

Data Capture and Analysis - Lab Assignment

by Josh Evans

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Data Capture and Analysis Assignment – Lab Report

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Executive Summary

An energetics trial was conducted at COTEC, UK, to identify an unknown munition based on data collected from blast gauges, velocity foils, strawboard packs, and Fourier Transform Infra-Red (FTIR) chemical analysis.

Blast pressure analysis narrowed the candidates to the RGD-5 and M-67 grenades and a pipe bomb, eliminating others with higher explosive yields. Fragmentation characteristics were examined, with frag shape, size, and mass aligning more closely with the RGD-5 grenade. Pipe bomb data showed distinct differences, leading to its exclusion.

FTIR analysis confirmed TNT as the explosive fill, ruling out the M-67 grenade, which uses a TNT-RDX mix. The trial conclusively identified the RGD-5 grenade as the munition used.

This study highlights the value of comprehensive data collection and analysis in identifying unknown munitions, with broad applications in the energetics sector.

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1. Introduction

This trial investigates the identification of an unknown munition using blast, fragmentation and explosive trace data. A list of seven possible munitions was provided, to which an evidence-based argument was required to discount the incorrect weapon systems and identify the likely munition fired on the trial. The munitions of potential interest are included in Appendix A.

2. Method and Materials

2.1. Variables

Independent:

- Type of munition

Dependent:

- Blast overpressure
- Fragment velocity
- Fragment distribution and mass
- Fourier Transform Infra-Red (FTIR) spectra of forensic samples

Controlled:

- Instrumentation positions
- Blast gauge type
- Velocity foil type
- Strawboard material
- Detonation method

2.2. Chemicals and Equipment

- 1 off unknown munition
- 1 off detonator
- 1 off trigger
- Instrumentation cables
- 12 off make foils
- 3 off mushroom gauge housings
- 3 off integrated electronics piezo-electric (IEPE) pressure gauges
- 1 off frag pole
- 3 off blast gauge stands
- 16 off strawboard packs
- 4 off strawboard stands
- Data recorder
- PerkinElmer FTIR machine

2.3. Procedure

1. Upon arrival, a range safety briefing was provided. The brief outlined the general and specific hazards around the trial site and reviewed the trials plan to ensure that range staff and students were content with their roles and responsibilities.

2. Trials staff were split into several groups, each with their own responsibilities in the trial's setup:
 - a. Team 1: strawboard placement
 - b. Team 2: make foil placement
 - c. Team 3: blast gauge placement
 - d. Team 4: data recorder setup
3. Each team set up the instrumentation that had been provided to them. Upon completion of the arena assembly, a pre-firing brief was provided.
4. All personnel went under hardcover for the firing.
5. The trigger was connected to detonation chords. A countdown to the firing began. The trigger was initiated upon the elapse of the countdown timer.
6. After the firing, COTEC staff checked the pad for any leftover explosives.
7. COTEC staff gave the all-clear so the rest of the trials personnel could leave hardcover.
8. The trials team inspected the trials arena for fragments and other evidence.
9. Students dismantled the capture packs by removing fragments from each panel. Fragments were then placed into a bag and labelled (not in all cases).
10. Upon return to the university, 50% of fragmentation samples were placed in isopropyl alcohol solution and the other 50% in acetone.
11. Fragments were soaked and agitated in the solution for several minutes before being placed in the FTIR.

