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Laboratory Report: Data capture and analysis of an OME item

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Data Capture and Evaluation ACDA 6021

Ordnance, Munitions and Explosives Degree Apprenticeship
Academic Year: 2025 - 2026

Abstract

An Ordnance, Munition and Explosive (OME) item was detonated during a fragmentation trial with the aim to identify the munition from a list of seven potential items. The list includes six standardised munitions and one improvised device.

During the trial Piezoelectric blast pressure gauges measured the incident pressure from the munition. While one gauge was rendered unusable due to a fragmentation strike, the remaining two showed results with high interference making interpretation difficult. Analysis of the physical fragmentation collected identified the casing to have natural fragmentation and ruled out a number of munitions based on the spatial pattern. The fragmentation velocity was calculated based on strike time of the fragmentation pieces. The velocity did not exceed 825.97ms^{-1} which was significantly lower than the expected velocity. This indicated that there was energy lost during the detonation, highlighting the likelihood of the munition being an improvised device. Fourier Transform Infrared Spectroscopy (FTIR) analysis was undertaken on the fragmentation pieces which indicated a strong presence of RDX with a plasticizer.

Based on the evaluation of the results from the trial, it was concluded that the unknown munition was the Pipe Bomb, an improvised explosive device filled with PE8 a RDX based plastic explosive.

Word count: 1,991

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1 Introduction

This report details the evaluation of post-detonation data gathered during a fragmentation trial. The primary objective was to identify an unknown munition by assessing the three key parameters: blast pressure, fragmentation characteristics and chemical analysis. Blast pressure provides insight into the explosives strength and efficiency by comparing measured peaks and impulses against theoretical formulae. Fragmentation analysis examines the size, shape, distribution and velocity of recovered fragments to reveal casing design and charge characteristics. Chemical analysis of post-blast samples identifies explosive compounds and differences between chemical compositions. Together these methods can provide a coherent profile to aid the identification of munitions.

To support the identification, a list of six standardised potential munitions and one Improvised Explosive Device (IED) was provided along with their characteristics, these are detailed in Table 1-1. This evaluation demonstrates the systematic approach and critical thought required to determine the size and nature of an unknown munition in the Ordnance, Munitions and Explosives (OME) field, while the methodologies have been evaluated in a Critique of the Data Capture Methods Used in Ordnance Identification [1].

Table 1-1 - List of Potential Weapon Systems and Their Key Characteristics

<i>Munition</i>	<i>PHYSICAL PARAMETERS</i>		<i>EXPLOSIVE PARAMETERS</i>		<i>FRAGMENTATION PARAMETERS</i>						
	<i>All up round mass (kg)</i>	<i>Length (mm)</i>	<i>Explosive composition</i>	<i>Charge mass (kg)</i>	<i>Case mass (kg)</i>	<i>Fragmentation type</i>	<i>Average fragmentation mass (g)</i>	<i>Average fragmentation area (cm²)</i>	<i>Fragment drag coefficient</i>	<i>Initial fragment velocity (ms⁻¹)</i>	<i>Final fragment velocity (ms⁻¹)</i>
Mk 83 <i>Air Dropped Munition</i>	454	3000 [2]	Composition B	225	229	Natural [2, 3]	115	0.48	0.82	1950	1991 at 92m
M-67 Grenade <i>US Anti-Personnel Grenade</i>	0.398	90 [4]	Composition B	0.185	0.213	Preformed [4, 5]	2	1	0.5	Not Provided	1674 at 5m 1425 at 15m 44 at 230m
RGD-5 <i>Soviet Anti-Personnel Grenade</i>	0.310	117 [5]	TNT	0.110	0.200	Preformed [5]	0.12 - 0.46	1	0.5	1567	Not Provided
81mm AR-M81 <i>High Explosive Mortar Round</i>	4.15	487 [6]	TNT	0.760	1.334	Natural [6]	Not Provided	Not Provided	1.6	1734	1700 at 1m 1600 at 4m 1150 at 20m 900 at 32m 357 at 77m

<i>Munition</i>	<i>PHYSICAL PARAMETERS</i>		<i>EXPLOSIVE PARAMETERS</i>		<i>FRAGMENTATION PARAMETERS</i>						
	<i>All up round mass (kg)</i>	<i>Length (mm)</i>	<i>Explosive composition</i>	<i>Charge mass (kg)</i>	<i>Case mass (kg)</i>	<i>Fragmentation type</i>	<i>Average fragmentation mass (g)</i>	<i>Average fragmentation area (cm²)</i>	<i>Fragment drag coefficient</i>	<i>Initial fragment velocity (ms⁻¹)</i>	<i>Final fragment velocity (ms⁻¹)</i>
PG-7VL RPG <i>High Explosive Anti-Tank Round</i>	1.975	700 [7]	RDX/TNT - 95% HMX 5% Wax	0.730	1.600 (including rocket motor)	Natural [7]	0.1	Not Provided	Not Provided	1831.5	Not Provided
155mm Artillery Round	4.155	874 [8]	Composition B	1.150	3.105	Natural [8]	2.1	Not Provided	Not Provided	1551	Not Provided
Pipe Bomb Improvised Explosive Device	0.681	Various [9]	PE 8	0.264	0.417	Natural [9]	Not Provided	Not Provided	1.6	2047	2022 at 1m 1602 at 20m

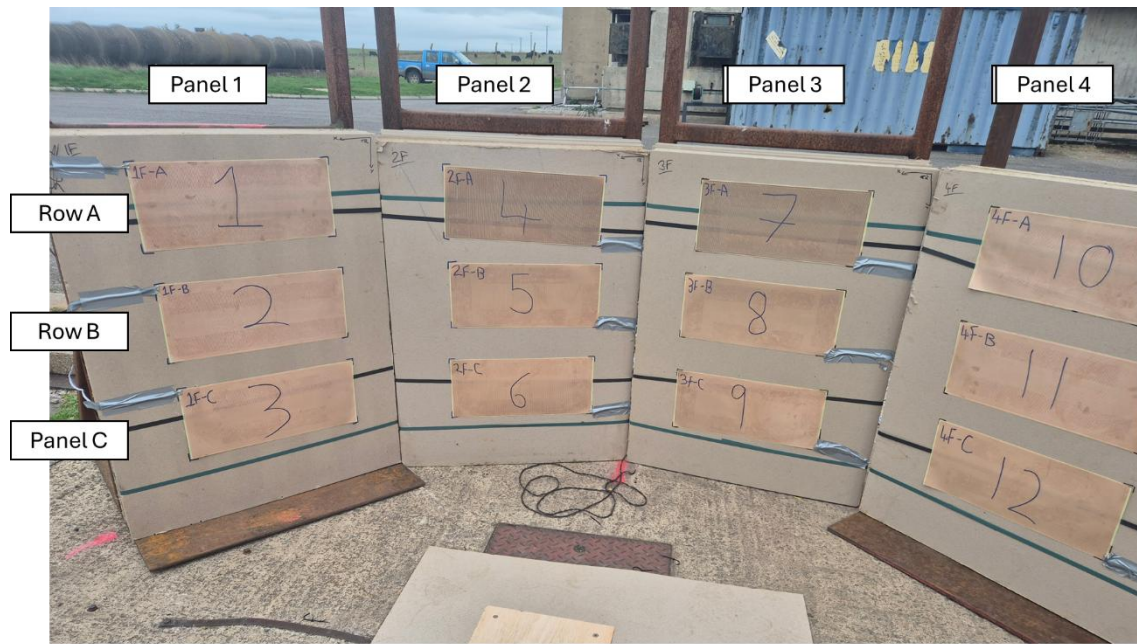
2 Materials and Methodology

The trial took place at the Cranfield Ordnance Test and Evaluation Centre (COTEC). A small fragmentation arena trial was constructed by a group of students in accordance with ITOP-4-3-813 – Static Testing of High-Explosive Munitions for Obtaining Fragment Spatial Distributions, shown in Figure 2-1.



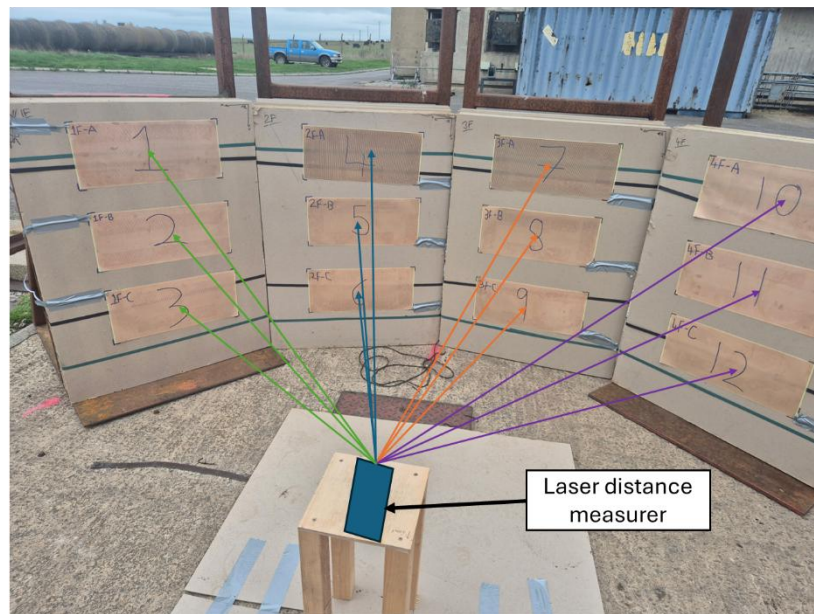
Figure 2-1 - Small Fragmentation Arena Trial Used to Identify an Unknown Munition

The munition was positioned vertically on a wooden stand at the central point of the arena. Four panels of calibrated strawboards were positioned in a 113° arc with the munition at the central point, with twelve velocity foils attached, as depicted in Figure 2-2. Three Piezoelectric blast pressure gauges were positioned as shown in Figure 2-3 and Figure 2-4. Technical specifications of the equipment and their respective triggers (T_0) are provided in Table 2-1.



