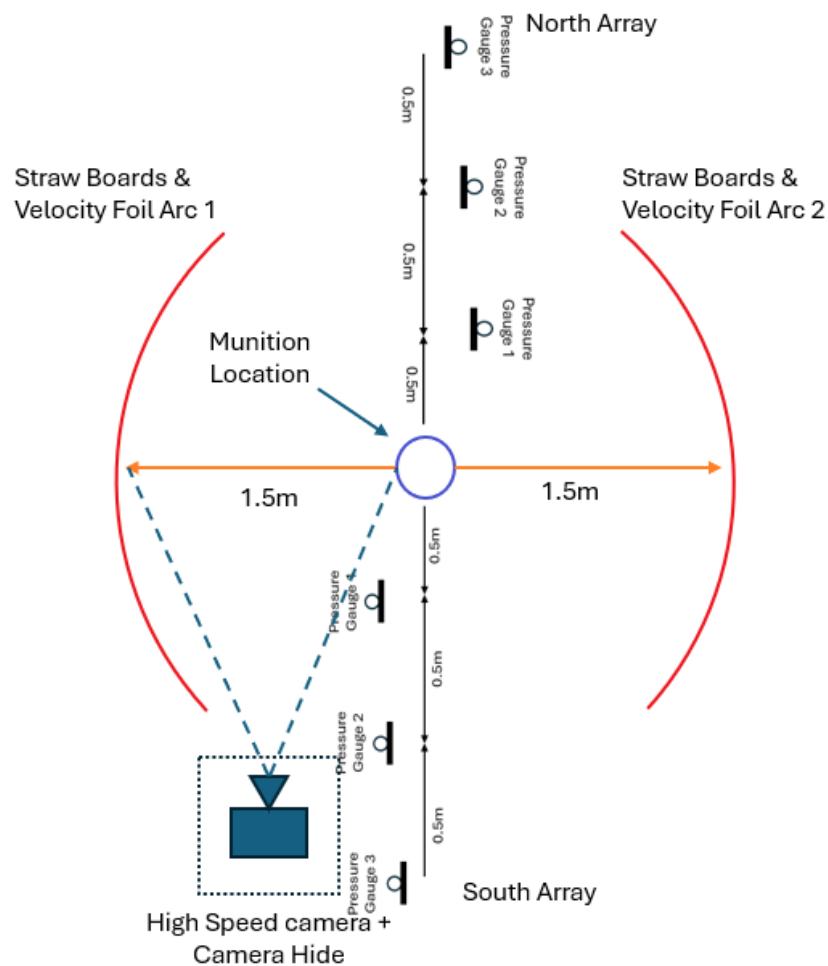


Figure 7 – Arena layout evolution: Additional Array on Different Bearing (Opposite)

6.5. Secondary Pressure Estimation Using High-Speed Video

High-speed cameras can provide an independent pressure estimate by tracking shock propagation. Shock front position is tracked frame-to-frame to obtain radius–time data, differentiated to obtain shock velocity, and converted to peak overpressure using Rankine–Hugoniot jump conditions [11]. For blast work, the shock front is most reliably captured using schlieren imaging or shadowgraphy, which visualises the refractive index changes in air caused by pressure and density gradients across the shock. Using an appropriate optical arrangement (collimated light and knife-edge for schlieren, or a suitable background/lighting configuration for shadowgraphy), the shock front appears as a distinct bright/dark boundary that can be tracked more consistently than the fireball edge. This would require a dedicated high-speed optical set-up and exposure settings optimised for shock contrast rather than fragment tracking [12].