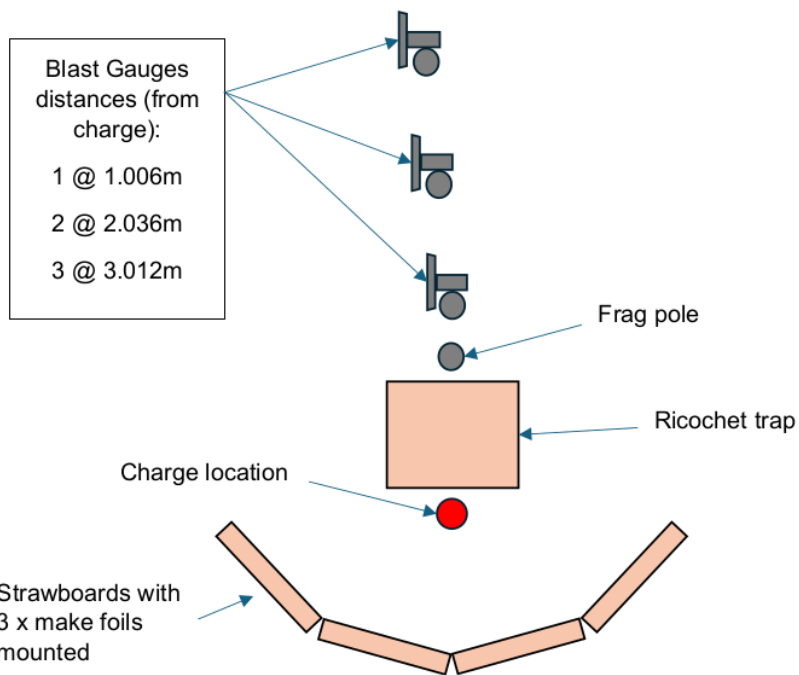


Figure 1 - Trial arena layout

2.4. Observations

- Heavier fragments may still have passed through the capture packs as only the front panels were in contact with adjacent packs rather than all four. Due to the circular shape of the arena, this could not be easily avoided.
- Packaging straps for securing the strawboards were quite thin, but fragments could still impact these. As the straps are of a different density than the strawboards, this could have altered the penetration depth of the fragments if struck.
- Upon return to university it was identified that not all fragment bags had been labelled. Whilst the trial's teams identified which bags were theirs, these could have been mixed up.
- The frag pole before the blast gauges could have interfered with the blast pressure recorded by the gauges.
- A ricochet trap protected blast gauges from frag strikes, but no traps were placed in front of the strawboards. Therefore, additional fragmentation could have been captured in the strawboards, which wouldn't have been fully representative for data capture purposes.

3. Results

3.1. Blast Overpressure Results

The blast overpressure results from the three gauges are presented in Figure 2. The data for this plot was processed to isolate irrelevant measurements captured pre- and post-firing. A 25-point moving average was also applied to the results to remove noise from the raw data. The output provided a clearer plot of pressure, but the pressure magnitude values were reduced.

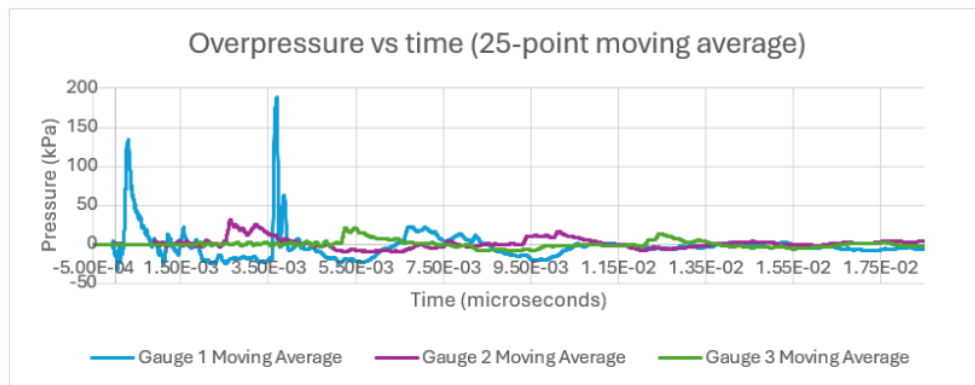


Figure 2 - a pressure-time plot of the firing (using a 25-point moving average)

Original pressure magnitude values recorded by each gauge are as follows:

1. 299.82 kPa at 1.006 metres
2. 50.403 kPa at 2.036 metres
3. 27.139 kPa at 3.012 metres

3.2. Fragmentation Results

Fragmentation results are available below. Table 1 details the collected fragments from the strawboard packs, while Table 2 lists the average frag velocities for each foil. Table 3 amalgamates the foil averages into an average value for each panel.