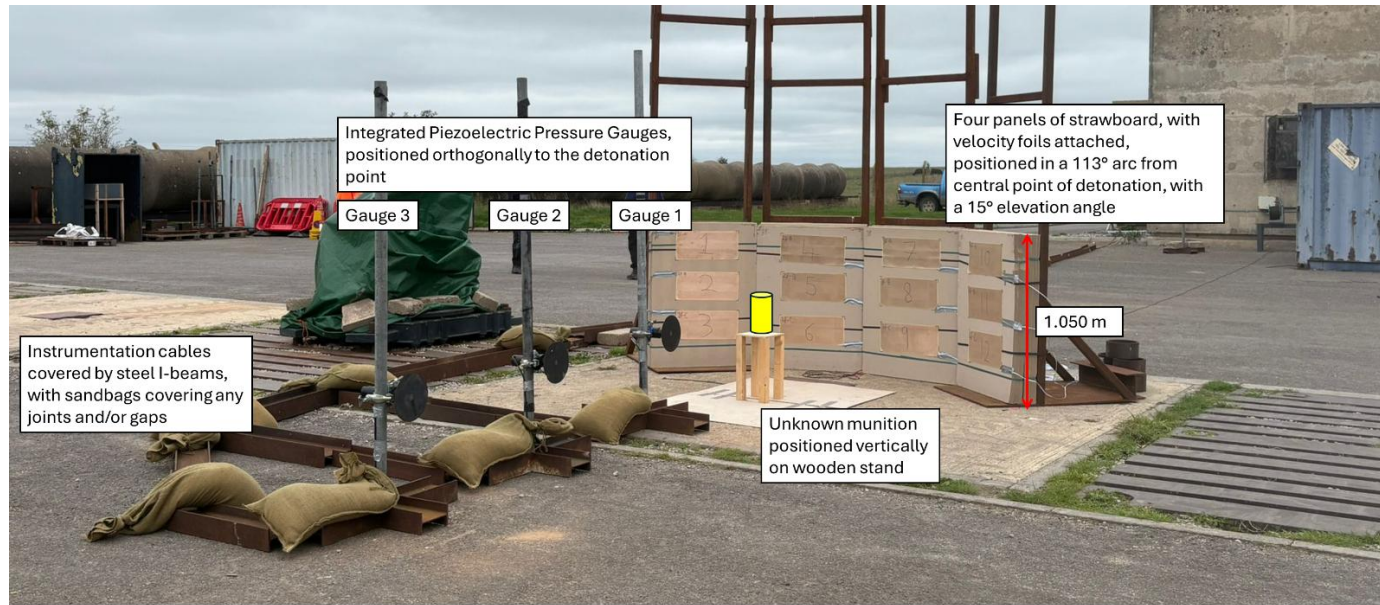
a)

	Foil	Distance (m)
Panel 1	1	1.462
	2	1.337
	3	1.327
Panel 2	4	1.411
	5	1.358
	6	1.354
Panel 3	7	1.452
	8	1.392
	9	1.390
Panel 4	10	1.495
	11	1.439
	12	1.430



b)

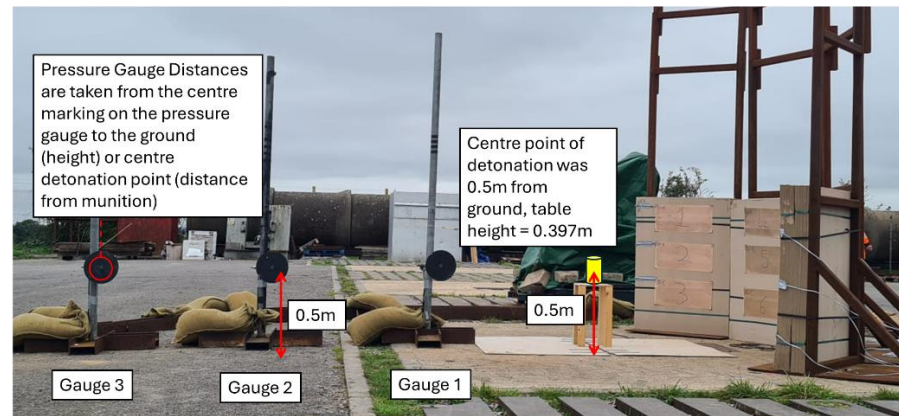
Figure 2-2 - a) Configuration of Velocity Foils on Strawboards with b) Distance Measurement Points from the Central Point of the Wooden Stand



a)



b)



c)

Figure 2-3 - Small Arena Trail a) Detail and Configuration of Equipment Used, b) Highlighting Misalignment of Piezoelectric Pressure Gauges and c) Their Positioning from the Central Point

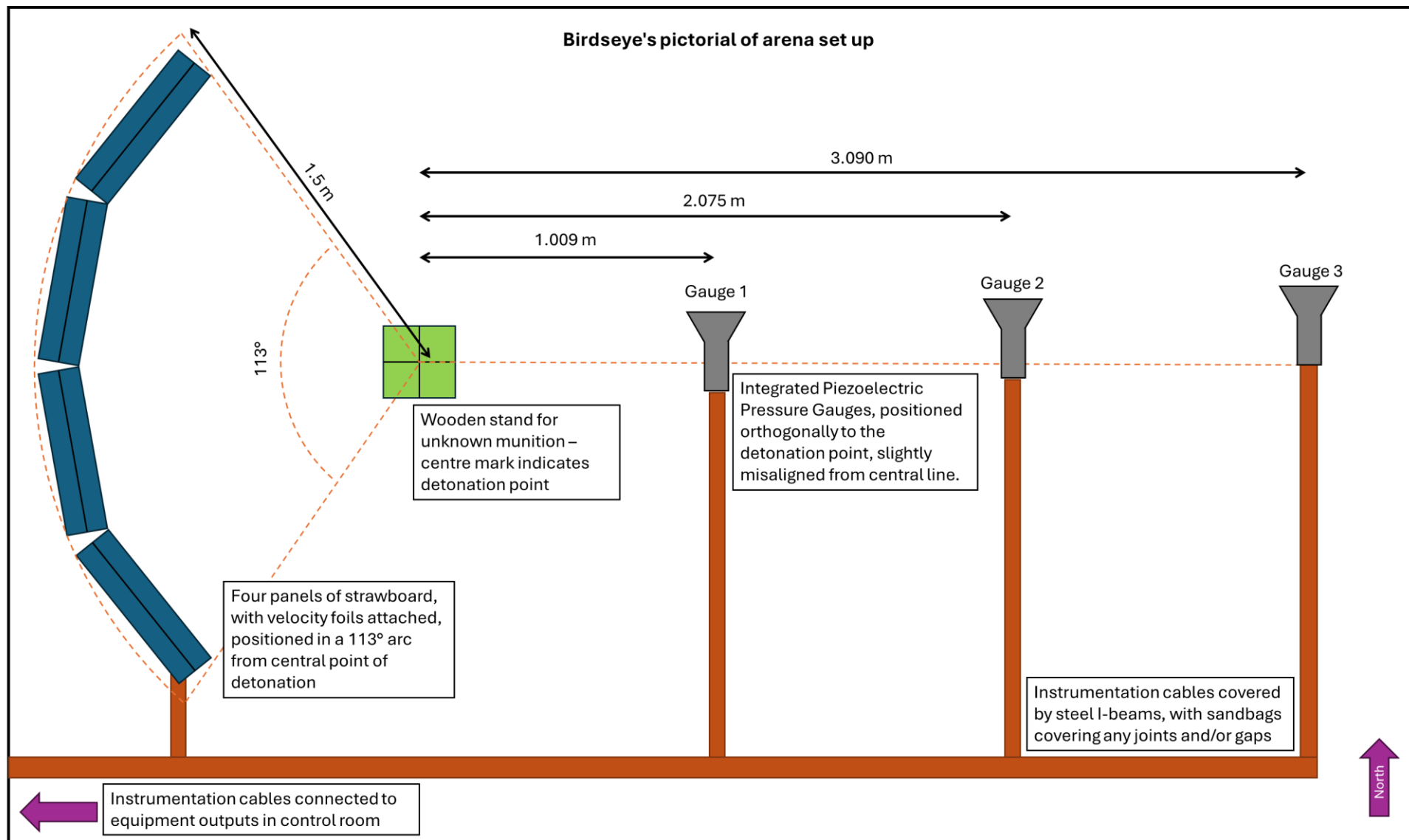


Figure 2-4 - Small Arena Trial Birdseye Pictorial

Table 2-1 - Equipment Used in Trial

EQUIPMENT	USE	SPECIFICATIONS	DATA COLLECTED
Velocity Foils	To measure fragmentation strike time, to enable the calculation of fragmentation velocity	Type Make Foils Size 460mm X 200mm Output Signal generated on a logic analyser when foil registers an impact in the form of a closed circuit Cable Type Umbilical Data Cable Trigger (T₀) The functioning of a break wire around munition	Time of fragmentation strike Number of fragmentation strikes
Strawboards	To collect fragmentation pieces for analysis	Material Calibrated Cardboard Sheets Size 1050mm X 800mm Number of Packs 2 packs per panel, 20 sheets per pack	Physical fragmentation pieces
Pressure Gauges	To measure blast pressure	Type Piezoelectric Blast Gauge Sample Rate 250 kHz Conversion Constant 30 mV = 3 kPa Time Interval 4 μs Cable Type Bayonet Neill-Concelman (BNC) Recording Window 10% Pre-Trigger 90% Post-Trigger Trigger (T₀) Gauge 1 receiving an increase of Pressure	Incident pressure

3 Results

The successfully detonated munition is shown in Figure 3-1. Fragmentation, blast and chemical data was collected to support the identification of the weapon system.



Figure 3-1 - Arena Post-Detonation

3.1 Blast Pressure

Blast pressure was detected from two of the three pressure gauges. Gauge One was impacted by fragmentation causing significant damage, shown in Figure 3-2, rendering any data collected unusable. Gauges Two and Three provided blast pressure measurements at 4 μ s intervals, with the results provided in Figure 3-3.



