

Analysis of Potential Munitions Used in the Attack on Mariupol Theatre

by Ryan Garry

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Figure 1: Photo of Mariupol Theatre by Pavel Klimov/Reuters

Analysis of Potential Munitions Used in the Attack on Mariupol Theatre

An Explosive Engineering Assessment of Visual Evidence

Ryan Garry (2024366)
Scientific Principles of OME
Design: ACDB6008

Background:

Mariupol Theatre Civilian use

By March 2022, the besieged area of Mariupol, in the South-East Region of Donetsk in Ukraine, had suffered widespread destruction as a result of intense fighting and Russian attacks during the Ukraine war. On the 16th March the Donetsk Academic Regional Drama Theatre, or Mariupol Theatre, was destroyed by one or more large explosions. The building had been in use at this time as a humanitarian shelter for civilians, as well as a hub for medicine, food, and water, and as a gathering point for civilians hoping to be evacuated via humanitarian corridors. The word “Children” had been painted in large letters, visible from the air, on the paved ground outside, to discourage attacks on the structure. Due to the success of the evacuation of civilians from the area, as well as growing unease on the part of the local population on the proximity and increase in Russian bombing leading up to the attack, the theatre did not contain as many civilians as it had previously, and the number of casualties created during the attack was therefore likely to be relatively low, however, witness evidence from the field kitchen within the theatre has confirmed that they were preparing food for up to 800 people on the day of the attack. Rescue attempts of survivors in the following days were severely hindered by further attacks by Russian forces, however in the days following the attack some 130 survivors were rescued, and witnesses report up to 200 people escaping the building via rear entrances following the attack. [1]

Russian Authorities subsequently denied responsibility for the attack, and still maintain that the theatre was not “deliberately targeted” by their forces. The Russian forces initially suggested that the theatre was destroyed from within as an act of sabotage by Ukrainian forces. Witness testimony collected by Amnesty International refutes this, suggesting that a Russian attack is more likely.

Independent access to the site for rescue or any collection of evidence following the attack was blocked by Russian Authorities who subsequently occupied the area. In late 2022, following reports of Russian forces clearing the area and removing bodies from the rubble, the occupying forces surrounded the site with scaffolding and a sight screen and demolished the remains of the theatre. As such, any analysis possible can only be carried out on photographic and verbal evidence provided by witnesses and satellite imagery following the attack.

Building Structure

Mariupol Theatre was constructed in 1960 to a standardised Soviet architectural design, to which multiple other theatres were constructed across Ukraine at the time. [2] Its construction comprises masonry walls with steel-frame roof supports and frangible sheet metal roof structure, to enable the large open areas used for the stage and viewing areas. Floors within the building constructed largely of poured reinforced concrete.

The building is approximately East facing, and situated within a largely open area in the Tsentralnyi District of Mariupol. An open paved area at the front serves as a car-park, and the theatre is surrounded on all other sides by trees and green space. The area is bounded by a roadway at a distance of approximately 100m from the theatre at it's closest point, as seen in

figure 4 below, taken 10 months prior to the attack. The building is therefore sufficiently isolated from neighbouring buildings to suggest that any munitions impacting the theatre are targeted to do so, whether they be unguided or precision weapons.



Figure 2: Mariupol Theatre in May 2021 [2]

The building contains a forum at the entrance supported by pillars, and numerous other small rooms to the rear of a central performance area. The building comprises 3 floors above ground level, with the stalls stepping from basement to ground level. The ground, first, second, and third floors at the front of the building contain the main viewing areas and galleries, with a fourth floor providing a loft storage area above the main stage. All floors contain numerous rooms ranging in size to the rear of the performance area. The basement comprises a front area used as a bomb shelter, as well as below-stage areas to the rear of the building. The lower stalls of the concert hall begin at basement level and are stepped up to the ground level gallery at the rear of the viewing area.

The main concert hall of the theatre measures approximately 36m from the back of the stage to the back of the stalls, with the stage itself taking up approximately 20m of this. The approximately 16m diameter circular audience area is surrounded by galleries on the 2nd and third floor. The stage area is 22m wide with 7m wings to the sides, and larger rooms to the rear that at the time of the attack contained a field kitchen and medical centre. From original plans of the building and photos of the aftermath to the attack, it would appear that interior walls are of heavy masonry construction.