Table 1 - Details of collected fragments

Parameter	Value
Material	Steel, density 7860 kg/m ³
Number of fragments collected	138
Mass of all fragments collected	154 g
Average mass of fragments	1.116 g
Average fragment area	28.05 mm ²
Average fragment thickness	1.24 mm

Table 2 - Average Fragment Velocity (per foil)

Panel Number	Foil Number	Average velocity (m/s)
1	1	1361.593
	2	1107.531
	3	1278.86
2	1	1292.294
	2	No strike
	3	717.765
3	1	1220.466
	2	1300.014
	3	1180.2
4	1	1232.558
	2	465.856
	3	341.304

Table 3 – Average fragment velocity (per panel)

Panel Number	Average velocity (m/s)
1	1249.328
2	1005.029
3	1233.56
4	679.906

3.3. Fourier Transform Infra-Red (FTIR) Results

Fragments soaked in the isopropyl solution did not yield significant results from the FTIR analysis, while fragments soaked in the acetone solution did provide a reasonable return. The FTIR output can be seen in Figure 3.

PerkinElmer Spectrum IR 10.7.2

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Spectrum

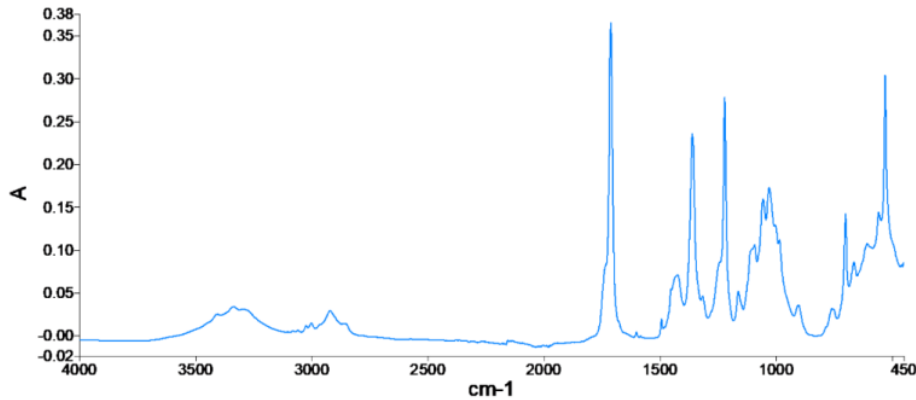


Figure 3 - FTIR analysis of fragments soaked in acetone solution

4. Discussion

4.1. Blast Pressure

The maximum blast pressures experienced by gauges 1, 2, and 3 were 299.82 kPa (discounting the second pressure spike), 50.4 kPa, and 27.14 kPa, respectively. To help identify the munition used on the trial, theoretical blast pressures were calculated for each munition using the listed performance data in Appendix A and a Kingery-Bulmash calculator [1]. Table 4 displays each munition's free-air and surface blast pressures at the distance of each gauge and shows the delta between the theoretical surface blast and the experimental pressures recorded. This table indicates that the RGD-5 grenade has the closest theoretical blast parameters to the trials data. The pipe bomb and M-67 grenade are also relatively close to this data and so cannot be discounted based on this evidence alone.

Table 4 - Calculated blast pressures using Kingery-Bulmash calculator [1]

Munition	Distance (m)	Experimental pressure (kPa)	Pressure (Air blast) (kPa)	Pressure (Surface Blast) (kPa)	Delta from max recorded pressure (kPa)
Mk 83 air dropped munition	1.003	299.82	19611.13	22790.73	22490.9
	2.036	50.403	7988.3	9143.19	9092.79
	3.016	27.139	4160.62	5170.51	5143.37
M-67 grenade	1.003	299.82	277.14	407.46	107.64
	2.036	50.403	61.01	85.73	35.327
	3.016	27.139	29.87	41.16	14.021
RGD-5 grenade	1.003	299.82	175.92	255.66	-44.16
	2.036	50.403	41.66	57.92	7.517
	3.016	27.139	21.53	29.39	2.251