Figure 3-2 - Gauge One - Fragmentation Damage

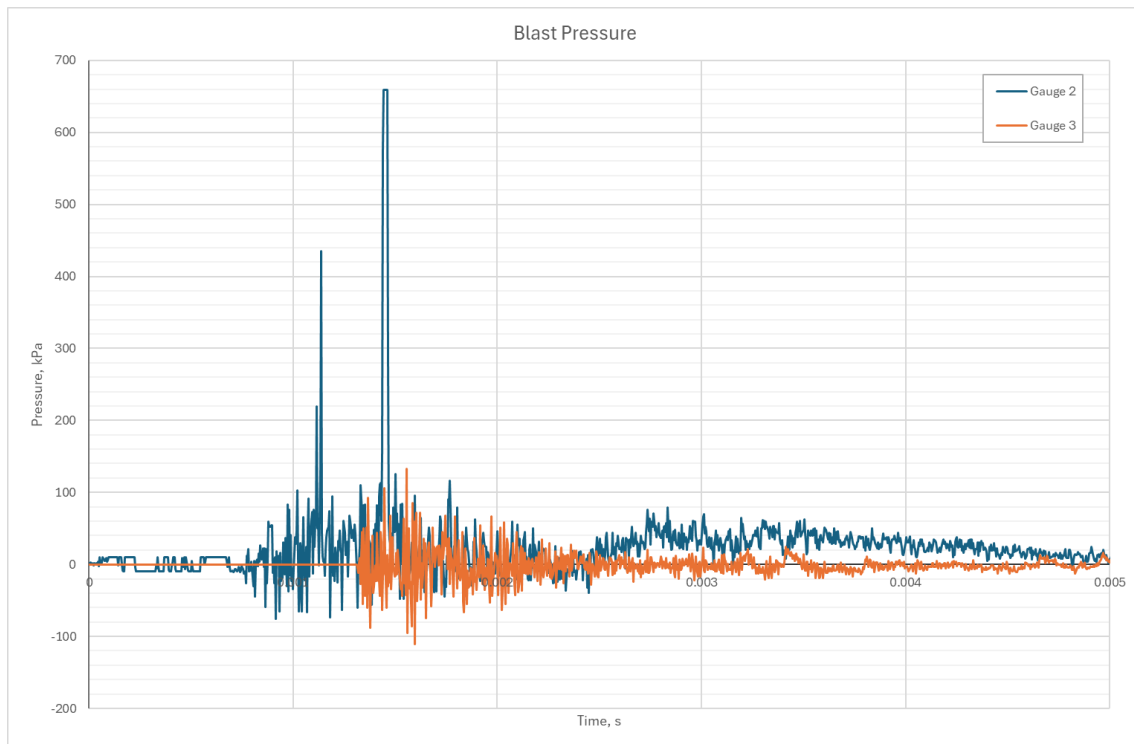


Figure 3-3 - Blast Pressure Results for Gauge Two and Three

3.2 Fragmentation

The significant release of pressure and gas from the detonation caused the munitions' casing to fragment, striking the strawboards and velocity foils as demonstrated in Figure 3-4. This enabled two types of data to be collected for further analysis:

- Physical fragmentation pieces
- Fragmentation impact time



Figure 3-4 - Fragmentation Strikes Captured on Strawboard

3.2.1 Physical Fragmentation Data

The students, divided into four groups, collected a total of 90 pieces of fragmentation of varying size and shape from the four strawboard panels. A selection of the collected samples is provided in Figure 3-5. The total mass of fragmentation collected was 74.5g, averaging at 0.862g per piece with an average thickness of 3.3mm. Due to the fragmentation being used to provide information on the casing of the munition, data was not collected on the exact positioning and depth of the fragmentation.



Figure 3-5 - Sample of Fragmentation Collected

3.2.2 Fragmentation Velocity Data

All twelve foils registered a fragmentation hit. Table 3-1 provides the number of strikes and their corresponding impact time from T_0 .

Table 3-1 - Velocity Foils Strike Time from T_0

	Foil	Distance (m)	Number of Strikes	Strike 1 Time (ms)	Strike 2 Time (ms)	Strike 3 Time (ms)
Panel 1	1	1.462	2	4.595	6.955	
	2	1.337	1	1.710		
	3	1.327	1	1.725		
Panel 2	4	1.411	2	2.071	3.150	
	5	1.358	2	1.763	1.798	
	6	1.354	3	1.731	1.760	1.800
Panel 3	7	1.452	1	2.653		
	8	1.392	1	1.785		
	9	1.390	2	1.766	1.794	
Panel 4	10	1.495	1	2.663		
	11	1.439	1	1.742		
	12	1.430	1	1.782		

3.3 Chemical Sampling Results

Fourier Transform Infrared Spectroscopy (FTIR) analysis has been performed to determine the explosive compound used. Samples were taken from both the fragmentation collected and from various positions in the arena. Only the fragmentation pieces provided usable samples. The transmission peaks detected are presented in Figure 3-6 while Table 3-2 shows the specific vibration frequencies.

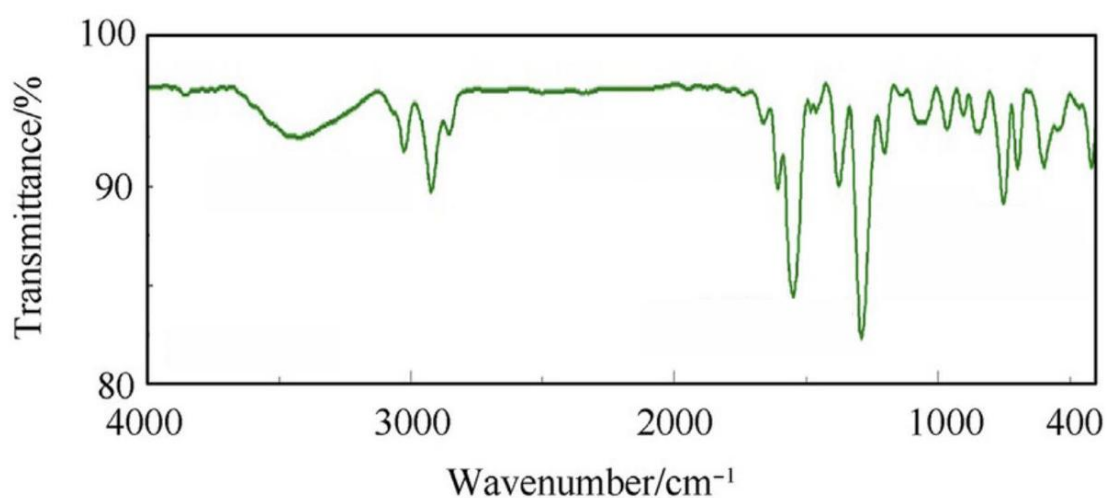


Figure 3-6 - Fragmentation FTIR Transmittance Graph

Table 3-2 - FTIR Results from Fragmentation Collected

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 Data Evaluation and Discussion

The limitations of the range enable the Mk83 to be eliminated. The Mk83 has a charge mass of 229kg which exceeds the explosive licence limits of COTEC which has a Net Explosive Quantity (NEQ) of 10kg. To eliminate the remaining munitions, analysis of the data collected is required.

4.1 Blast Pressure Data Analysis

The data from Gauges Two and Three provided limited insight with regards to identification of the munition. The initial data collected showed significant interference, making interpretation problematic.

Figure 4-1 and Figure 4-2 show the measured incident and reflective peak overpressure detected by each gauge, while Figure 4-3 and Figure 4-4 show the 10-point moving average values. The moving average enables the trend of the data to be easily visualised and clearer peaks to be identified, simulating the removal of potential interferences. Comparing these values to the theoretical

pressures in Table 4-1, the measured pressures are higher than expected¹, making it difficult to determine a plausible munition based on this data alone.

Table 4-1 - Theoretical Incident and Reflective Pressures based on Kingery-Bulmash Air Blast Equations

Munition	Explosive	Charge Mass (kg)	TNT Equivalence [10]	Incident Pressure (kPa)		Reflected Pressure (kPa)	
				Gauge 2 (2.075m)	Gauge 3 (3.090m)	Gauge 2 (2.075m)	Gauge 3 (3.090m)
Mk 83	Comp B	225	1.11	7826.25	4021.03	70612.77	31666.05
M-67	Comp B	0.185	1.11	59.42	28.94	146.82	64.20
RDG-5	TNT	0.110	1.00	40.25	20.73	93.06	44.74
81mm	TNT	0.760	1.00	146.68	64.01	449.20	160.48
RPG	RDX/TNT	0.730	1.14	156.71	67.95	488.81	172.47
155mm	Comp B	1.150	1.11	215.06	90.76	734.54	245.74
Pipe Bomb	PE8	0.264	1.37	68.70	40.15	232.23	92.78

Table 4-2 presents the theoretical NEQ required to match the measured incident pressures. The differing NEQs highlight discrepancies in the blast data, as values from each gauge should be comparable if the pressures followed the scaled-distance relationship [11].

Table 4-2 - Theoretical NEQ Required to Generate Incident Pressure Measured From Trial Calculated using Kingery-Bulmash Air Blast Formulae

Explosive	TNT Equivalence [10]	NEQ for Measured Pressure (kg)		NEQ for 10 Point Average Pressure (kg)	
		Gauge 2 (434.58kPa)	Gauge 3 (92.65kPa)	Gauge 2 (111.14kPa)	Gauge 3 (10.74kPa)
TNT	1.00	3.235	1.315	0.517	0.027
RDX/TNT	1.14	2.836	1.154	0.454	0.024
Comp B	1.11	2.914	1.185	0.465	0.025
PE8	1.37	2.361	0.955	0.377	0.020

¹ With the exception of the Mk83 munition which can be discounted based on the NEQ limits of the explosive licence for COTEC.

