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LAB REPORT ON THE DETERMINATION OF AN UNKNOWN ENERGETIC DEVICE THROUGH TRIAL RESULTS

References. See footnotes and embedded documents section at end of document.

1. Abstract

This report details the trial performed on the 15th October 2025 by the Student and their peers. The intent of the Trial was to determine the munition involved from the resultant data. The trial was conducted and the data evaluated to determine that the likely munition was a pipe bomb made from uncapped steel tube containing an RDX based high explosive.

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2. Introduction and Background

Post event analysis is a regular and critical aspect in evaluating, determining or investigating an energetic event. Commonly it is used post planned trials when a deliberate event has been planned and executed for scientific purposes. In planned trials the Munition is known and certain characteristics are being measured with the intent of demonstrating aspects such as Power, Performance or Regulation Compliance. In an unplanned blast such as a terrorist attack [1] or incident [2] this form of analysis is used to understand the device based upon the destruction present and any other available information. [3]

This trial is a mixture between an unplanned event and a planned event as the trial will be setup to best capture the information from the blast but the munition is unknown and therefore the trial cannot be fully customised to suit it.

3. Purpose and Aim

The Aim of this trial is to determine the likely explosive device based upon the resultant data from the blast. To assist in identification a list of munitions was provided pretrial. These are summarised at Annex 2. [4] from the munitions list it is initially hypothesised that the munition is either a Grenade, Mortar or Pipe bomb. Due to the initial eliminations in Annex 2.

4. Setup and Procedure

The trials team was split down into a series of groups to ensure the key aspects of the trial were individually managed. The student was assigned to the group responsible for the pressure gauges.

The trial location was Cranfield Ordnance Test and Evaluation Centre (COTEC) at Gore Cross, West Lavington, Devizes, Wiltshire, SN10 4NA, UK. Specifically at the forward battery Pad 2 (51°15'37.6"N 1°57'46.6"W) shown below.



Table 1 - COTEC Aerial View [5]

The trial was setup with the wooden support table at the centre of the concrete pad this held the munition prior to detonation. All measurements were taken from the centre of the support table and 0.5m off the ground as the detonation point (DP). To the west side of the DP the strawboard stands, strawboards (SB) and Velocity Foils (VF) were erected. The gauges were placed in an offset line to the east, directly opposing the DP and fragmentation boards. Lastly the cables were run from the southeast corner of the control building to the required locations of the VF's and Gauge. The full layout and measurements of the trial are available in Annex 1.



Figure 1 - Final Trial Setup



Figure 2 - Offset Gauges

5. Data Processing

The data achieved from the trial can be broken down in to clear types, initial visual observations, Pressure, Fragment Velocity, Fragment Properties and Chemical Analysis. These categories have been evaluated individually below.

5.1. Visual Data



Figure 3 - Post Blast Left



Figure 4 - Post Blast Right

The post blast photography shows that the structure of the trial other than the support table remained largely in place. Additionally the initial observation of the fragmentation showed a broadly even spread of around 50cm along the middle of the strawboards centered slightly above the top of the table with minimal fragmentation above or below this tight arc. Lastly the cardboard on the ground showed clear charring and the table was disintegrated and dispersed from the detonation point.

5.2. Pressure

As with most experiments of this kind the raw data achieved is very chaotic. This is demonstrated by the graph of the raw pressure data below.

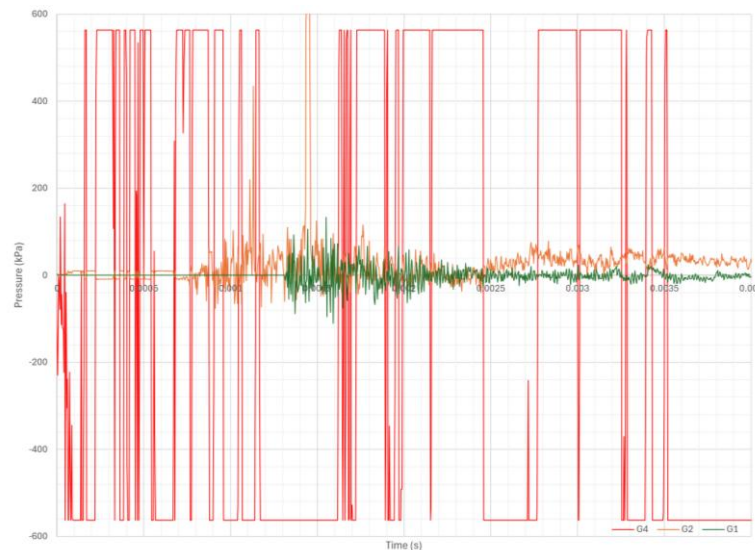


Figure 5 - Raw Pressure Data

From initial post blast observations we can see that Gauge 4 was initially struck by a piece of fragmentation, on further investigation this strike cut the wires of the gauge causing the signal oscillation seen in Figure 5. For the remainder of the pressure data processing Gauge 4 will be removed due to the lack of valuable data. To further speed processing time the timeframe plotted will be between 0.0005s and 0.0025s as beyond this time the blast has passed and only noise remains.

Even with the removal of Gauge 1 and limiting the timeframe there is a significant amount of noise in the results, this is likely caused by fragmentation strikes on the gauge, stand, wire protection or support structure. To remove this noise a process of data smoothing can be applied.

Data smoothing is the process of removing noise from a data set to obtain the true signal. In electronics the most common form of this is the noise created from the 50Hz wave of the National Grid. [6] This frequency can impact measuring equipment use on trials such as oscilloscopes and picoscopes. Fortunately, as the national grid has a relatively stable frequency this oscillation can be tuned out from the signals measured. In this experiment the noise created from the fragmentation is not standard, consistent or stable hence a simple filter cannot be used.