81 mm Mortar AR-M81	1.003	299.82	756.63	1107.85	808.03
	2.036	50.403	152.89	221.23	170.827
	3.016	27.139	67.15	94.62	67.481
RPG PG-7VL	1.003	299.82	804.55	1175.38	875.56
	2.036	50.403	162.34	235.34	184.937
	3.016	27.139	70.90	100.08	72.941
155 mm artillery shell	1.003	299.82	1098.57	1579.99	1280.17
	2.036	50.403	221.68	324.28	273.877
	3.016	27.139	94.38	134.42	107.281
Pipe bomb	1.003	299.82	275.04	404.31	104.49
	2.036	50.403	60.62	85.16	34.757
	3.016	27.139	29.70	40.92	13.781

4.2. Fragmentation

Table 5 below compares the theoretical Gurney fragment velocities possible for each munition against the maximum fragment velocity found for fragment strikes in Bay 1. Bay 1 data was selected as a comparator as other bays experienced lower average velocities. It was determined that the maximum velocity found would be the most appropriate value to compare against. Only three weapons had enough data from the munitions list to determine a theoretical fragment velocity at the foil positions. However, from the initial fragment velocities that were provided, there is a possibility that the 155mm artillery shell could provide similar velocities to those experienced on the trial due to its initial velocity being comparable to the RGD-5 grenade.

Table 5 - Theoretical/experimental fragment velocity comparison

Munition	Initial fragment velocity (m/s)	Average fragment velocity @ foils (theoretical) (m/s)	Maximum average fragment velocity (Bay 1 experimental) (m/s)	Fragment velocity delta (m/s)
Mk 83 air-dropped munition	1950	1949.355	1249.33	700.025
M-67 grenade	2108.868733	2056.059		806.729
RGD-5 grenade	1567	1268.495		19.165
81 mm mortar AR-M81	1700	Not available		Not available
RPG PG-7VL	1831.5	Not available		Not available
155 mm artillery shell	1551	Not available		Not available
Pipe bomb	1990	Not available		Not available

Another consideration for fragmentation is the fragments' size, shape, and mass. The fragments captured from the trial (Figure 4) had an average mass of 1.116 grams and an average area of 28.05 mm² [2]. There were no immediate matches comparing the fragment area to the known details of the shortlisted munitions (Appendix A). However, the pipe bomb was discounted based on evidence from other studies. Da Silva et al. [3] and Oxley et al. [4] both conducted experiments using pipe bombs. It can be seen from their studies that the

pipe bomb fragmentation has a larger average mass of approximately 11-18 grams. Furthermore, the fragmentation size is much larger and contains 'bacon-strip' fragments and clear evidence of end-cap fragments.

From the blast and fragmentation data to this point, it can be determined that the munition used on the trial was either the M-67 or RGD-5 grenade. An analysis of the explosive composition should confirm which was used in the trial.



Figure 4 - Fragmentation collected from strawboards

4.3. FTIR

FTIR is a confirmatory analysis used to determine the makeup of substances. The technique excites the chemical bonds between organic elements, which absorb energy from the IR source. The leftover energy is then emitted, which identifies the present bonds. In the case of this experiment, the trace explosive was captured in an acetone solution. It was, therefore, essential to determine the spectra of acetone to discount it from the results. Figure 5 displays a library spectra for acetone. Compared with the experimental spectra (Figure 6), there is a similar set of peaks between 1750 cm^{-1} and 1000 cm^{-1} wavelengths.