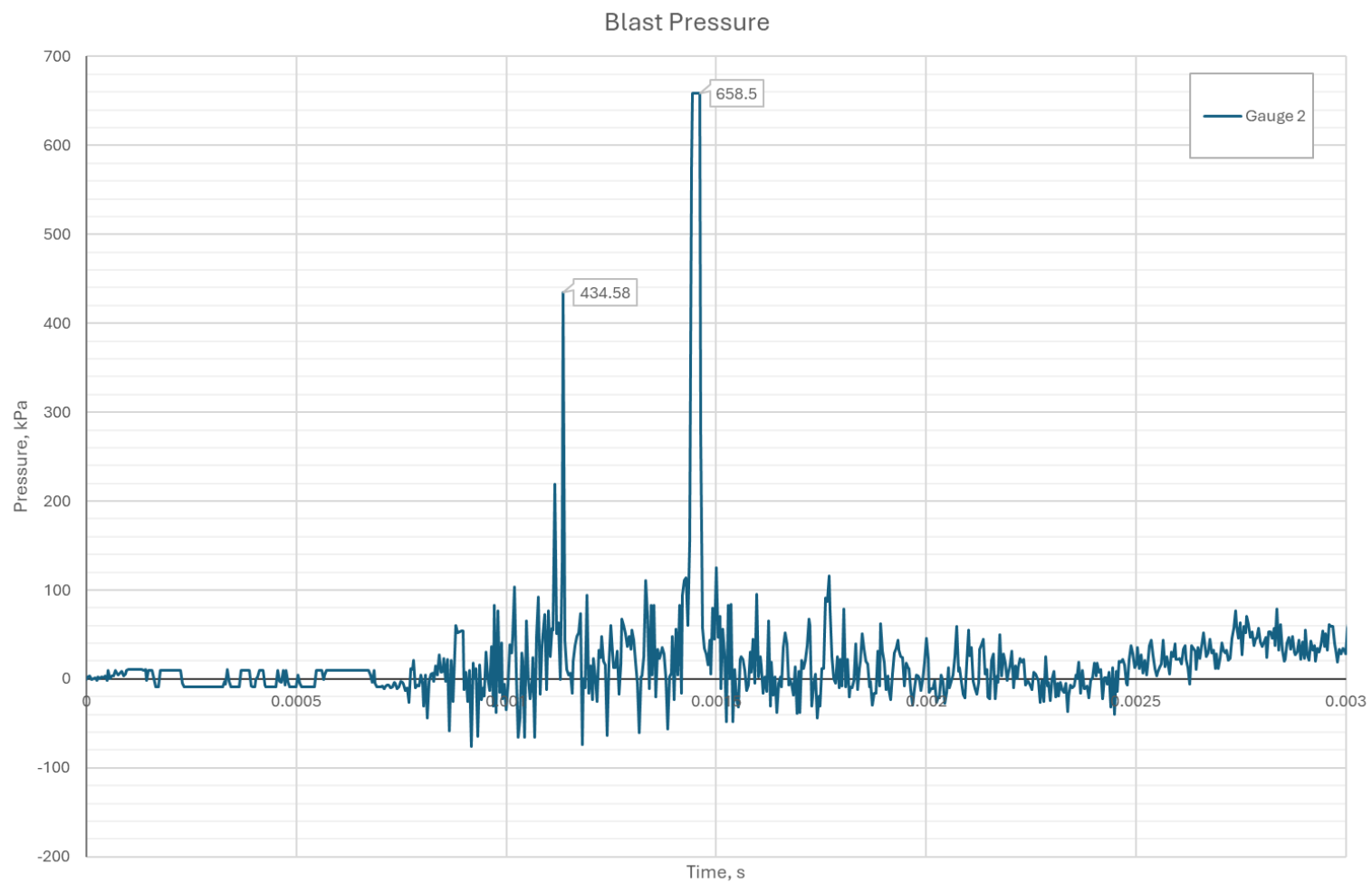


Figure 4-1 - Gauge Two Blast Pressure Highlighting the Peak Incident Pressure and Peak Reflected Pressure

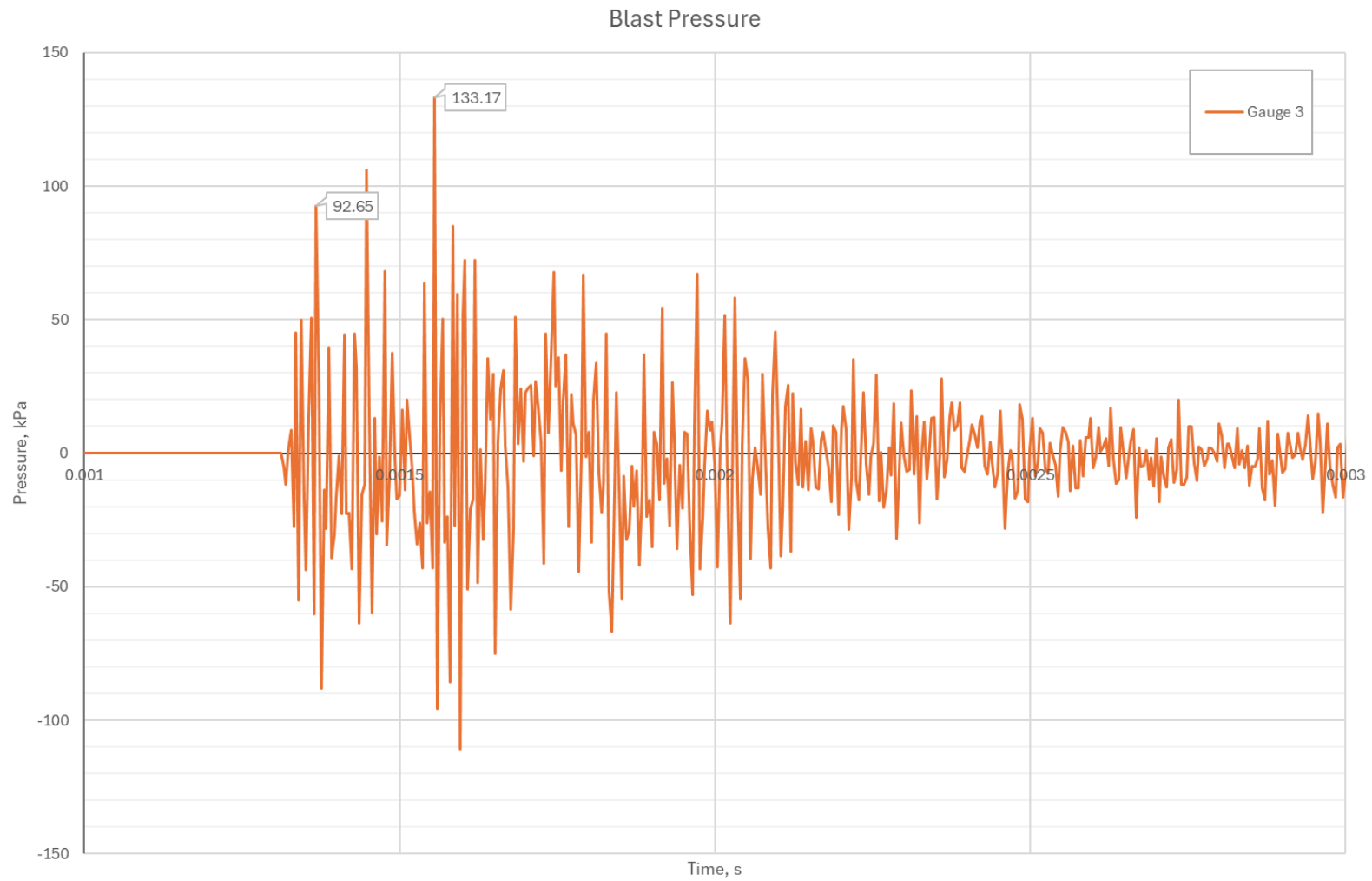


Figure 4-2 - Gauge Three Blast Pressure Highlighting the Peak Incident Pressure and Peak Reflected Pressure

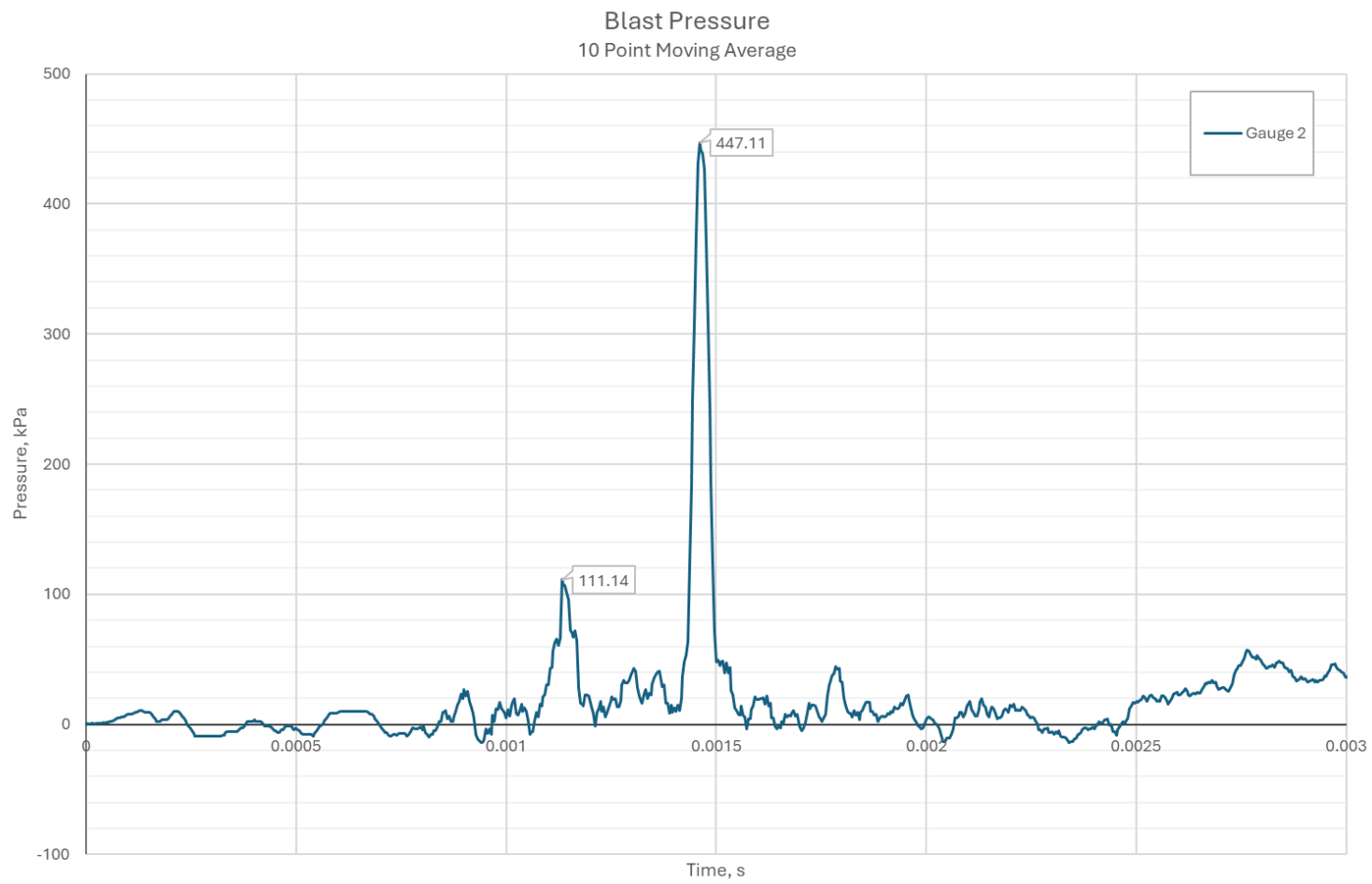


Figure 4-3 - Gauge Two 10 Point Moving Average Blast Pressure Highlighting the Peak Incident Pressure and Peak Reflected Pressure