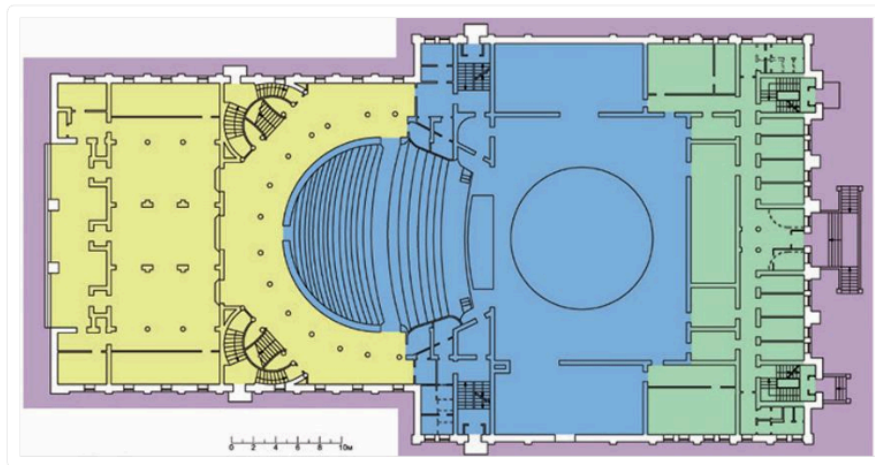


Figure 3: Scaled CAD Drawing of the ground floor of the theatre and stalls [1]

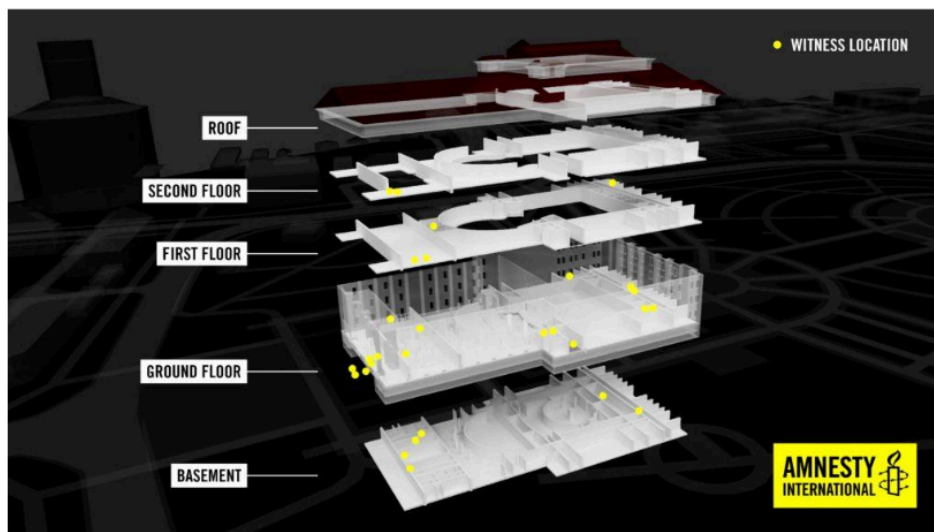


Figure 4: 3D model of Mariupol Theatre Produced by Amnesty International showing location of witnesses within the structure at the time of attack [3]

The Explosion

Between 10:00 and 10:20 EET, the theatre suffered extensive damage as a result of one, or possibly multiple near-simultaneous explosions. Witnesses describe the roof being blown up to 30m into the air before falling back in on the theatre. From photographs taken of the damage

caused, The blast seems to have centred on the stage of the concert hall, largely destroying the internal walls and levelling exterior walls to either side. The debris field from the blast extends some distance from the building with elements of the displaced structure visible almost to the distance of the road on the southern-side of the building. Figure 5 below shows an aerial view of the damage following the attack.



Figure 5: Aerial view of damage caused in the attack from front of building



Figure 6: Aerial view of damage to wings of concert hall taken from Northerly direction



Figure 7: Photo showing damage to structure above audience viewing area



Figure 8: View from opposite side of audience viewing area



Figure 9: Close up of damage to audience area

Witness accounts collected by Amnesty international [1] seem to indicate that only one blast was experienced, although one witness describes seeing a plane launch 2 missiles toward the area of the theatre immediately prior to the explosion. Multiple, near-simultaneous explosions in sufficient proximity would most likely be indiscernible to witnesses nearby or inside the building from one singular strike.

Overpressure from an explosion is recorded in terms of peak value (incident overpressure) and its duration (impulse). Two explosives detonating in close proximity would not increase the level of peak overpressure, but would extend the overall impulse.