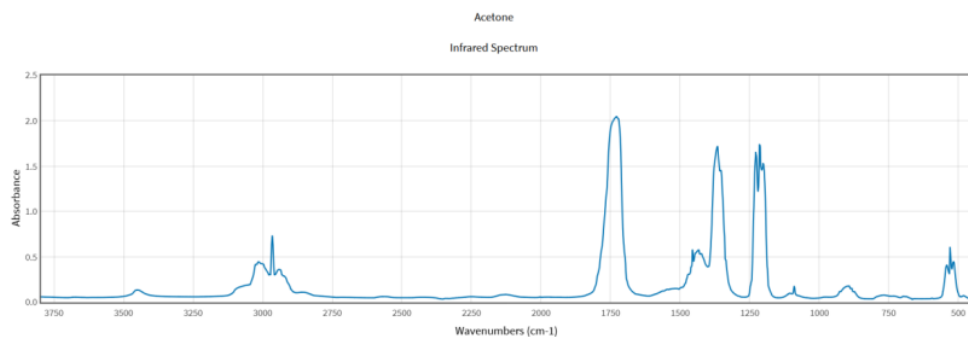


Figure 5 - Acetone FTIR spectra

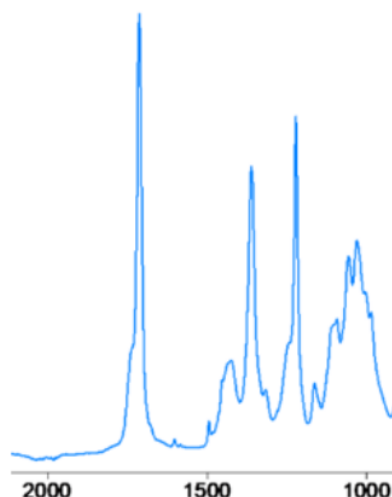


Figure 6 - Sample of fragment swab FTIR spectra

The general and fingerprint peaks were approximated using Image-J to measure the wavelengths of each peak from the experimental spectra. An IR spectroscopy absorption table [5] was then used to identify the present functional groups.

Table 6 - Key peaks and functional groups of fragment swab FTIR spectra

Key general peaks / functional groups	Key fingerprint peaks/functional groups
3411.97 – O-H stretching	1225.35 – C-N stretching, amine
3334.51 – N-H stretching	1169.01 – C-O stretching
3288.73 – N-H stretching	1098.59 – C-O stretching
3080.96 – C-H stretching (aromatic)	1063.38 – C-O stretching
3063.38 – C-H stretching (aromatic)	1035.21 – C-O stretching
3028.17 – C-H stretching	1007.04 – C-O stretching or C-H bending
3003.57 – C-H stretching	989.44 – C-H bending
2926.06 – C-H stretching	908.45 – C-H bending
2855.63 – C-H stretching	760.56 – C-H bending
2147.89 – C $\equiv$ N (nitrile)	707.75 – C=C bending
1718.31 – C=O stretching	665.49 – aromatic C-H out of plane bending
1605.63 – C=C stretching	612.68 – C-H bending or deformation
1500.00 – N=O stretching	563.38 - ?
1457.75 – C-H bending	528.17 - ?
1429.58 – C-H bending	
1362.68 – C-H bending	
1320.42 – C-N bending	

The first explosive composition looked at to compare against the captured functional groups was TNT. The key functional groups present in TNT (as can be seen in Figure 7) are:

- Aromatic C-H stretching (which comes from the benzene ring)
- C=C stretching (from the aromatic ring)

- N-O stretching (from the nitro groups)
- C-H bending (from the methyl group attached to the benzene ring)

All of these functional groups are present in Table 6, which means that it is likely that TNT is present from the forensic swabs taken from the fragments.

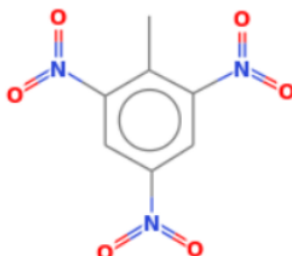


Figure 7 - Skeletal formula for TNT

The next explosive composition looked at was cyclotrimethylene trinitramine (RDX). The key functional groups present in RDX (as seen in Figure 8) are:

- N-N stretching (amine groups)
- N-O stretching (nitro groups)
- C-H stretching (from the cyclic methylene group)
- C-N stretching (amines or nitroamines)

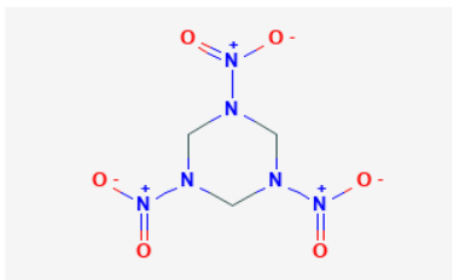


Figure 8 - Skeletal formula for RDX

From the FTIR analysis, no N-N functional groups were identified. From the sample captured, it can be determined that no RDX was present in the explosive composition of the munition.