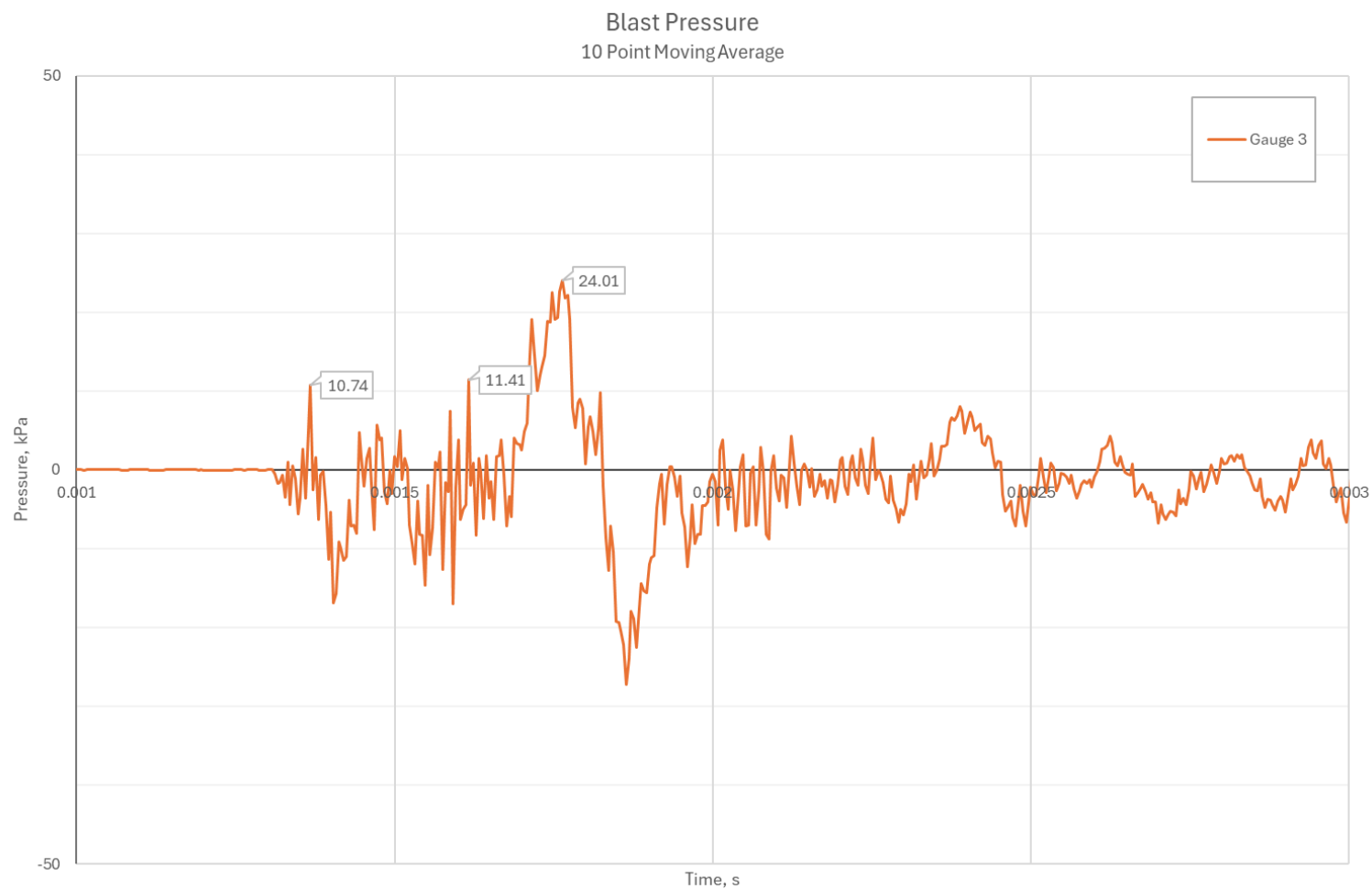


Figure 4-4 - Gauge Three 10 Point Moving Average Blast Pressure Highlighting the Peak Incident Pressure and Peak Reflected Pressure

The shape of the munition can impact the blast pressure measured. The unknown munition was described as a cylindrical shape which can produce non-ideal blast waves [10]. Figure 4-5 illustrates how the blast waves from a cylindrical charge progresses to cause increased reflected waves which may impact pressure results. Pressure measured close to the charge can be over double that of a spherical charge of the same mass [10]. Kingery-Bulmash air blast equations assume the charge is spherical, to calculate the predicted pressure for a cylindrical charge, additional parameters such as the charge length and diameter are needed [12, 13].

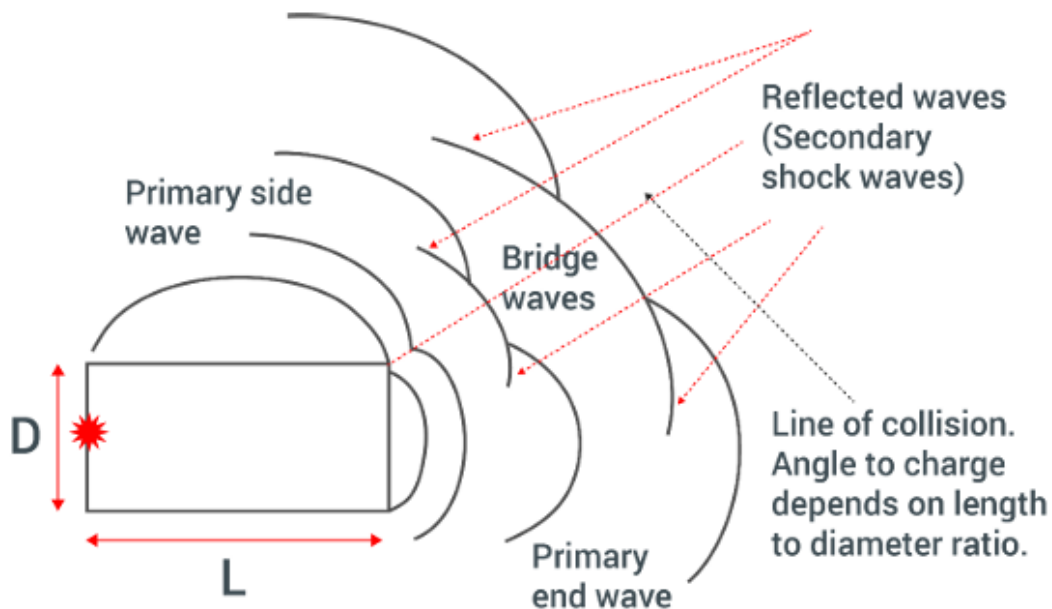


Figure 4-5 - Blast waves from a Cylindrical Charge [14]

The munition was detonated from an elevated position; therefore, consideration should be given to the formation of a Mach Stem. The combined incident and reflected wave can produce an overpressure measuring double the initial blast wave [15]. A Mach Stem would occur if the scaled distance were less than 10, however it is difficult to determine when it might occur. The scaled distance can be determine using equation 4-1, where, Z is the scaled distance, R is the height of the burst above the ground (m) and W is the mass of the explosive (kg).

$$Z = \frac{R}{W^{\frac{1}{3}}}$$

4-1

It can be seen from Table 4-3 that all the potential munitions would produce a Mach Stem in the trial conducted. This could account for the significantly higher reflected pressure measured on the gauges.

Table 4-3 - Scaled Distances of Potential Munitions from a Height of 397mm

Munition	Explosive	Charge Mass (kg)	Scaled Distance
Mk 83	Comp B	225	0.065
M-67	Comp B	0.185	0.697
RDG-5	TNT	0.11	0.829
81mm	TNT	0.76	0.435
RPG	HMX	0.73	0.441
155mm	Comp B	1.15	0.379
PB	PETN	0.264	0.619

Interference and noises can contribute to unclear results for blast pressure. As shown in Figure 4-6, the trial was conducted in a noisy environment with multiple obstacles that could cause additional reflective waves, impacting the data. Gauge One was rendered unusable due to a catastrophic fragmentation strike, therefore it is plausible the other gauges were also struck by fragmentation thus adding further noise to the results. To determine the munition used, analysis of the additional data collected is required.

4.2 Fragmentation

4.2.1 Physical Fragmentation Analysis

Fragmentation from a munition can either be natural or preformed, with the differences represented in Figure 4-7. Figure 4-8 shows the fragmentation collected was irregular in size and shape which indicates the casing produced natural fragmentation.