The explosion(s) completely destroyed the roof from the concert hall to the rear of the building, as well as exterior walls on either side of the stage area. Exterior walls and stairwells on the corners on the rear of the building remained intact to a large extent but suffered extensive damage. Photos of the building following the damage caused by the explosion(s) show burn and blast damage throughout the building to a greater or lesser extent as discussed further below.

Analysis

Analysis of Photographic and Witness Evidence

Photos show that damage caused by the explosion is centred on the stage of the concert hall, with roughly equivalent damage to the structure of the building on either side. There is limited evidence of damage from small fragmentation to parts of the frangible roof structure and interior walls of the building, which indicates the use of a munition designed to produce a blast effect rather than a fragmentation effect, and as such it is likely that a relatively thin-cased munition was employed for its blast effect rather than a heavy fragmenting munition.

From the spread of damage visible in figure 6, it seems likely that the damage was caused by a likely cylindrical charge detonating in roughly the centre of the performing space, not far from stage level. Photos illustrating the damage to the roof show that the roof forward of the audience area remained roughly intact, albeit with significant damage. More damage can be seen to the Southerly side of the building, and it is likely that overpressures experienced, either incidental or reflective, were somewhat higher than on the Northern side.

Calculations

In order to compare the scale of damage caused to the potential munitions that may have caused it, The size of the charge can be calculated by the established level of overpressure required to destroy a masonry structure such as the theatre. (GICHD) estimate the pressure required to severely damage or demolish a masonry structure as being 69 kPa or approximately 10 psi. [5]

Explosive effects scale over distance rapidly, and scaled distance plots are commonly used in explosives engineering practice to aid determination of charge size [6]. Scaled distance is a measure combining both distance and bare charge mass measured in $\text{m/kg}^{1/3}$. Plots of this phenomenon produced by Kingery and Bulmarsh for various explosive types by experimentation are recognised by the engineering profession as the standard when determining the size of charge required to deliver overpressures at specific scaled distances.

The graph shown below in Figure 10 confirms that in order for a TNT equivalent charge to provide an overpressure of 10 psi, a scaled distance of between approximately $3.3 \text{ m/kg}^{1/3}$ and $3.9 \text{ m/kg}^{1/3}$ is required for spherical (air-burst) and Hemispherical (surface-burst) respectively. As the munition employed in the Mariupol attack was most likely detonated in free air above the stage, plots for spherical bursts are most appropriate here.

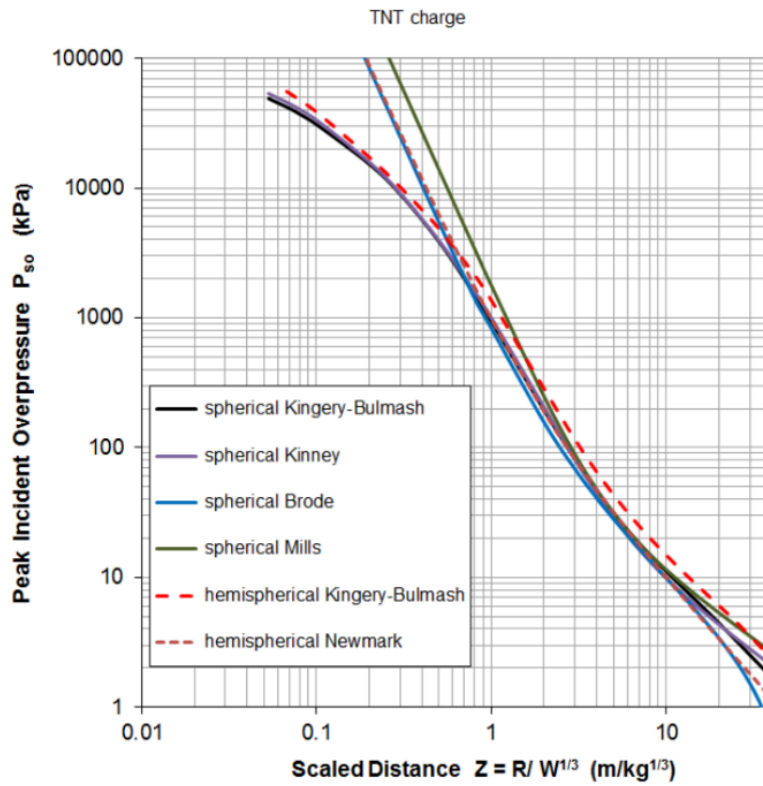


Figure 10: Kingery-Bulmarsh Curve showing Peak Overpressure against Scaled distance for Air-burst and Surface bursts