There are several types of smoothing that can be applied without the need of specialist software such as 'OriginPro' or custom 'MATLAB' scripts. [7] [8]. Outside of these tools, the most common methods are Moving Average (MA) and Simple Exponential, which are commonly implemented through Excel. [9]

Moving Average smoothing takes an average of a set number of contiguous values that moves through the data set. Whereas Simple Exponential (SE) smoothing takes this moving average one step further by applying a weighting/ damping to the values with greater weighting to the most recent observed point. [10] [11]

Both methods can be valuable when removing the noise from the data, as there is a certain level of skill and background knowledge required to determine the appropriate application of these techniques.

To evaluate the most appropriate technique for this data a series of 6 datasets were created from the G1 Data for the relevant methods of, 10 Point MA, 5 Point MA, SE with 0.9 Damping (SE 0.9D), SE 0.7D, SE 0.5D and SE 0.3D. These were then graphed and compared to the Raw Data seen in Annex 3 – Gauge 1 Smoothing Trials.

From these tests the Simple exponential smoothing graphs show that 0.3D and 0.5D proved ineffective leaving significant noise and 0.9D demonstrated over smoothing with a loss of detail. A damping of 0.7D seems ideal for this data.

Comparing this 0.7D data to the results for 5P and 10P MA the 10P MA again shows slight over smoothing. Leading to a close final ideal damping between 5P MA and SE 0.7D.

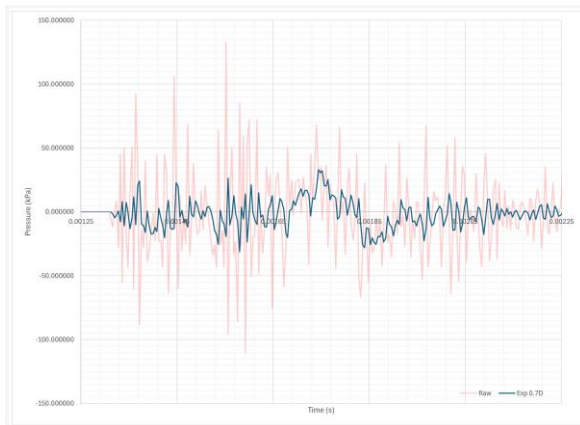


Figure 6 - G1 SE 0.7D

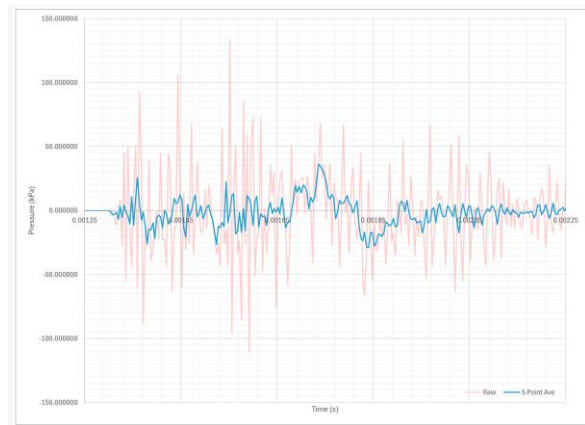


Figure 7 - G1 5P MA

Taking the 4 most successful methods and completing the same tests on the Gauge 2 data the results at Annex 4 Gauge 2 Smoothing Trials are achieved. These showed a similar pattern to the gauge 1 results with SE 0.9D and 10P MA over smoothing.

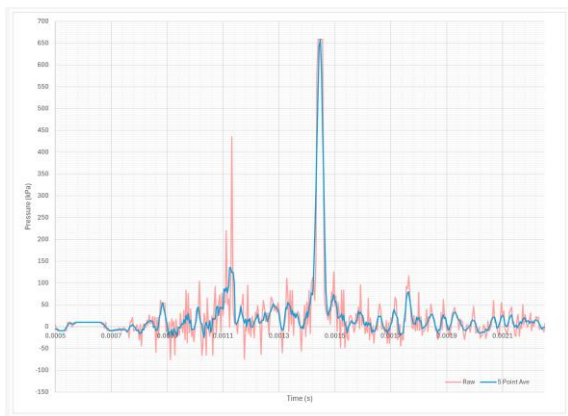


Figure 8 - G2 5P MA

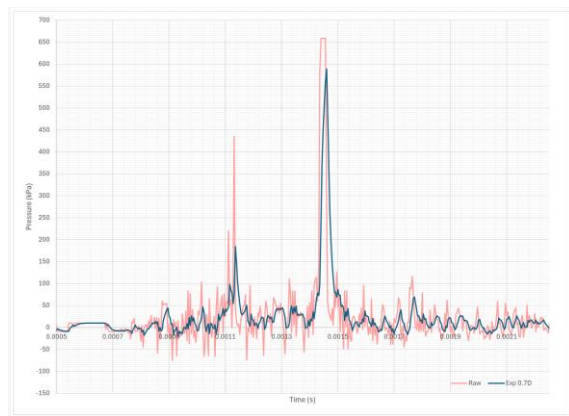


Figure 9 - G2 SE 0.7D

For the final Data analysis 5P MA will be used for G1 and SE 0.7D used for G2 as these options demonstrated a good balance between smoothing and data loss for each gauge.

5.3.Fragment Velocity

The results achieved from the velocity foils (VF) were limited despite the numerous strikes that were observed on the foils.

By averaging the data and removing values that were outside of the average ± 1 Standard Deviation (Std Dev), anomalies in the data could be identified. Repeating this stage 3 times created 2 data sets, one with close correlation and one with varying correlation. The summarised results are in Table 2. Graphing these results against distance the two data sets become obvious. Ignoring the anomalies in the data the average velocity for the fragments is 772 ms^{-1} .