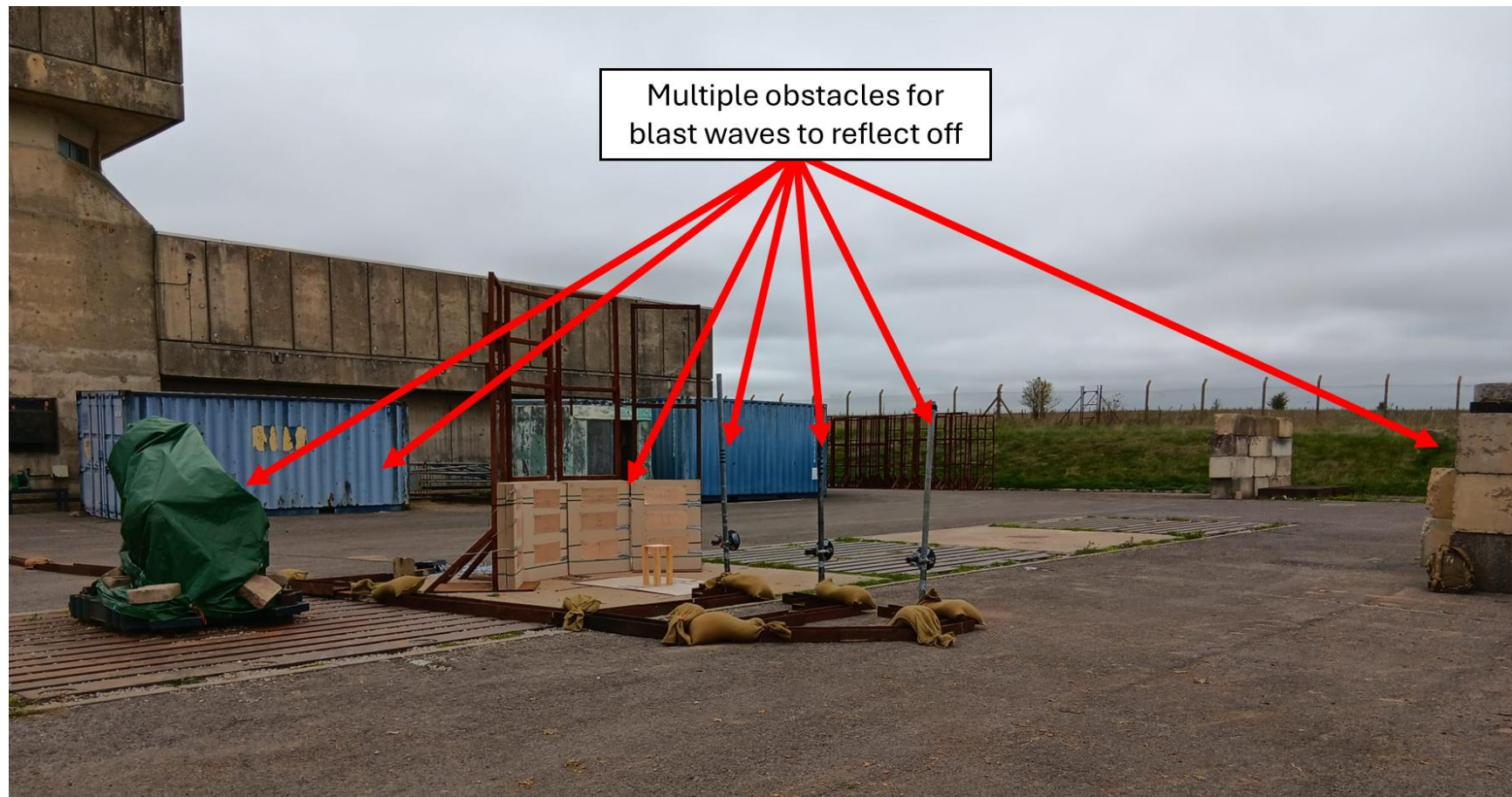


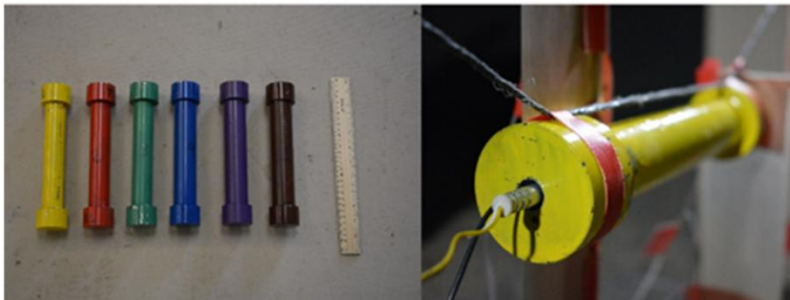
Figure 4-6 - Obstacles Present at Trial Location Which May Have Caused Reflective Blast Waves

Natural Fragmentation

Source: Experimental fragmentation of pipe bombs with varying case thickness by Luciana A. da Silva et al. [9]

Weapon System: Pipe Bomb

Casing Material: Mild Steel



Fragmentation Observations:

Irregular in size and varying in length

Fairly rectangular in shape but random and raw in edges

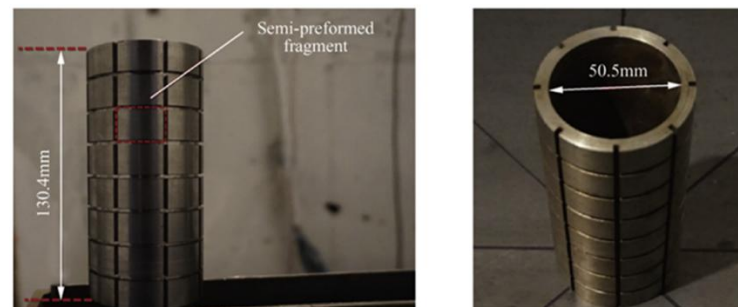


Preformed Fragmentation

Source: Effect of initiation manners on the scattering characteristics of semi-preformed fragment warhead by Xu-yang Wang et al. [16]

Casing Type: semi-preformed fragment warhead

Casing Material: Metal



Fragmentation Observations:

Square in shape

Slight variation in size but majority are within a tolerance of each other



Figure 4-7 - Natural and Preformed Fragmentation Comparison [9, 16]

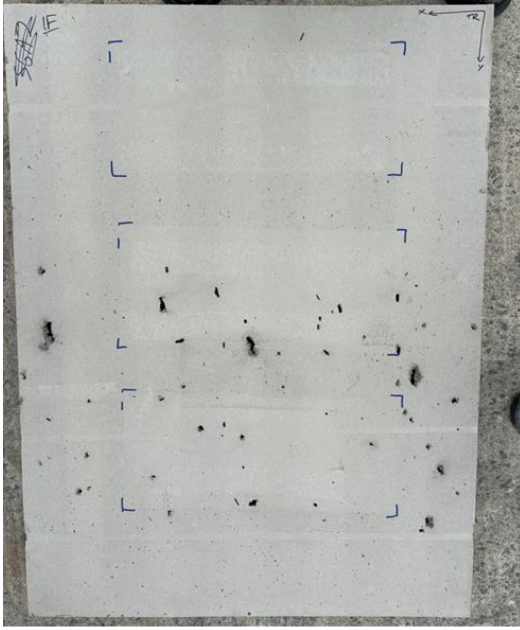


Figure 4-8 - Detailed View of a Sample of The Fragmentation Collected

The amount of fragmentation collected can provide an insight to the size and weight of the casing. The trial was conducted in a partial arena with a 113° radius, equating to approximately 30% of a full 360° arena. This means the position of the strawboards could only collect a maximum of 30% of the casing, not accounting for any loss beyond the 15° elevation angle.

While 74.5g of fragmentation was collected, an element of uncertainty was introduced reducing the accuracy of the collection per panel. This was due to the potential for different student groups to employ inconsistent picking methods. Based on these possible inconsistencies, it is plausible that the amount of fragmentation collected was approximately 20-30% of the overall casing, indicating that the casing was in the region of 250-370g.

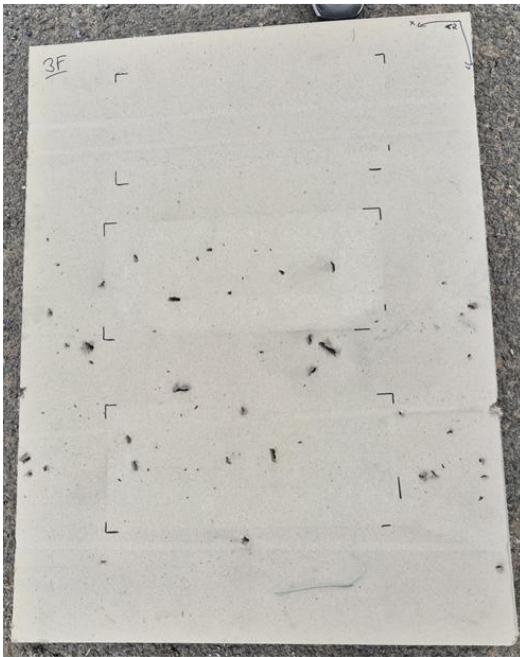
The spatial pattern of the fragmentation can help identify to the size and shape of the casing. Figure 4-9 illustrates the main impact points of the fragmentation



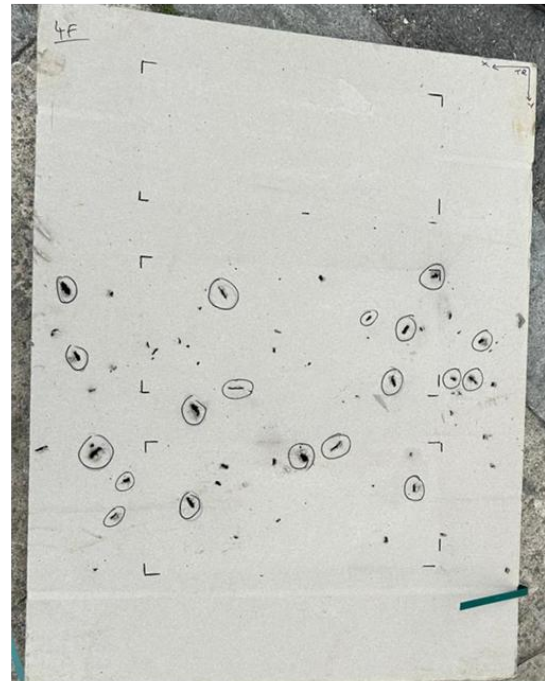
a)



b)



c)



d)

Figure 4-9 - Fragmentation Impact Points of Front Strawboard of a) Panel 1, b) Panel 2, c) Panel 3 and d) Panel 4

on each panel. The main bulk of the fragmentation struck the lower two thirds of the boards (Bands B and C), which is approximately 700mm from the bottom of the boards. The fragmentation pattern indicates that the munition was no taller than 653mm and most likely approximately 300mm tall as depicted in Figure 4-10.

Evaluation of the physical fragmentation data discounts all but one system as demonstrated in Table 4-4.