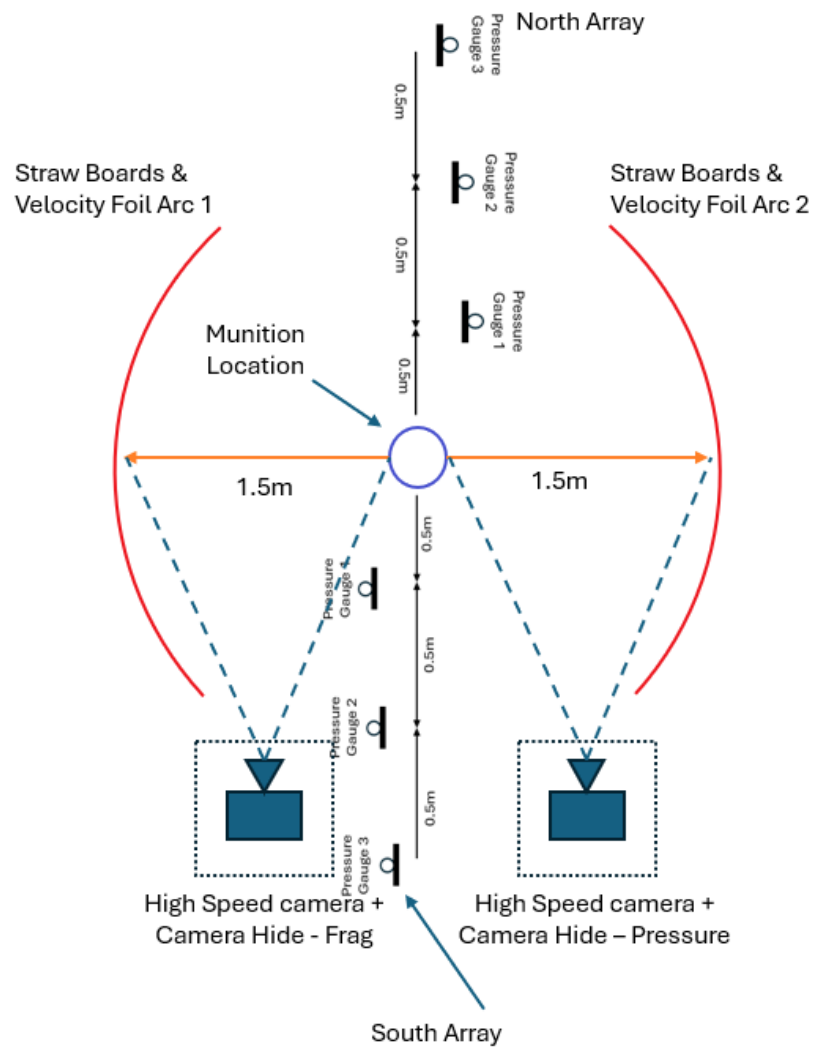


Figure 8 – Arena layout evolution: Shock Front Tracking Using High Speed

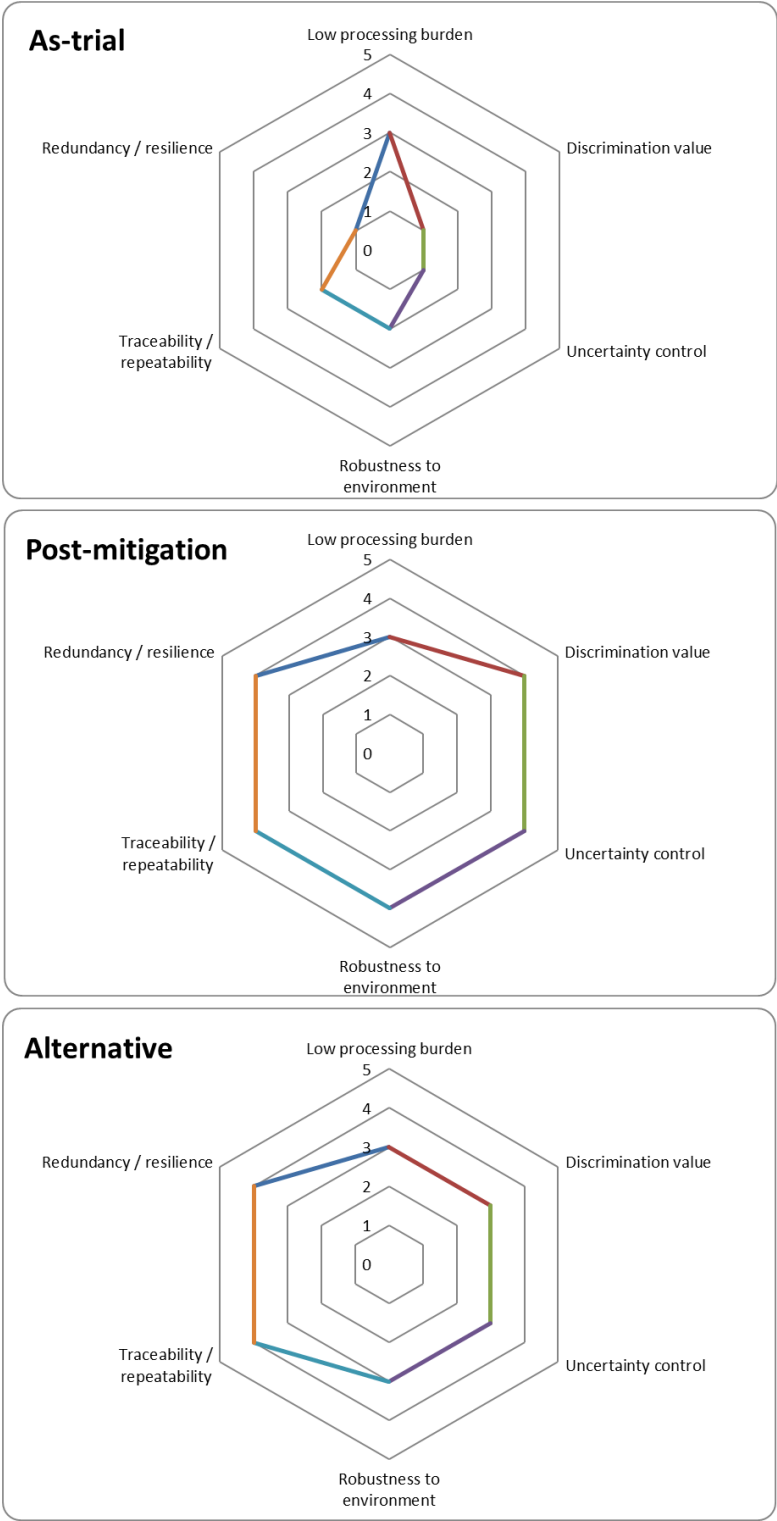


Figure 9 – Pressure evaluation method radar chart

7. Energetic Residue Indication

Fourier Transform Infrared spectroscopy (FTIR) provides functional-group evidence that constrains energetic family and binder/plasticiser indicators. It does this by measuring which frequencies of infrared radiation are absorbed by the sample; each absorbance band corresponds to a characteristic vibrational mode of a chemical bond or functional group (e.g., C–H, C=O, N–O, C–N) at a specific wavenumber (cm^{-1}) [13]. The position, shape, and intensity of bands provide structural information and allow interpretation by comparison against known spectra and reference libraries. In this trial, FTIR had high discrimination value because it indicated a nitramine signature consistent with RDX [14] and also indicated a plasticiser/binder component consistent with PE-8, while lacking features expected of TNT-based fills [15]. Limitations arise from contamination and mixture complexity. Solvents and handling can add or mask features, so blanks and controlled sampling are required. Confidence is improved by replicate spectra across multiple fragments and consistent sample preparation.

7.1. Alternatives/secondary confirmation checks

Confidence can be increased by applying a second analytical method to the same fragment set. Raman spectroscopy can provide rapid surface screening, while GC–MS can better resolve organics where mixtures are present [16] (specifically useful for this trial as the fragments were bathed in acetone).