VF Foil	Dist (m)	Impact Time (ms)	Velocity 1 (ms^{-1})	Velocity 2 (ms^{-1})	Velocity 3 (ms^{-1})	Final Anomalies
2A	1.411	2.07088	681	681	681	An
2C	1.354	1.7996	752	752	752	752
2B	1.358	1.79764	755	755	755	755
2C	1.354	1.76032	769	769	769	769
1C	1.327	1.72476	769	769	769	769
2B	1.358	1.76334	770	770	770	770
3C	1.39	1.7938	775	775	775	775
3B	1.392	1.78502	780	780	780	780
1B	1.337	1.71048	782	782	782	782
2C	1.354	1.7305	782	782	782	782
3C	1.39	1.76556	787	787	787	787
4C	1.43	1.7822	802	802	802	An
1A	1.402	6.95548	202	An	An	An
1A	1.402	4.5953	305	An	An	An
2A	1.411	3.15038	448	An	An	An
3A	1.452	2.65346	547	547	An	An
4A	1.499	2.6625	563	563	An	An
4B	1.439	1.7422	826	826	An	An
Average			672	743	767	772
1 Std Dev			179	79	29	11
Ave + 1SD			851	822	796	783
Ave -1SD			493	663	738	761

Table 2 - Velocity Foils Data Summary

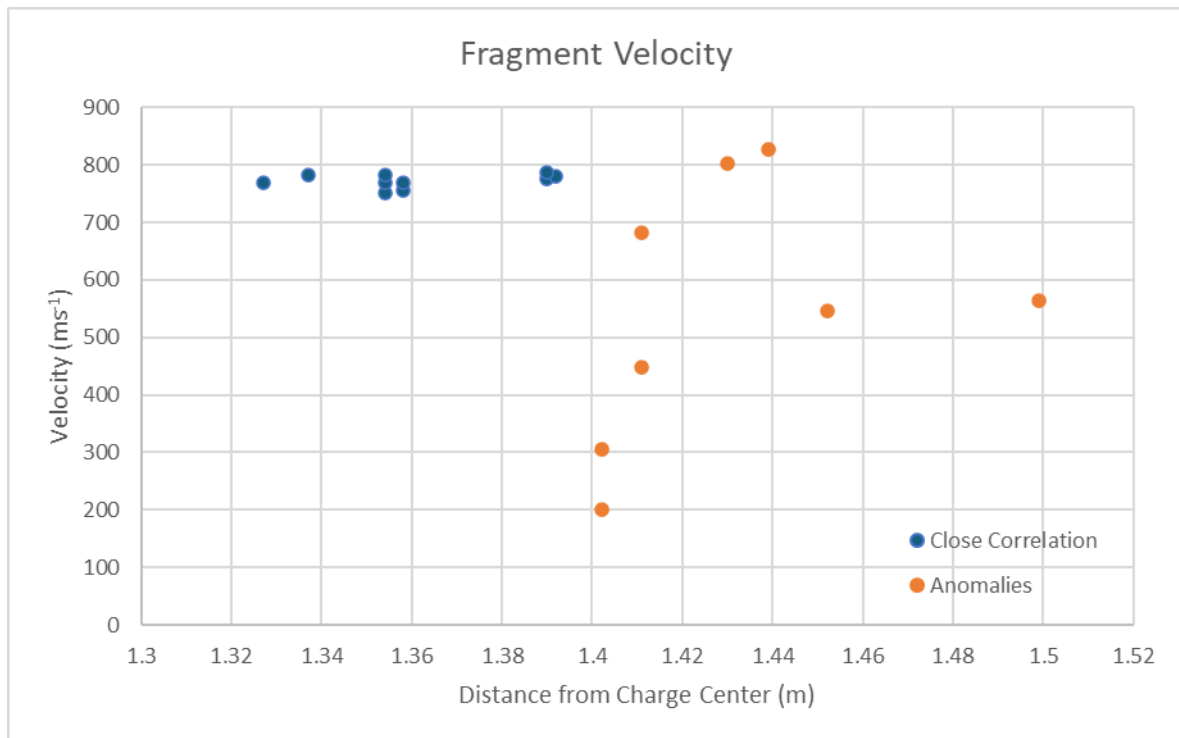


Figure 10 - Fragment Velocity Graph

5.4.Fragment Properties

The fragmentation from the trial was recovered from the strawboards and analysed to determine that the average data listed in Table 4. Unfortunately, due to time constraints fragment tracking and energy calculations could not be made.



Table 3 - Recovered Fragmentation [12]

Average Thickness	Average Mass	Total Fragments Collected	Total Mass
3.3mm	0.826g	90	74.5g

Table 4 - Fragment Data

Although the individual fragment characteristics cannot be measured or calculated some further analysis can be performed on the available data. By assuming a percentage of fragmentation produced within the field of arc of strawboard was captured a total estimated case mass can be calculated below. In this case a 60% capture is assumed.

$$\frac{360 \times \text{Total Mass Recovered}}{\text{Strawboard Arc Angle} \times \text{Recovery estimate \%}} = \text{Total Case Mass Estimate}$$

$$\text{Total Case Mass Estimate} = \frac{360 \times 74.5}{108.51 \times 0.6}$$

$$\text{Total Case Mass Estimate} = 412g$$

5.5. Chemical Analysis

Post blast a series of swabs were taken to chemically analyse under a Fourier Transform Infrared Spectroscopy (FT-IR) Machine. The intent of these swabs was to capture explosive remnants and enable the absorption data to be analysed. The general absorption spectra are in Figure 11.