The plot below in Figure 11, produced by the same method as for Figure 10 above, provides more detailed information on spherical TNT bursts. The dotted red line shows the values relevant to this report on both axes:

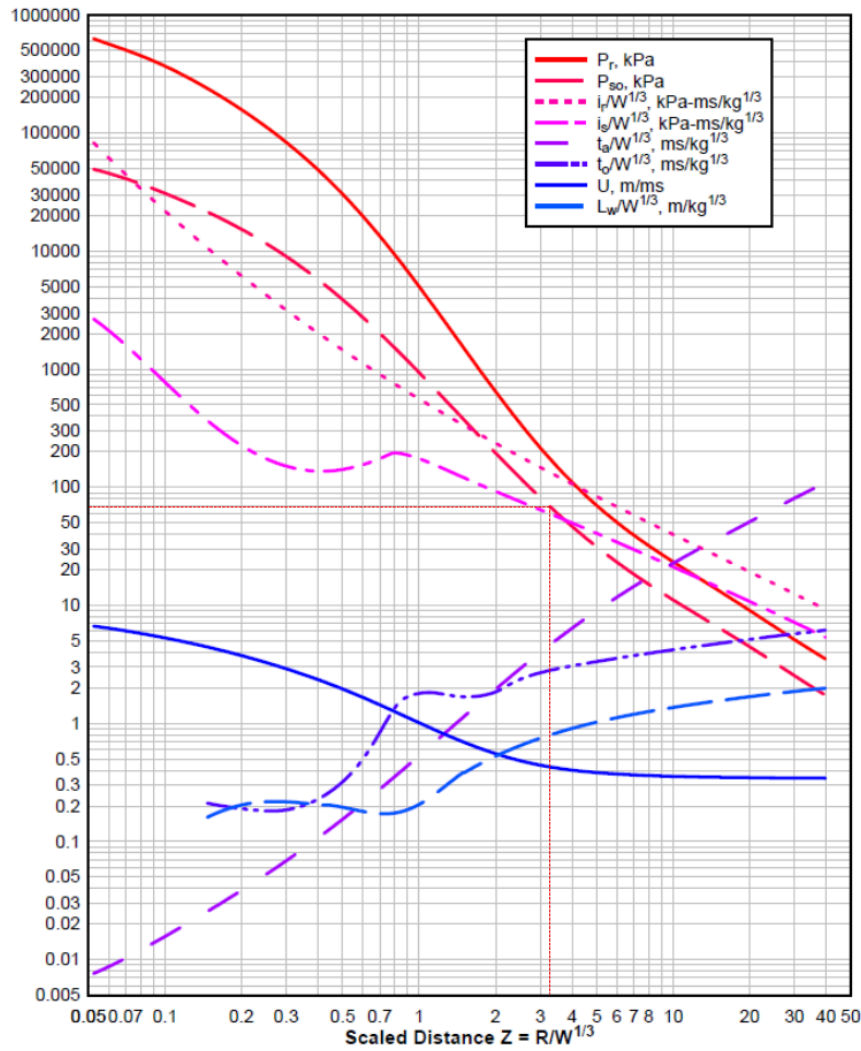


Figure 11: Kingery-Bulmarsh Curve for spherical bursts (TNT)

Hopkinson scaling laws detail this reduction in effect over distance, which as can be seen from the equation below, reduces in an inverse cube relationship with distance [6]. In Hopkinson's equation to calculate scaled distance (Z), R represents the radius of the burst, or distance to the structure, and W_b the bare charge mass.

$$Z = \frac{R}{\sqrt[3]{W_b}}$$

Taking the assumption that the charge detonated in the centre of the stage, the distance to the outer walls of the stage area would be approximately 18m. Rearranging this formula and calculating based on the information provided in the above plots, a bare charge mass of 148 kg of TNT would be required to deliver the required pressure at 18m.

$$W_b = \left(\frac{R}{Z}\right)^3$$

Pressures above 138 kPa are sufficient to destroy even heavily built concrete structures and it is unlikely that peak overpressures approaching this were generated. The same method can be used to show the NEQ required to achieve 138 kPa at this distance to be approximately 300 kg.