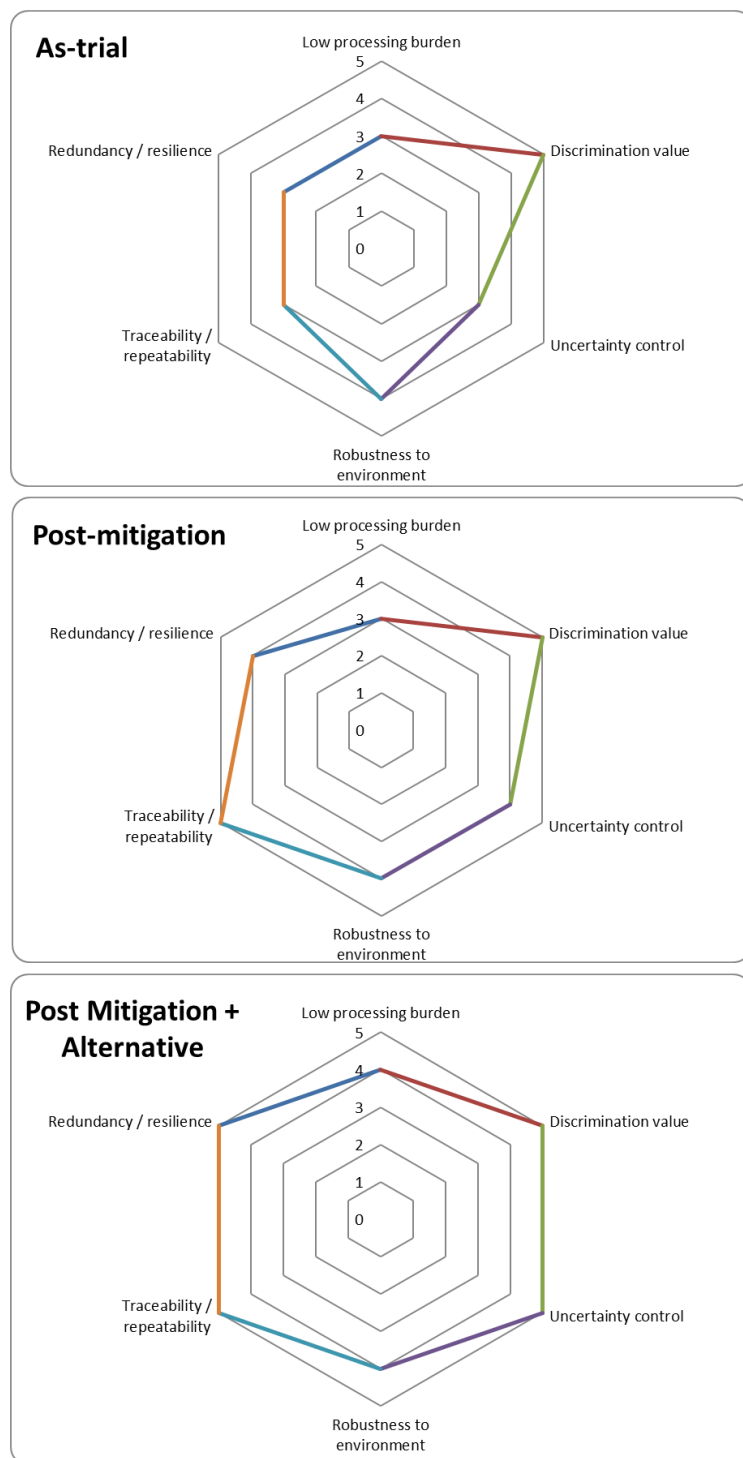


Figure 10 – FTIR method radar chart

FTIR is most effective when used to constrain energetic family and formulation indicators with controlled sampling, blanks, and replicate measurements. It is best used

when interpretation is based on functional-group evidence rather than software library matches, and where a second analytical method is available for confirmation in ambiguous mixtures.

8. Cross-Method Integration and Weighting

No single measurement stream provided a complete identification basis. The identification strength in CW1 came from convergence fragment population statistics (mass, thickness, morphology and spatial distribution) constrained the munition set, FTIR constrained the energetic family and formulation, and velocity foils provided supporting consistency within expected uncertainty for a small dataset. Pressure gauges did not provide strong discrimination for this event due to ringing and ambiguous peak assignment, so their evidential weight was reduced.

Cross-method integration should therefore be treated as a weighting problem. Data streams should be weighted as per the candidate list set out in **3**. In this trial, the highest weighting was justified for strawboard-derived fragment statistics and FTIR energetic indication, because both were directly comparable to candidate descriptors and had lower ambiguity mechanisms than the blast gauges. Velocity foils provided a secondary constraint but required time-zero management and outlier handling, so their weighting should be moderate unless optical validation is available. Pressure gauges should be weighted low when ringing dominates and when peak selection changes the implied candidate.

Where a firing cannot be repeated, integration should prioritise two independent methods for the same derived parameter. Fragment velocity is a key example: foil time-of-arrival can be cross-checked with high-speed video in selected sectors to prevent a single timing stream from dominating conclusions. Blast overpressure is another: gauge waveforms can be cross-checked with shock-front tracking (already described in Section 6) to verify peak assignment when gauge ringing is present.

9. The Use of Redundancy Within Data Capture Methods

Redundancy is essential for reliable data capture in arena trials because individual sensors and witness media are exposed to fragment hazard, local reflections, and set-up imperfections. Single points of failure reduce the evidential weight of an entire measurement stream and can force identification to rely disproportionately on other datasets.

The trial configuration highlighted this risk; loss or corruption of a single gauge, foil, or witness sector can remove the only dataset at a given radius/bearing, preventing comparison and preventing confirmation of whether an anomaly is local or global. The mitigation principle is to deploy redundant instrumentation at the same nominal radius but on different bearings and, where practicable, at more than one height. This decreases the probability that a single fragment strike, local clutter reflection, or mounting resonance removes the only usable measurement at that standoff.

Redundancy should also be applied across measurement types. Where the cost and effort permit, the same parameter should be measured by at least two independent methods (for similar reasoning as **8**). These approaches provide both a fall-back if one system fails, and a validation route to bound error and reduce false positives driven by peak misinterpretation.

This becomes operationally important in industry contexts where trials may be “one-off” due to budget constraints, restricted range slots, limited munition availability, and procurement lead-time pressures. Under such constraints, redundancy increases the probability that a single event yields a defensible dataset rather than an inconclusive outcome.