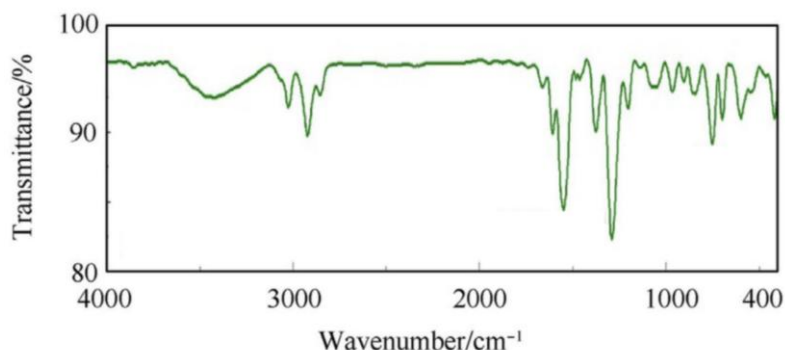


Figure 11 - FTIR Trace Averaged Sample

The FT-IR trace has had the noise removed from the acetone solution and has been averaged across the relevant sample swabs. The sample shows lots of C-N stretching which is indicative of RDX when compared to Figure 12. In addition, there is C-H stretching that is likely from the binder around the 3000 cm⁻¹ area. Lastly there is likely a close correlation with the trace achieved and the DMNB taggant spectra in Figure 13 but without a library search function and specialised software separating any taggant profile from a raw FT-IR trace is difficult.

Wave Number Range (cm⁻¹)	Chemical Feature	Strength	Likely Compound
3066 - 3070	C-H stretch	Strong	Binder
1040	C-N stretch	Strong	Explosive
1593	N-O stretch	Strong	Explosive NO ₂ Groups
1269	C-N stretch	Very strong	Explosive
3000	Unknown Fingerprint	Varying	

Table 5 - Feature Identification

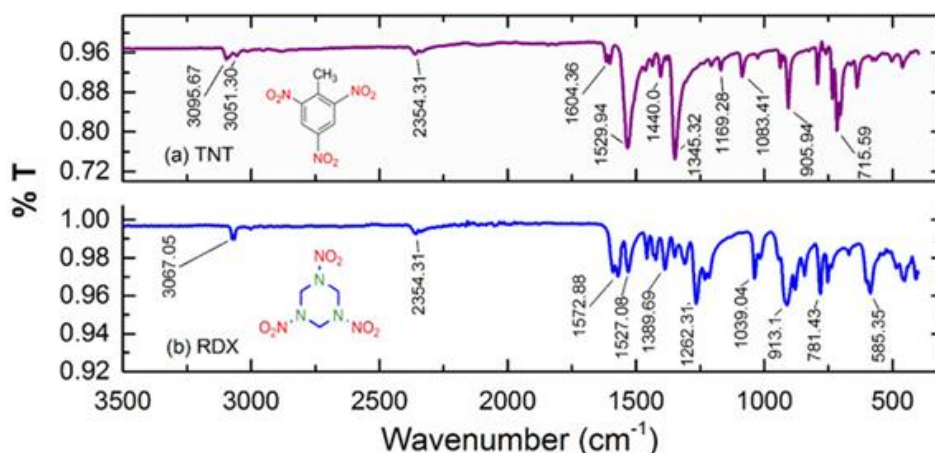


Figure 12 – Transmission Spectra of RDX and TNT [13]

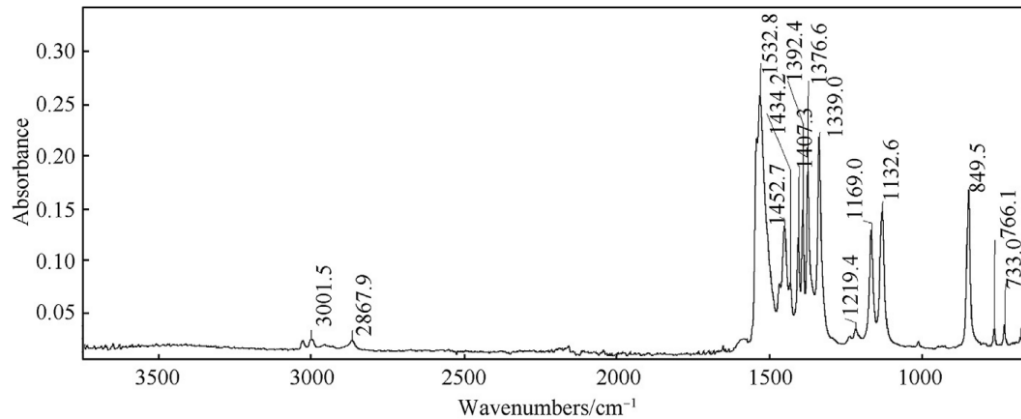


Figure 13 - Absorption Spectra of DMNB [14]

Munition	Explosive	Energetic	Taggant	Plasticiser and Binder
Pipe Bomb	PE8 [15]	RDX 86.5%	DMNB 1%	12.5%
81mm Mortar	TNT	TNT	Unknown	Unknown

Table 6 - Energetic Material Constituents

6. Results

The visual data evaluated indicated a small charge with a metal body.

The Final Pressure results show a peak pressure of G2 of 80 kPa and a reflected pressure of 335 kPa.