4.4. Munition Identification

Based off of an analysis of the blast, fragmentation and FTIR data captured, the evidence suggests that the munition used on the trial was the RGD-5 grenade (Figure 9). The blast pressures experienced by the blast gauges had the closest match to the RGD-5, whilst the fragmentation also seemed to be conducive with a thin-walled munition. Finally, the FTIR analysis of the explosive traces found there to be a presence of TNT, but did not find RDX. This result discounted the M-67 grenade, which has a Comp-B fill containing RDX.



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Figure 9 - Sectioned view of RGD-5 grenade [6]

5. Conclusion

An energetics trial was conducted at COTEC, near Salisbury, UK. The identity of the munition was not known before the firing. Using data collected from blast gauges, velocity foils, strawboard packs and Fourier Transform Infra-Red (FTIR) chemical analysis, the identity of the munition could be determined.

Blast pressures were the first dataset analysed. These results required substantial processing to focus on the blast event. Once processed, it could be determined that the blast magnitudes experienced by the three blast gauges were most comparable to the RGD-5 grenade. This data alone was not sufficient to discount the M-67 grenade or the pipe bomb but was adequate to discount all other shortlisted munitions which had significantly larger net explosive quantities.

The fragmentation was then analysed. The velocities were captured and compared against the theoretical velocities of the shortlisted munitions. However, data on the munitions shortlist was limited and did not provide conclusive evidence. It was noted that the RGD-5 grenade was the closest match to those munitions, which could be compared against experimental data.

In addition to velocity, frag shape, size, and mass were also assessed. The frag size was slightly larger than anticipated compared to the listed performance specifications of the RGD-5 and M-67 grenade. However, relevant studies using pipe bomb munitions demonstrated very different frag sizes, shapes, and masses. The pipe bomb was discounted as a result of this assessment.

The final analysis was an investigation into the FTIR spectra of recovered fragment samples. The spectra showed evidence of all the key function groups of trinitrotoluene (TNT).

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However, they did not show proof of nitrogen-nitrogen bonds, which would be present if RDX had also been included in the explosive fill. The omission of RDX meant that the RGD-5 grenade was identified as the munition used on the trial, as the M-67 grenade was listed as containing a Comp-B fill – TNT and RDX mix.

This trial demonstrated the importance of data capture and analysis by identifying an unknown munition. The data capture methods used are widely implemented across the energetics sector, from warhead trials to forensic analysis of battlefield investigations.

References

- [1] P. Shelley, *Kinney Graham Overpressure Calculator*, Peter Shelley, 2006.
- [2] G. Collet, *Data Capture Fragment Details and Explosive Trace Data*, Swansea: UWTSO, 2024.
- [3] L. A. da Silva, S. Johnson, R. Critchley, J. Clements, K. Norris and C. Stennett, "Experimental fragmentation of pipe bombs with varying case thickness," *Forensic Science International*, vol. 306, 2019.
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- [5] LibreTexts, "Infrared Spectroscopy Absorption Table," LibreTexts, 2024. [Online]. Available: https://chem.libretexts.org/Ancillary_Materials/Reference/Reference_Tables/Spectroscopic_Reference_Tables/Infrared_Spectroscopy_Absorption_Table. [Accessed 10 December 2024].
- [6] GICHD, "Explosive Ordnance Guide for Ukraine," GICHD, Ukraine, 2022.