10. Modelling as Validation Tools

Secondary affirmation can be achieved by reconstructing the event using modelling to test whether captured data is consistent. This does not replace measurement but provides a method to disprove incompatible interpretations and bound plausible parameter ranges when instrumentation is imperfect.

Where blast and fragmentation behaviour must be anticipated in advance (e.g., known test items), modelling can be used to inform instrument placement and survivability [17]. For example, simple scaling relationships can be used to select pressure gauge standoffs that are close enough to capture incident pressures but sufficiently distant to reduce damage risk. For shaped-charge or high-velocity fragment hazards, more detailed analysis (e.g.,

finite element analysis for casing break-up behaviour or penetration) can be used to test whether a proposed configuration is physically achievable before expending range assets. If a requirement cannot be achieved in an idealised modelling case (with controlled boundary conditions), then a full trial may not be justified until the concept is revised. Where defence modelling is used to support decisions, it should be conducted within an established governance framework consistent with the UK Defence Modelling and Simulation Standards Profile, including model purpose definition, documented assumptions and limitations, verification/validation planning, and configuration control, so that modelling outputs remain traceable and defensible.

In this arena trial the munition was unknown to those setting up the instrumentation, which constrained how far pre-trial optimisation could be taken. However, modelling remains valuable post-event to test hypotheses such as whether measured foil-derived velocities are consistent with observed fragment mass distributions and likely confinement conditions, or whether a proposed blast peak assignment is consistent with arrival-time behaviour across bearings.

11. Data Limitations and Dependence on Candidate Reference Datasets

The analysis relied on the candidate munition list as the reference dataset for explosive type, NEQ, and fragment statistics. This introduced uncertainty because the accuracy and level of specificity in the list could not be independently verified during the trial. A clear example was the entry labelled “155 mm ammunition,” which stated an NEQ of 1150 g and a total mass of 3105 g. In practice, 155 mm ammunition exists in many variants across

manufacturers and fills, with specifications that can differ significantly. Because no specific 155 mm model or configuration was stated, a like-for-like comparison against a single real-world 155 mm munition was not possible. As a comparator, the BAE Systems 155 mm L15 has a total mass of 43.5 kg and an NEQ of 11.3 kg (RDX/TNT) [18], which is considerably higher than the candidate entry and illustrates that the candidate dataset may not represent a realistic 155 mm service munition.

This limitation does not invalidate the trial outcome, but it constrains the defensibility of any conclusion that depends strongly on candidate reference values rather than on measured evidence. Where a candidate list is used, confidence improves if each candidate has traceable provenance for NEQ, casing mass, casing material, and expected fragment population behaviour, and if the list identifies model variants explicitly rather than broad munition families.

12. Conclusion

The trial demonstrated that correct identification can still be achieved with imperfect data, but it also showed why a robust trial design is essential, the reliability of the conclusion was limited more by trial architecture than by the underlying physics. The critical gap between the trial conducted and an ideal trial was not the absence of specialist equipment, but the lack of system-level resilience traceable geometry, controlled installation, and planned redundancy required to prevent a single anomaly from dominating interpretation.

A robust arena trial should therefore be designed around two principles. First, instrumentation must be placed and configured using pre-trial bounding so that sensors are within usable measurement range yet protected from predictable damage mechanisms. This includes using analytical estimates and modelling (under an established governance framework) to select standoffs, bearings, mounting approaches, and survivability measures before committing range time. Second, no critical parameter should rely on one measurement path. Redundancy by radius and bearing reduces single-point failures, but robustness is maximised when key outputs are captured by independent methods. fragment velocity should have both primary timing (foils) and optical validation, and blast characterisation should have both gauges and an independent confirmation route (e.g., shock visualisation or impulse witnesses). This matters most where firings cannot be repeated due to budget, range access, and munition availability constraints.

The principal limitations identified were single points of failure, susceptibility to local artefacts (mounting resonance, reflections, environmental effects), and reliance on a candidate reference dataset whose specificity and accuracy cannot be guaranteed. These limitations do not negate the outcome, but they reduce confidence margins and would be more consequential in less discriminating cases. The overarching conclusion is that ordnance identification trials should be treated as an engineered measurement system: when redundancy, cross-validation, and traceability are designed in from the outset, the resulting dataset supports more defensible conclusions with less dependence on judgement under uncertainty.

Word count $\approx$ 3,280 (excluding abstract, headings, figures, references).

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