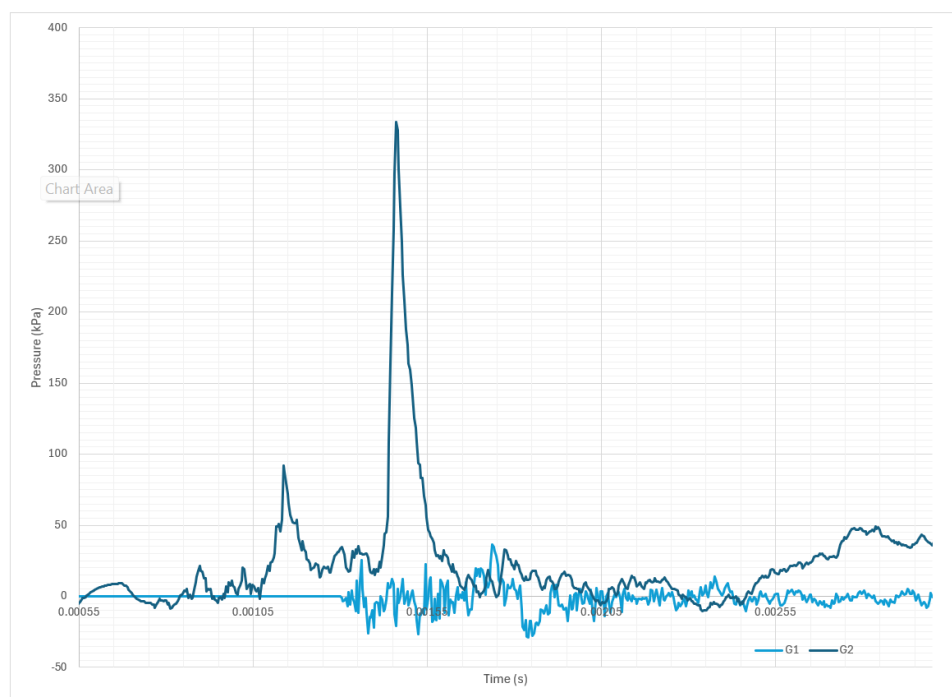


Figure 14 - Final Pressure Results

These pressure results can be compared to the expected pressures from a Kingery Blast Calculator with input values for the pipe bomb. Seen below in Figure 15.

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by
Charles N Kingery & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F. Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	0.26
TNT Equivalence Figure	1.149

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	82.0464442	116.3366508
Incident Impulse (Is) [kPa.msec]	43.1085236	62.1509279
Peak Reflected Pressure (Pr) [kPa]	216.9805993	333.1305356
Reflected Impulse (Ir) [kPa.msec]	98.6313896	150.4157874
Shock Front Velocity (U) [m/msec]	0.4427527	0.4799475
Arrival Time (Ta) [msec]	2.6531871	2.3578963
Positive Phase Duration (T+) [msec]	1.7918104	1.8877909

Figure 15 - Kingery Blast Calculator Results [16]

These pressures show a close correlation between the calculated and measured results providing confidence that the munition in question is a pipe bomb.

The average fragment velocity achieved was 772 ms^{-1} once anomalies of smaller or larger fragments than 0.8g are removed. This cannot be directly compared to any available information as the fragment velocity from a pipe bomb is not standardised or widely available.

The final chemical analysis indicated the likely energetic was RDX based with some form of plasticiser and taggant. This would support the hypothesis of a pipe bomb as the PE8 detailed to be in the pipe bomb is RDX based with a plasticiser and DMNB taggant.

Lastly the fragment analysis showed a relatively even but small fragment size that was randomly distributed in a tight band around the charge. This further supports a brittle metal case with an explosive with a high brisance these are characteristic of a pipe bomb made from a scaffold tube.

7. Conclusions

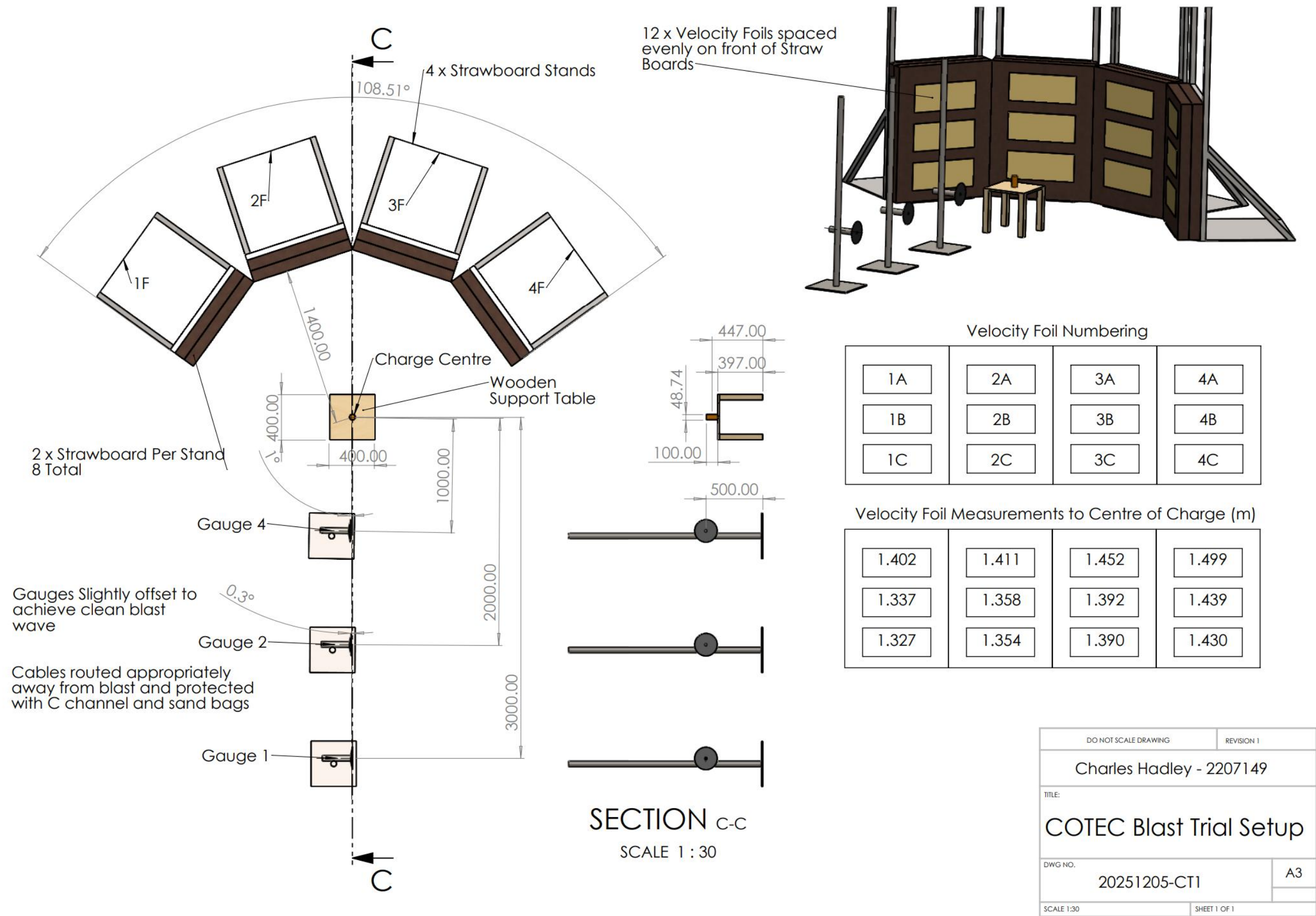
In conclusion the results from this trial provide clear indication that the likely munition is a pipe bomb containing around 260g of an RDX based High explosive, Likely PE8 as this is readily available in the UK military and commercially. The post blast photography, pressure, fragmentation and chemical analysis support this conclusion.