Explosive effects are also highly dependent on the mass and thickness of the casing employed within the weapon, due to the energy required to break up and distribute the mass of the munition casing. This means that the thicker the casing, the less energy that will contribute to overpressure, and as such, warheads designed for a blast effect tend to have a thinner casing.

The equation below can be used to provide further information on the particular warhead used to generate the level of overpressure by suggesting the actual weight of the charge employed. As per the following equation where W_b again equals the mass of the bare charge (in N.E.Q. of pressure of TNT) and c the actual weight of the charge:

$$W_b = 1.19 \left(\frac{1 + M_r(1 - M_c)}{1 + M_r} \right) c$$

Here, M_r represents the ratio of the mass of the casing to the mass of charge, and M_c a constant dependent on this ratio. In blast munitions, this ratio is likely to be less than 1, and as such, M_c is taken as equalling m/c , changing the equation to that below:

$$W_b = 1.19 \left(\frac{1 + M_r \left(1 - \frac{m}{c} \right)}{1 + M_r} \right) c$$

TNT Equivalence

For the purposes of calculation, TNT equivalence is employed as a normalised value of explosive characteristics. This is effectively a ratio of the performance of a specific explosive material against that of TNT, and is listed as a multiplier to apply in order to determine the mass of any other explosive required to produce the same effect. This is applied in terms of the materials ability to generate peak pressure and the overall impulse pressure. It is employed here in terms of its peak overpressure and will be used to compare the potential munitions known to employ compositions other than TNT.

Name of explosive	TNT equivalent mass factor	
	Peak pressure	Impulse
TNT	1.00	1.00
C3	1.08	1.01
C4	1.37	1.19
CYCLOTOL	1.14	1.09
OCTOL 75/25	1.06	1.06
TETRYL	1.07	1.05
HMX	1.02	1.03
AMATOL	0.99	0.98
RDX	1.14	1.09
PETN	1.27	1.11

Figure 12: TNT Equivalent quantity (Pressure and Impulse) for various explosives [6]

Discussion of potential munitions

In order to provide the destruction seen in photographs and from calculations above, certain criteria can be applied to give a clearer idea of the potential munitions under consideration. The weapon or weapons must be capable of delivering a peak overpressure of 68.9 kPa at a scaled distance of $3.4 \text{ m/kg}^{-1/3}$. In order to accomplish this, each weapon must feature a blast charge (and not a fragmenting warhead) with a minimum bare charge mass of 148 N.E.Q TNT. It is extremely likely therefore that either an air-delivered munition was employed from the bare charge mass alone, as transportation and deployment of a charge of this size without alerting people within the building would have otherwise been impossible.

Any fragmenting weapons can be excluded from analysis of photographic evidence. Likewise the use of thermobaric weapons is not supported by witness testimony from those within the building and weapons of this nature can also be excluded. A cruise missile can also be considered unlikely, from evidence produced by Amnesty International, due to a lack of recorded detection of munitions of this kind as would usually be the case. It is likely that the munition was of Russian origin, however air-dropped weapons from either side will be included for consideration. Given the isolated location of the buildings, its use and the forces fighting in the area at the time, it seems highly likely that the attack was targeted and deliberate.

Given the standard ratio of length to height for a cylindrical blast warhead (>2) and the density of TNT and other explosives it can be estimated that a cylindrical warhead will likely measure between 750-900mm in length and between 350-400mm in diameter and as such represents a sizeable munition. As per the above, it is likely to be an air dropped munition.

GICHD have produced a report on weapons known to be in use in the area during the Ukraine war and that would have been available to the forces fighting at the time, and this list will form the basis for our consideration. From the criteria listed above, the list of potential munitions drops to 2. These are the Russian FAB-500 unguided air-dropped bomb, and the Ukrainian employed GBU-38. These are tabled below.

Descriptor	Explosive Fill	Explosive Weight (kg)	AUR Weight (kg)	Dimensions (m)	Country of Origin
FAB-500 M62	TNT	209	497	2.47*0.4	Russian
GBU-38 (Mk83)	TNT/Aluminium	202	453	1.9*0.36	American

Table 1: Potential munitions

Conclusions

As per the analysis above, it is possible to determine the following with a reasonable amount of certainty:

- An air-dropped weapon, or pair of, was used in the attack on Mariupol Theatre. This penetrated the roof above the performance area and detonated somewhere above the stage floor.
- The weapon featured a thin cased, cylindrical blast warhead with a minimum N.E.Q. of 148 kg and most likely not above 250 kg given the damage caused.
- Considering those weapons listed by GICHD as being in use in the area, the weapon used was most likely a FAB-500 unguided bomb, or pair of, although the use of an American-made GBU-38 cannot be ruled out by calculations based on pressure requirements alone.