Appendix A – Munition Data

Mk 83 air dropped munition

- Charge mass – 225 kg
- Mass of case – 229 kg
- AUW – 454 kg
- Explosive – Comp B
- Average fragment area - 0.48 cm²
- Average fragment mass – 0.115 kg
- Frag drag coefficient – 0.82
- Density of air 1.23 kg m⁻³
- Frag V_i = 1950 ms⁻¹
- Frag V_f = 1911 ms⁻¹ at 92 m

M-67 grenade

- Charge mass – 185 g
- Mass of case – 213 g
- AUW – 398 g
- Explosive – Comp B
- Average frag area – 1.0 cm²
- Average frag mass – 2g
- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m⁻³
- Frag V @ 5m -1674 ms⁻¹
- Frag V @ 15m – 1424 ms⁻¹
- Frag V @ 230 m – 44 ms⁻¹

RGD-5 grenade

- Charge mass – 110 g
- Mass of case – 200 g
- AUW – 310 g
- Explosive – TNT
- Average frag area – 1.0 cm²
- Average frag mass – 0.12 - 0.46g
- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m⁻³
- Frag V_i = 1567 ms⁻¹
- Number of fragments 350

81 mm Mortar AR-M81

- Charge mass – 0.76 kg
- Mass of case – 1.334 kg
- AUW – 4.15 kg
- Explosive – TNT
- Frag drag coefficient – 1.6
- Density of air 1.23 kg m⁻³
- Frag V_i = 1734 ms⁻¹
- Frag V @ 1m – 1700 ms⁻¹

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- Frag V @ 4m – 1600 ms-1
- Frag V @ 20m – 1150 ms-1
- Frag V @ 32m – 900 ms-1
- Frag V @ 77m – 357 ms-1

RPG PG-7VL

- Charge mass – 730 g
- Mass of case – 1600 g (including rocket motor)
- AUW – 1975 g
- Explosive – RDX/TNT - 95% HMX 5% wax
- Average frag mass – 0.1 g
- Density of air – 1.29 kg m-3
- Frag Vi -1831.5 ms-1

155 mm

- Charge mass – 1150 g
- Mass of case – 3105 g
- AUW – 4255 g
- Explosive – Comp B
- Average frag mass – 2.1g
- Density of air – 1.29 kg m-3
- Frag Vi -1551 ms-1

Pipe Bomb

- Charge mass – 200 g
- Mass of case – 200 g
- AUW – 400 g
- Explosive – TNT
- Average frag mass – 0.23g
- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m-3
- Frag Vi = 1990 ms-

Data Capture and Analysis - Lab Assignment

GRADEMARK REPORT

FINAL GRADE

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GENERAL COMMENTS

Hi Josh,

Overall,

In detail:

A very well laid out laboratory report, with clear executive summary. Try not to use 'frag' in a report, full name please.

For some reason, Turnitin always raises an Error! Bookmark not defined message. In this case Appendix C, so no penalty.

Try using List of Figures and List of Tables in the headings. Table of Tables always sounds strange.

Try using the past tense - the trial investigated. This is a report of something that has happened.

For your Method and Materials, there is no problem with the structure but 2.1 and 2.2 could have been placed in a table and worked into the description. This may have saved word count and made the report more pithy.

A very good description of the method undertaken, with excellent use of diagrams (Figure 1).

Excellent observations on the limitations of the trial relating to fragment collection. For blast, the height of the munition would have been useful to know since the angle of incidence and reflection could have been calculated. As such, we do not know the reflection coefficient, which would have explained the large reflected overpressure.

Cannot fault the way you have laid out your results. Well done. Do you know why isopropyl alcohol did not work? It was all about looking at the solubilities of the potential candidate explosives. IPA is no good for TNT.

Great discussion on blast overpressure, but please note my comments on the reflected overpressure, which could have swamped all the results. I liked the colour coding and explanation for Table 4. It is looking like the RGD-5 at this point.

For fragmentation we can determine that although the velocities for the 155 and RGD-5 were similar, the peak overpressure reading immediately discounts the 155 mm. It was nice to see that you do not use the range NEQ as the discounting factor.

Yes, for the FTIR you looked at chemical fingerprints in Table 6, which clearly identify TNT as the culprit. There is some obfuscation from the acetone, but the absorption peaks are evident. The icing on the cake would have been to label the peaks with the functional groups and lay TNT beside it,

4.4 Munition Identification. I did not like based off of. Based upon? Or, "The blast, fragmentation and FTIR data captured on this trial suggests that....."

I cannot argue the points of your conclusion. Well done on a positive identification from a very limited trial.

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