8. References

- [1] P. Murphy, "Report into the London Terrorist Attacks on 7 July 2005," Cabinet Office, London, 2006.
- [2] M. Masr, "The Beirut Port Explosion," 17 11 2020. [Online]. Available: <https://forensic-architecture.org/investigation/beirut-port-explosion>. [Accessed 19 12 2025].
- [3] A. Bull and J. Clasper, Blast Injury Science and Engineering, London: Springer, 2023.
- [4] G. Collette, "Types of Munition of Potential Interest," 2025. [Online]. Available: <https://moodle.uwtsd.ac.uk/mod/resource/view.php?id=697370>. [Accessed 05 12 2025].
- [5] Google, "Google Maps," Google, 2025. [Online]. Available: <https://www.google.com/maps/place/51%C2%B015'37.6%22N+1%C2%B057'46.6%22W/@51.2604338,-1.9635817,237m/data=!3m2!1e3!4b1!4m12!1m7!3m6!1s0x4873dea8c48a7b6b:0xba95dd105e43b249!2sC+O+T+E+C!8m2!3d51.258604!4d-1.9866419!16s%2Fg%2F11hfbmw9k!3m3!8m2!3d51.260433!4>. [Accessed 13 12 2025].
- [6] NESO, "System Frequency," NESO, 2025. [Online]. Available: <https://www.neso.energy/data-portal/system-frequency-data>. [Accessed 06 12 2025].
- [7] OriginLab, "OriginLab," OriginLab, [Online]. Available: <https://www.originlab.com/>. [Accessed 06 12 2025].
- [8] MathWorks, "MATLAB for Data Analysis," MathWorks, [Online]. Available: <https://www.mathworks.com/products/matlab/data-analysis.html>. [Accessed 06 12 2025].
- [9] B. Vishwas and A. PATEL, "3. Smoothing Methods," in *Hands-On Time Series Analysis with Python*, Apress L. P., 2020, pp. 31-44.
- [10] H. Xu, "7 Data smoothing," in *Handbook of Statistics*, El, 2020, pp. 337-348.
- [11] Excel Easy, "Exponential Smoothing in Excel," Excel Easy, [Online]. Available: <https://www.excel-easy.com/examples/exponential-smoothing.html#:~:text=This%20example%20teaches%20you%20how,%200.3%20and%20alpha%20=%200.8..> [Accessed 06 12 2025].
- [12] G. Collett, "Moodle," 2025. [Online]. Available: <https://moodle.uwtsd.ac.uk/course/view.php?id=11814>. [Accessed 13 12 2025].
- [13] K.Rao, D.Ganesh, F.yehya and A.Chaudhary, "A comparative study of thermal stability of TNT, RDX, CL20 and," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy ANTA explosives using UV 266 nm-time resolved photoacoustic pyrolysis technique*, vol. 211, no. 1, pp. 212-220, 2019.
- [14] J. Cailes, R. Dunsmore and K. Linge, "Assessment of portable FTIR and Raman spectroscopy for the detection of 2,3-dimethyl-2,3-dinitrobutane (DMDNB) in plastic explosives," *Defence Technology*, vol. 44, no. 1, pp. 11-18, 2024.
- [15] Chemring Energetics UK, "PLASTIC EXPLOSIVE (PE8)," 04 2022. [Online]. Available: <https://www.chemring.com/~media/Files/C/Chemring-V3/documents/energetics/heds/pe8-apr22.pdf>. [Accessed 25 12 13].

- [16] Unknown, "L6 - Data Capture and Evaluation (ACDA6021)," 2025. [Online]. Available: <https://moodle.uwtsd.ac.uk/mod/resource/view.php?id=592979>. [Accessed 19 12 2025].
- [17] CAT UXO, "Home / Explosive Hazzards/ All Hazards / All UXO," CAT UXO, 2025. [Online]. Available: <https://cat-uxo.com/explosive-hazards/>. [Accessed 05 12 2025].
- [18] M. Sucasca, Test Methods For Explosives, Zagreb: Springer, 1995.
- [19] C. E. Needham, Blast Waves, New Mexico: Springer, 2018.

9. Annex 1 CAD Trial Setup



10. Annex 2 – Munitions Data

Black Data is was Provided by the lecturer [4], Red is Reference to CAT UXO [17].