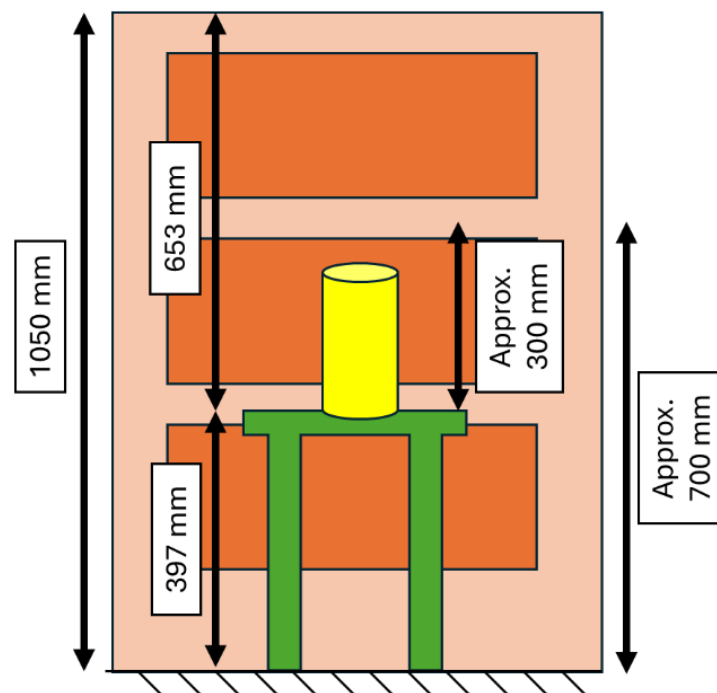


Figure 4-10 - Illustration of Potential Munition Height

Table 4-4 - Elimination Status of Potential Munitions Based on Physical Fragmentation Analysis

MUNITION	CASE MASS (kg)	FRAGMENTATION TYPE	AVERAGE FRAGMENTATION MASS (g)	AVERAGE FRAGMENTATION AREA (cm ²)	RAG STATUS	RAG JUSTIFICATION
MK 83	229	Natural [2, 3]	115	0.48	Discounted	Discounted based on average mass of fragmentation, significantly exceeds the 0.826g collected from trial.
M-67 GRENADE	0.213	Preformed [4, 5]	2	1		Discounted based on analysis of physical fragmentation collected, as it indicates unknown munition had natural fragmentation and average mass of fragmentation exceeds the 0.826g collected from trial.
RGD-5	0.200	Preformed [5]	0.12 - 0.46	1		Discounted based on analysis of physical fragmentation collected, as it indicates unknown munition had natural fragmentation.
81MM AR-M81	1.334	Natural [6]	Not Provided	Not Provided		Discounted as based on analysis of the total mass (74.5g) and amount of fragmentation collected (approximately 30% of casing), the munition casing would need to be in the region of 250 - 370g.
PG-7VL RPG	1.600 (including rocket motor)	Natural [7]	0.1	Not Provided		Discounted as based on analysis of the total mass (74.5g) and amount of fragmentation collected (approximately 30% of casing), the munition casing would need to be in the region of 250 - 370g. Average mass of fragmentation is lower than the 0.826g collected from trial.
155MM	3.105	Natural [8]	2.1	Not Provided	Discounted	Discounted as based on analysis of the total mass (74.5g) and amount of fragmentation collected (approximately 30% of casing), the munition casing would need to be in the region of 250 - 370g. Average mass of fragmentation exceeds the 0.826g collected from trial.
PIPE BOMB	0.417	Natural [9]	Not Provided	Not Provided		Deemed Plausible as based on analysis of the total mass (74.5g) and amount of fragmentation collected (approximately 20-30% of casing), the munition casing would need to be in the region of 250 - 370g. Plausible option due to inconsistency of collection method and the improvised nature of a Pipe Bomb.

4.2.2 Fragmentation Velocity Analysis

The velocity of fragmentation was calculated using the time data in Table 3-1 and equation 4-2:

$$velocity = \frac{distance}{time} \quad 4-2$$

From Table 4-5, it can be demonstrated that the velocity does not exceed 825.97ms^{-1} . This is considerably lower than expected velocities provided in Table 1-1. While equation 4-2 provides the average velocity and does not consider acceleration/deceleration or non-linear motion, it would still provide an initial approximation in the region of the actual instantaneous velocity. The actual velocity would require additional data not recorded or provided for this trial.

Table 4-5 - Fragmentation Velocity Calculations

Band	Foil	Distance (m)	Strike 1		Strike 2		Strike 3	
			Strike Time (s)	Velocity (ms^{-1})	Strike Time (s)	Velocity (ms^{-1})	Strike Time (s)	Velocity (ms^{-1})
A	1	1.462	0.004595	318.15	0.006955	210.19		
B	2	1.337	0.001710	781.65				
C	3	1.327	0.001725	769.38				
A	4	1.411	0.002071	681.35	0.003150	447.88		
B	5	1.358	0.001763	770.13	0.001798	755.43		
C	6	1.354	0.001731	782.43	0.001760	769.18	0.001800	752.39
A	7	1.452	0.002653	547.21				
B	8	1.392	0.001785	779.82				
C	9	1.390	0.001766	787.29	0.001794	774.89		
A	10	1.495	0.002663	561.50				
B	11	1.439	0.001742	825.97				
C	12	1.430	0.001782	802.38				

Using the data obtained, the velocities can be evaluated to determine a potential munition. When initially evaluating the velocity data, it was assumed:

- The explosive composition was fully encased in the munition
- Majority of the energy in the munition was initially used to break up the casing

The discrepancies between the velocities in Table 1-1 and Table 4-5 suggest there could be a considerable energy loss within the design of the munition. One means of such energy loss can come from the unconfinement of the explosive composition, rendering the above assumptions false for the trial munition.

This would indicate that the most likely munition is the Pipe Bomb as it is the only improvised device and not a standardised design. The fragment data is plausibly consistent with a Pipe Bomb without plugged ends.

The velocity data in Table 1-1 for the Pipe Bomb assumes the device had plugged ends to ensure full encasement of the explosive. This is corroborated by the theoretical velocity values in Table 4-6 which have been calculated using Gurney's Equation [14, 17] for initial fragmentation velocity for a cylindrical charge (4-3).

$$v = \sqrt{2E} \left(\frac{M}{C} + \frac{1}{2} \right)^{-\frac{1}{2}} \quad 4-3$$

Table 4-6 - Initial Fragmentation Velocity Calculated Using Gurney's Equation for a Cylindrical Charge

System	Explosive	Gurney Constant - $\sqrt{2E}$ (ms ⁻¹) - [17]	Charge Mass - M (kg)	Casing Mass - C (kg)	Calculated Initial Velocity (ms ⁻¹)	Provided Initial Velocity (ms ⁻¹)
Mk 83	Comp B	2774	225	229	2251.66	1950
M-67	Comp B	2774	0.185	0.213	2158.67	Not Provided
RGD-5	TNT	2438	0.110	0.200	1601.25	1567
AR-M81	TNT	2438	0.760	1.334	1623.44	1734
RPG PG-7VL	RDX/TNT - 95% HMX 5% Wax	2402	0.730	0.600	2089.16	1831.5
155mm	Comp B	2774	1.150	3.105	1550.71	1551
Pipe Bomb	PE8	2926	0.264	0.417	2029.04	2047

4.3 Chemical Sampling

The FTIR results indicate the presence of key explosive identifiers. Figure 4-11 highlights strong N=O bonds ($1533\text{-}1593\text{cm}^{-1}$) along with C-N and N-N stretches in the fingerprint region ($1040\text{-}1390\text{cm}^{-1}$). These identify the explosive to be a Nitro-based compound such as RDX or TNT. Figure 4-12 illustrates that TNT can be eliminated due to the lack of a C=C-C aromatic ring in the sample, which would be present on the FTIR vibrations at $1615\text{-}1580\text{cm}^{-1}$ and $1510\text{-}1450\text{cm}^{-1}$ [18]. The addition of plasticizer at $1738\text{-}3001\text{cm}^{-1}$, supported by comparison with previously conducted FTIR analysis of TNT and Composition-4 (C4) [19], confirms the presence of a plastic-based RDX compound.

As demonstrated in Table 4-7, the unknown munition can only be the Pipe Bomb due to it containing a plastic-based RDX explosive without TNT.

Table 4-7 - Explosive Parameters for Potential Munitions

Munition	Explosive Composition	Charge Mass (kg)	RAG Status	RAG Justification
Mk 83 <i>Air Dropped Munition</i>	Composition B (Mixture of TNT and RDX)	225		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
M-67 Grenade <i>US Anti-Personnel Grenade</i>	Composition B	0.185		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
RGD-5 <i>Soviet Anti-Personnel Grenade</i>	TNT	0.110		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
81mm AR-M81 <i>High Explosive Mortar Round</i>	TNT	0.760		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
PG-7VL RPG <i>High Explosive Anti-Tank Round</i>	RDX/TNT - 95% HMX 5% Wax	0.730		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
155mm <i>Artillery Round</i>	Composition B	1.150		Discounted - Explosive Composition contains TNT. FTIR Analysis confirms sample does not contain TNT.
Pipe Bomb <i>Improvised Explosive Device</i>	PE 8 (RDX Based Plastic Explosive)	0.264		Highly Likely - Explosive composition is primarily RDX. FTIR analysis confirms high presence of RDX with a plasticizer.