References

- [1] Amnesty International, ““ CHILDREN”: THE ATTACK ON THE DONETSK REGIONAL ACADEMIC DRAMA THEATRE IN MARIUPOL, UKRAINE,” Amnesty International, London, 2022.
- [2] Centre for Spatial Technologies (CST), “Mariupol Drama Theatre Spatial Archive,” 2024. [Online]. Available: <https://theater.spatialtech.info/en>.
- [3] C. B.-S. 4. Oleksandr Malyon - Own work, “Wikipedia,” Wikipedia, 24 April 2024. [Online]. Available: <https://commons.wikimedia.org/w/index.php?curid=109758547>. [Accessed 24 03 2026].
- [4] T. J. & S. D. & S. Cooper, “Case Study: Modelling the Mariupol Drama Theatre Attack,” Amnesty International , London, 2023.

[5] The Geneva International Centre for Humanitarian Demining (GICHD), "Explosive Weapon Effects," GICHD, Geneva, 2017.

[6] JRC Technical Reports, "Calculation of Blast Loads for Application to Structural Components," Joint Research Centre, European Commission, Ispra, Italy, 2013.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Hi Ryan,

40/100

This was a LS I'm afraid, which is now capped at 40%. However, you score would have been only marginally higher - 49%.

What you submitted was of reasonable quality and demonstrated that you have a good grasp of explosive theory. Despite the differentiated deadline, which you exceeded, the document felt rushed and last minute. You did not conduct a lot of additional reading as far as I can see, and were very limited in referencing and explanation. Your scores against the rubric are as follows:

Engagement with literature skills 6/15.

Engagement with a limited range of mostly relevant and credible sources. Some omissions and minor errors.

Knowledge and Understanding 13/25. Knowledge is reasonably detailed, accurate with a good systematic understanding of the field of study and to some extent, current research and scholarship.

Cognitive and Intellectual Skills 10/20. Some critical thinking, analysis, synthesis and evaluation. Can analyse new and/or abstract concepts and data without guidance. An emerging awareness of different stances and ability to use evidence (that may be incomplete) to support the argument. Mostly valid arguments and logical judgements. Some tendency to assert/state opinion rather than argue on the basis of reason and evidence.

Practical Application 10/20. A good and appropriate application of standard methods, materials, tools and/or techniques. Clear appreciation of the context of the application. Mainly consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose mostly appropriate solutions in complex and unpredictable contexts.

Transferrable Skills 10/20. Can communicate effectively in a suitable format, but may have minor errors. Mostly coherent, organised work, in a suitable structure and is for the most part clearly expressed. Demonstrates the skills required in graduate employment, with some areas of strength and some of minor weakness.

In detail:

1. Good background, with just sufficient information to describe the circumstances.

2. I liked figures 2 and 5, which supported the humanitarian and isolation aspects of the structure.

3. Damage photography is of sufficient strength to allow you to determine the causality.

4. Spot on for thin-cased munition designed for blast. You topped this off with discussion on M/C ratios and what you would realistically expect. You would, however, need to support your analysis argument for shape of warhead and location of detonation since it is largely unreferenced. Also, are there any references to support why the witness testimonies vary during traumatic events. Should we worry that it was 86% one detonation, 14% two detonations?

5. Good explanation of scaled distance based on 10 PSI. Figure 11 was very powerful in determining Z.

Where is the information relating to where R comes from? It would have been useful to include a diagram that has the distances marked on it. You say all this on page 3 but do not reference it.

6. Where do you get 138 kPa from?

7. Your discussion of the list of munitions would have been better served in a more descriptive table, which included the KAB series as well. There is a lot of literature on their use in Ukraine. You have not discussed these at all. You mention the GICHD report on weapon use, but no reference. And, is this an accurate document?

8. What about TGAF-5 as a filling: RDX/TNT/Al, with a TNTe of around 1.3? Does this change your view?

9. There is no discussion on CEP, which was important in this scenario to determine the culprit. What id the CEP of an unguided FAB-500 vs a KAB-500S-E?

10. Referencing extremely limited and not sufficient for a L6 submission. Shows only limited independent study.

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