Munition Name	Charge Mass (kg)	Case Mass (kg)	All Up Mass (kg)	Energetic Material	Average Fragment Area (cm ²)	Average Fragment Mass (kg)	Frag Drag Coefficient	Frag Vi (ms ⁻¹)	Frag Vf @	
									(ms ⁻¹)	Dist (m)
Mk 83 Air Dropped Bomb	225	229	454	Comp B	0.48	0.115	0.82	1950	1911	92
	202	258	460	Tritonal, Minol, H6						
M67 Hand Grenade	0.185	0.213	0.398	Comp B	1	0.002	0.5	-	1674	5
									1424	15
									44	20
	0.18	0.22	0.4	Comp B						
81mm Mortar Unspecified Model	0.760	1.334	4.15	TNT	-	-	1.6	1734	1700	1
									1600	4
									1150	20
									900	32
									357	77
M821 81mm Mortar	0.91	3.15	4.06	Comp B						
RGD 5 Grenade	0.110	0.200	0.310	TNT	1	0.00012-0.00046	0.5	1567	-	-
	0.11	0.210	0.320	TNT						
PG-7VL ¹ RPG	0.730	1.600	1.975	RDX/TNT		0.0001		1831.5		
	0.730	1.73	2.60	HMX						
155mm Shell	1.150	3.105	4.255	Comp B		0.0021		1551		
L15A1 155mm	11.3	32.2	43.5	RDX/TNT						
Pipe Bomb	264	417	681	PE 8		0.00083	1.6	2047	2022	1
									1602	20

¹ Assumption is made that the PG-7L was intended as the PG-7VL only refers to the rocket propulsion system of the PG-7L warhead and rocket combination.

10.1. Initial Munition Eliminations

Mk 83 Air Dropped Bomb – NEQ of >200kg is higher than the range limit for COTEC which is 10kg.

155mm Shell – From a survey conducted on “CAT UXO” the likely fill of a 155mm HE shell is more than 10kg which would likely be greater than the NEQ limit of COTEC. In addition, the blast results of the trial were indicative of a blast of less than 1kg NEQ

10.2. Post Trial Eliminations

PG-7VL RPG – The RPG has a shaped charge warhead that is designed to penetrate with limited fragmentation. In addition, at the rear of the RPG is a rocket which is often left as a single large piece of shrapnel post blast. This was not found on the trial.

M67 Hand Grenade – The M67 Hand grenade contains a case with a preformed geometry on the inside; this leads to a uniform and predictable fragmentation pattern that was not present in the trial.

RGD-5 Hand Grenade – Has a preformed fragmentation liner. Trials results from this munition would yield a uniform and predictable fragmentation pattern that was not present in this trial

81mm Mortar – The quantity of fragmentation recovered was not adequate to indicate the presence of a large mortar as the indicated overall case mass was ~300-500g far below the 1-4kg that would be expected of a mortar round.