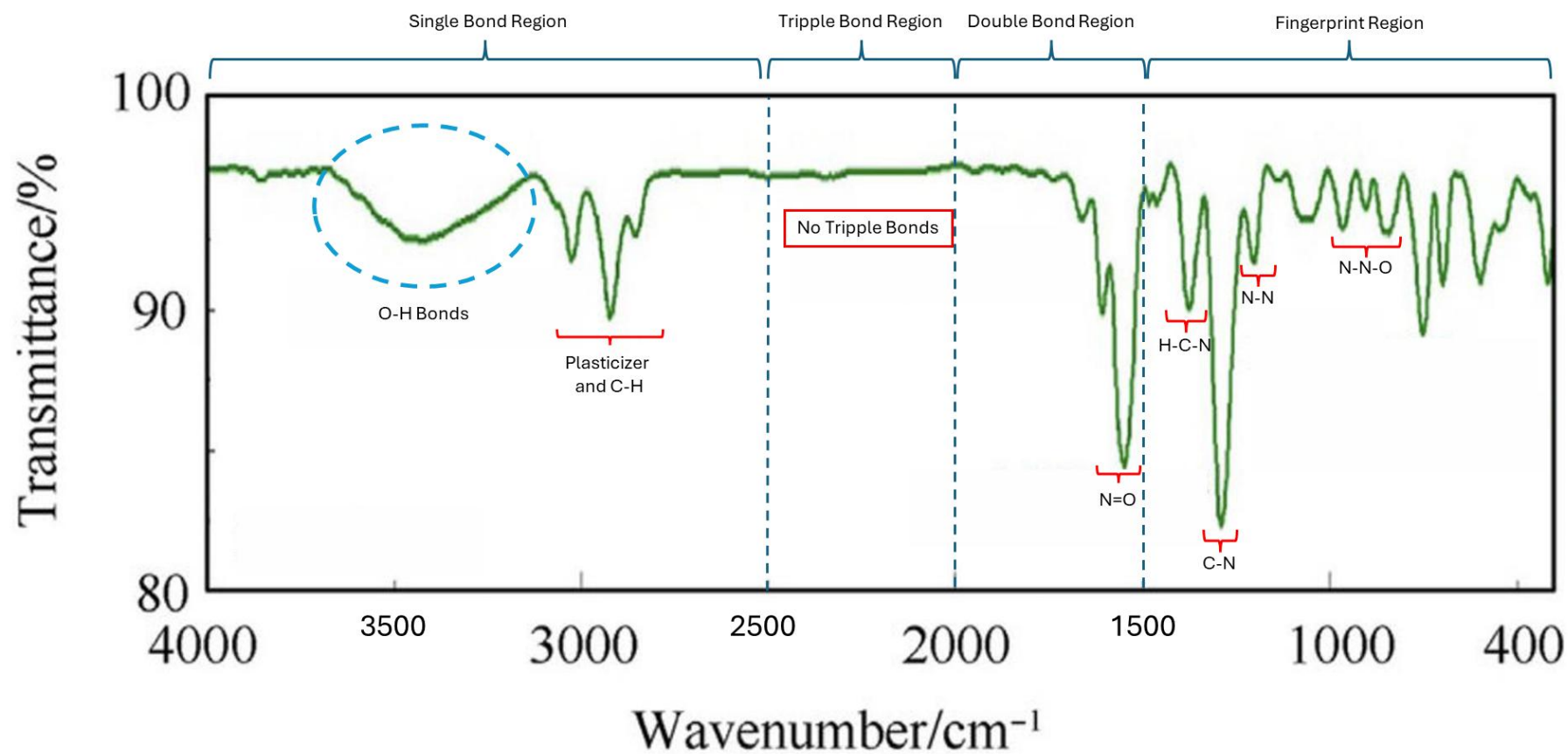


Figure 4-11 - FTIR Analysis

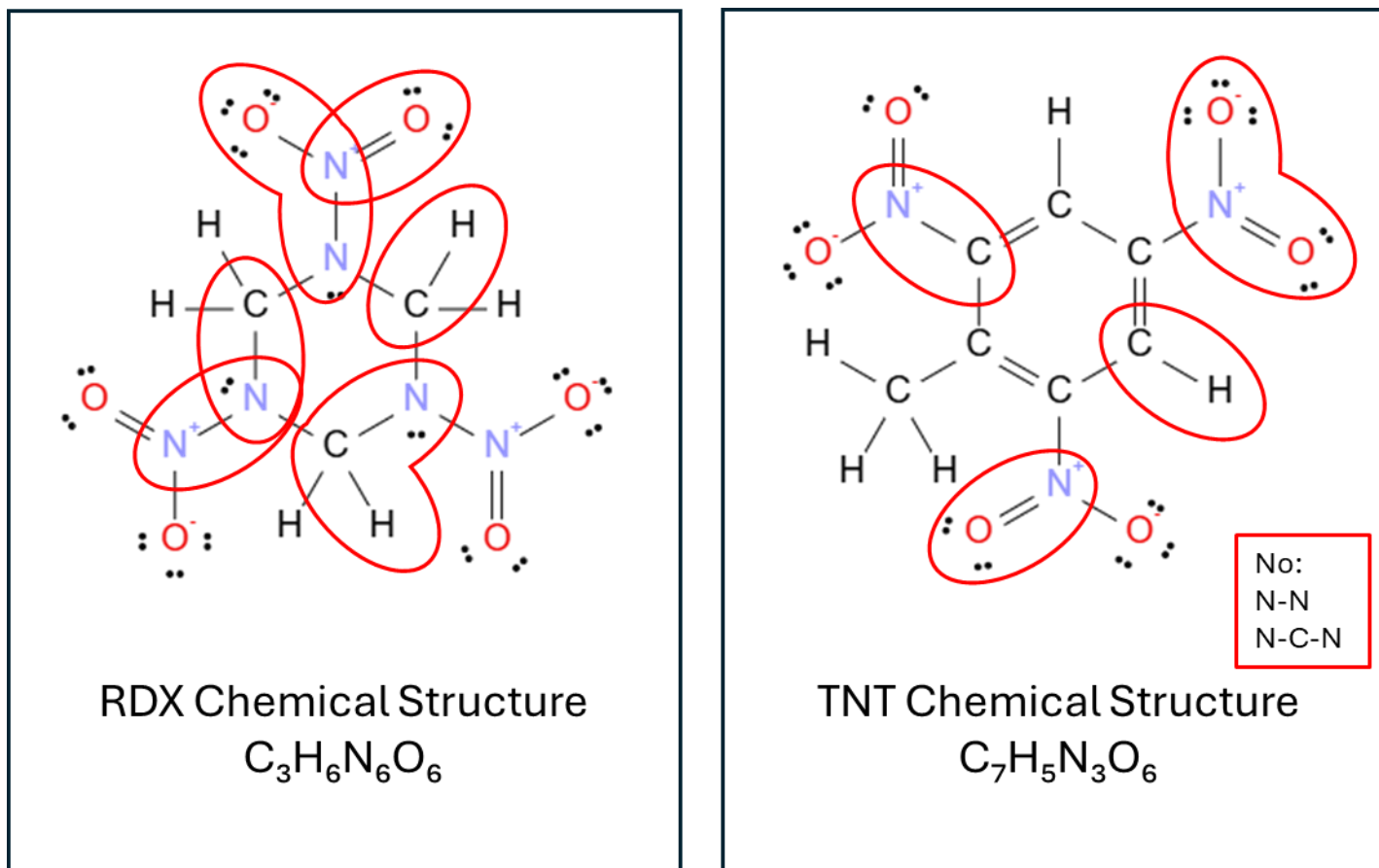


Figure 4-12 - Chemical Structure of RDX and TNT Highlighting Components from FTIR Analysis

5 Conclusion

Through critical evaluation of the blast, fragmentation and chemical data from the COTEC fragmentation trial and the list of potential munitions provided, this report concludes that the unknown munition was a Pipe Bomb.

While the blast data provided anomalous results to determine the charge mass, the non-ideal blast pressure graph was consistent with a blast wave produced from a cylindrical charge, impacted by reflective waves from obstacles.

Analysis of the natural fragmentation collected supported the identification of the munition. The lower-than-expected velocity values indicated considerable energy loss during detonation, which alluded to the Pipe Bomb due to its improvised nature of the casing.

The FTIR results confirmed the strong presence of RDX and the lack of TNT. This eliminated majority of the munitions based on the explosive composition used, leaving only the Pipe Bomb filled with PE8 as the only plausible option, as summarised in Table 5-1.

Although the munition has been identified, there are multiple discrepancies with the data collected which do not fully match the characteristics of the potential munitions, therefore the validity of the initial data set needs to be considered. The data collection methods should also be evaluated to identify lessons learnt and alternative options explored. This evaluation has been conducted in: A Critique of the Data Capture Methods used in Ordnance Identification [1].

Table 5-1 - Summary of Analysis and Identification of Unknown Munition

Munition	Explosive Composition	Explosive RAG Status	Fragmentation	Fragmentation RAG Status	Final RAG Status
Mk 83 <i>Air Dropped Munition</i>	Composition B	FTIR results indicate no presence of TNT in sample	Fragment Type – Natural Case Mass – 229kg Average Fragment Mass – 115g	Average mass of fragmentation significantly exceeds the 0.826g collected from trial.	Discounted as charge mass exceeds range NEQ limit
M-67 Grenade <i>US Anti-Personnel Grenade</i>	Composition B	FTIR results indicate no presence of TNT in sample	Fragment Type – Preformed Case Mass – 213g Average Fragment Mass – 2g	Fragmentation collected was natural	Discounted based on FTIR results and fragmentation type
RGD-5 <i>Soviet Anti-Personnel Grenade</i>	TNT	FTIR results indicate no presence of TNT in sample	Fragment Type – Preformed Case Mass – 200g Average Fragment Mass – 0.12-0.46g	Fragmentation collected was natural	Discounted based on FTIR results and fragmentation type
81mm AR-M81 <i>High Explosive Mortar Round</i>	TNT	FTIR results indicate no presence of TNT in sample	Fragment Type – Natural Case Mass – 1.334kg Average Fragment Mass – Not Provided	Case mass of unknown munition is assumed to be 250-370g	Discounted based on FTIR results and assumption of case mass
PG-7VL RPG <i>High Explosive Anti-Tank Round</i>	RDX/TNT - 95% HMX 5% Wax	FTIR results indicate no presence of TNT in sample	Fragment Type – Natural Case Mass – 1.6 kg Average Fragment Mass – 0.1g	Average mass of fragmentation is lower than the 0.826g collected from trial and case mass exceeded assumed mass (250-370g)	Discounted based on FTIR results and assumption of case mass

Munition	Explosive Composition	Explosive RAG Status	Fragmentation	Fragmentation RAG Status	Final RAG Status
155mm Artillery Round	Composition B	FTIR results indicate no presence of TNT in sample	Fragment Type – Natural Case Mass – 3.105kg Average Fragment Mass - 2.1g	Average mass of fragmentation is higher than the 0.826g collected from trial and case mass exceeded assumed mass (250-370g)	Discounted based on FTIR results and average fragmentation mass
Pipe Bomb Improvised Explosive Device	PE 8	FTIR results indicate strong presence of RDX	Fragment Type – Natural Case Mass – 417g Average Fragment Mass – Not Provided	Fragmentation collected was natural and assumed case mass is 250-370g. This is plausible due to the improvised nature of the device specific design parameters can vary.	Determined as unknown munition based on FTIR results and improvised nature of the device contributing to the variation in results for fragmentation velocity and case mass.

6 References

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