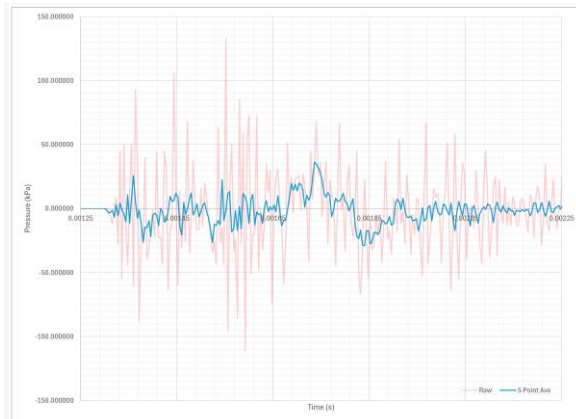
11. Annex 3 – Gauge 1 Smoothing Trials

Figure 16 - G1 5P MA

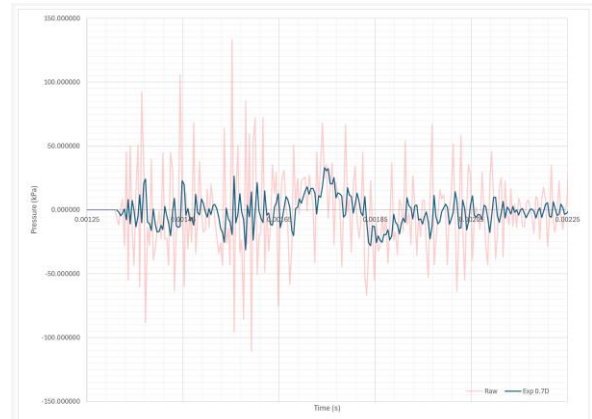


Figure 19 - G1 SE 0.7D

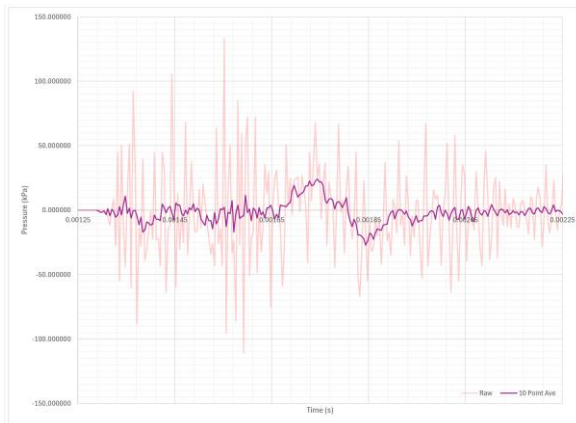


Figure 17 - G1 10P MA

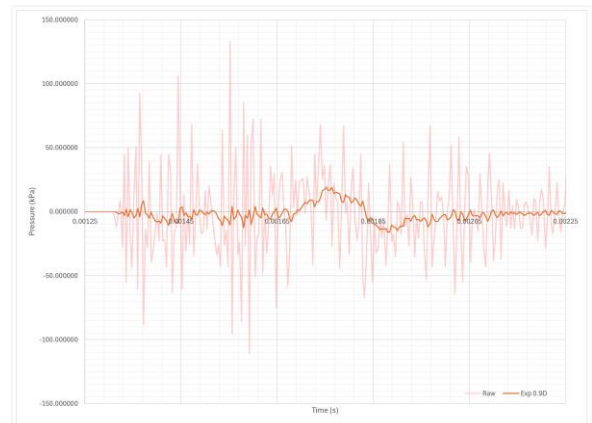


Figure 20 - G1 SE 0.9D

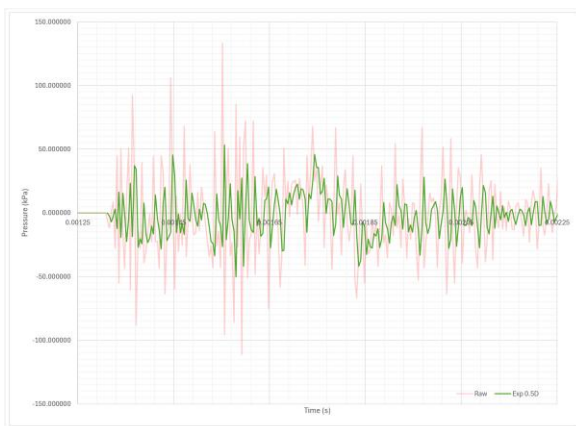


Figure 18 -G1 SE 0.5D

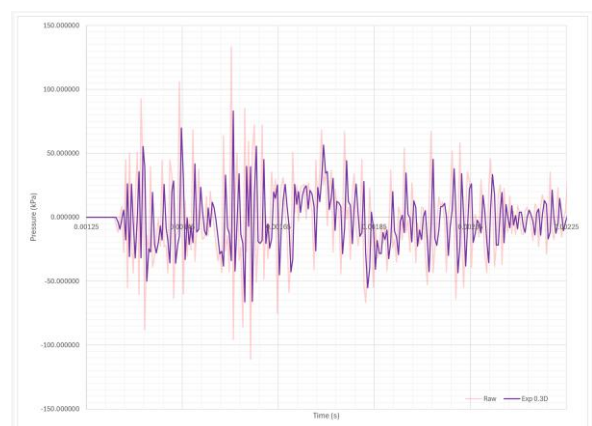


Figure 21 - G1 SE 0.3D

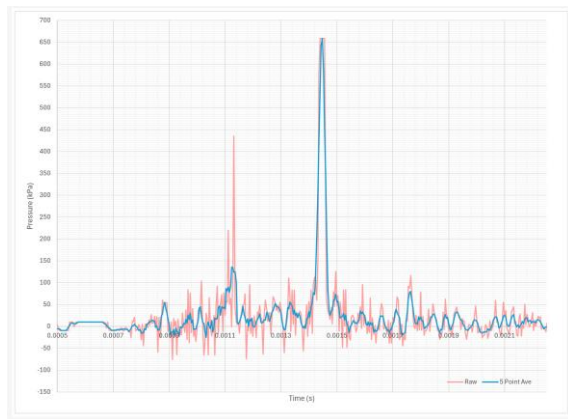
12. Annex 4 Gauge 2 Smoothing Trials

Figure 22 - G2 5P MA

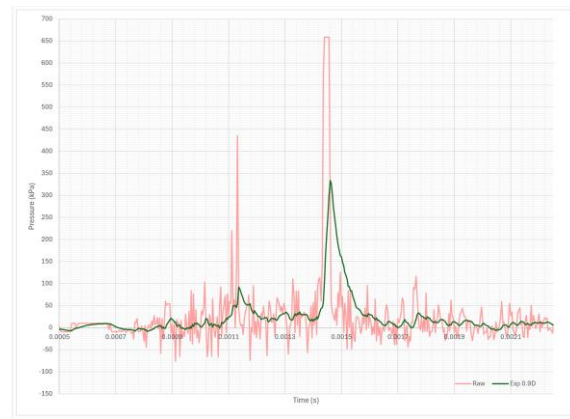


Figure 24 - G2 SE 0.9D

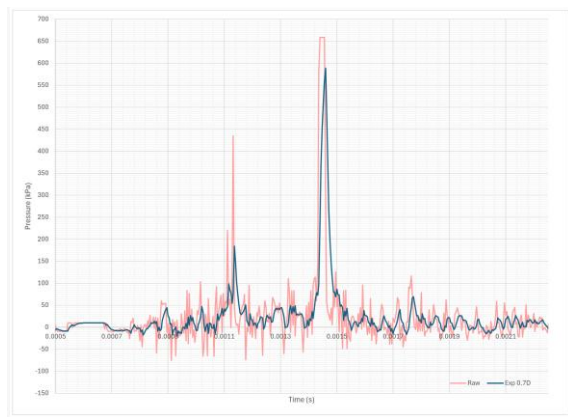


Figure 23 - G2 SE 0.7D

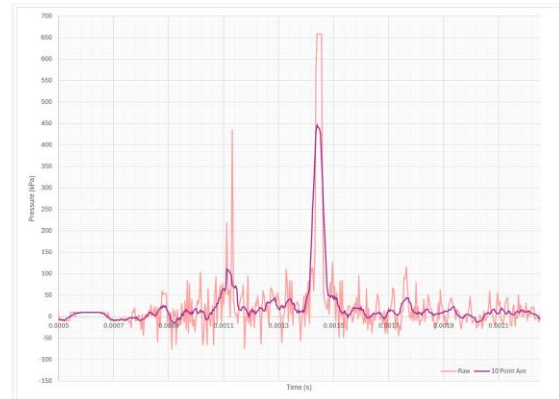


Figure 25 - G2 10P MA