

# **Primary Fragment Characterization Tools: A DDESB Technical Paper 16 Update**

Susan Hamilton, PE; US Army Engineering and Support Center; Huntsville, AL

## **Keywords**

Primary Fragment, Software, Method, Siting, Tools, Software

## **Abstract**

DDESB Technical Paper 16: Methodologies for Calculating Primary Fragment Characteristics details an analytical method for the determination of primary fragment characteristics used for explosives safety site planning, test prediction, protective construction, and other uses. Included within the technical paper package are multiple tools which are intended to implement the TP 16 methods in a user-friendly approach. These tools include: the Buried Explosion Module (BEM) the Generic Equation Calculator (GEQ), the Barricade Angle Calculator (BAC), the Jacobs Roslund Calculator (JRC), the Modified Pseudo Trajectory Normal Calculator (MPTNC), and the Stacked Munition Article Calculator (SMAC). Each of these tools will be briefly described and potential uses listed.

## **Introduction and Background**

DDESB Technical Paper 16<sup>Ref 1</sup>: Methodologies for Calculating Primary Fragment Characteristics details an analytical method for the determination of primary fragment characteristics used for explosives safety site planning, test prediction, protective construction, and other uses. While many of the methods used in TP 16 have been described in other documents, TP 16 strives to compile the most up-to-date and best available methodologies related to analytical determination of primary fragment characteristics. This is accomplished by compiling methodologies from multiple sources into a single document with detailed explanations and examples illustrating the use of the methods.

The analysis methods discussed within TP 16 are detailed and extensive, hand calculations have historically been tedious and prone to human error. In order to speed calculation time and ensure correct repeatable results, stand-alone software packages were introduced as a part of TP 16 revision 3<sup>Ref 2</sup>. These tools are included as attachments within the Adobe PDF download of the technical paper.

The six stand-alone software packages associated with this document (TP-16) are:

- Generic Equation Calculator (GEQ)
- Buried Explosion Module (BEM)
- Barricade Angle Calculator (BAC)
- Modified Pseudo Trajectory Normal Calculator (MPTNC)
- Jacobs-Roslund Calculator (JRC)
- Stacked Munition Article Calculator (SMAC)

Each of these software packages is written as an Excel Spreadsheet template. In order to run any of the packages, Excel must already be installed on the computer. When the template is opened, Excel makes a copy of the spreadsheet to use. Changes that are made affect only the copy--*the original template is preserved*. The copy of the template is a new, unsaved document with a temporary name based on the template name.

### **Generic Equation Calculator (GEQ v3.1)**

The Generic Equation Calculator (GEQ) was developed in response to work on the Munitions Response (MR) Program. Frequently, during MR activities, workers would unearth an item which was unexpected. This could result in work stoppages of several weeks while experts were consulted to provide a fragmentation analysis in order to properly assess the risks associated with the item. The GEQ provides a worst-case estimate of fragmentation effects by comparing the net explosive weight (NEW) and diameter of the munition item in question to those of hundreds of other munition items which have previously been analyzed.

Using trends in the historical fragment analyses, the GEQ provides a conservative estimate of maximum fragment distance, horizontal (MFD-H) and hazardous fragment distance (HFD). Alternatively, the GEQ can implement the historical trends in reverse providing a maximum permitted NEW and diameter based on the available distance for an MFD-H or HFD exposure. Additionally, the GEQ has the ability to provide a conservative estimate of required thicknesses for barricades and engineering controls to capture fragments.

The GEQ was first published in 2008 just before the publication of TP 16 revision 3<sup>Ref 2</sup>. The original version (GEQv1) only included the ability to approximate fragment distances based on NEW and diameter or to approximate NEW and diameter based on fragment distances. In version 2 (GEQv2), the ability to approximate required thicknesses to prevent perforation was added.

With each revision of TP 16, changes are made to the data trends used to provide the software output. Typically, these changes are minor adjustments resulting solely from the addition of new munitions to the analysis dataset. However, twice in the previous 10 years, major changes to the data trends have been made. The first major adjustment to the GEQ trend lines was in GEQv2 and TP 16 rev 4<sup>Ref 3</sup>. Data trends in GEQv1 were noted to be unrealistic beyond the NEW and diameter ranges of the data used to generate the equations. For example, due to the form of the trend line equations or asymptotes within the equations, extrapolated values could result in a lower NEW yielding a higher HFD. The second major adjustment to the GEQ trend lines was in GEQv3 and TP 16 rev 5<sup>Ref 1</sup>. It was discovered in GEQv1 and GEQv2 that the results between unit systems and between forward and reverse calculations did not precisely correlate. For example, if the user entered an NEW of 5 lbs to yield an output HFD of 300 ft, the user could then also enter an available HFD of 300 ft and receive an output of 4.25 lbs. Within GEQv3, a method of equation derivation was used to ensure GEQv3 results correlated to the greatest extent practical.

Since its original publication, the user interface hasn't changed significantly. As previously discussed, GEQv2 added a new worksheet providing the ability to calculate perforation

thicknesses. The only other significant change to the user interface was in GEQv3 which updated the known information input from a drop-down menu to a series of check boxes. This change permitted the GEQ to make appropriate comparisons and provide the correct output in a situation where previous versions required using the tool twice and comparing the output. This change has eliminated a great deal of user confusion in situations where the user knows both the NEW and diameter.

The GEQ is most useful when time is of the essence and space is plentiful. A work stoppage is costly so having a quick reliable answer when the unexpected occurs can result in significant cost savings to the government. However, the conservatism built into the GEQ, which allows it to be utilized without waiting for an expert analysis, can at times result in distances which are unmanageable from a logistical perspective. For instance, a munition with a 5 lb NEW has a HFD of 356 ft as determined using the GEQ while the same item has a HFD of 134 ft as determined using a TP 16 analysis. For this reason, use of the GEQ for activities which do not constitute an emergency is not always practical.

The methodologies utilized within the GEQ are discussed in detail in Chapters 4 and 7 of Technical Paper 16<sup>Ref 1</sup>. The user manual for the GEQ is provided in Chapter 9 of TP 16<sup>Ref 1</sup>. Unlike many of the other TP 16 tools, the GEQ is a Distribution A document and is approved for public release.

### **Buried Explosion Module (BEM v7.1)**

The Buried Explosion Module (BEM) was developed between 1995 and 1998 as part of an effort to determine public and operational personnel withdrawal distances for buried munitions<sup>Ref 5</sup>. While most of the methods originated from the DOE/TIC 11268<sup>Ref 4</sup> the BEM was developed to simplify and standardize the fragment calculations. The methods used in the BEM would later be incorporated into revision 1 of Technical Paper 16<sup>Ref 7</sup> and would remain in all future versions.

Using the methods originating from the DOE/TIC 11268<sup>Ref 4</sup> and summarized in TP 16<sup>Ref 1</sup>, the BEM determines the overpressure and fragmentation hazards associated with the detonation of a specified munition at a specified depth of burial in water or soil. The user may select from a range of built in soil types or input their own soil properties and input a depth of burial. The user may also select one of any munition item in the fragmentation database or enter properties for a user-defined munition. The user must input the properties of the donor charge used for detonating the buried item. Once all inputs are provided, the BEM outputs the following:

- Whether a Crater or Camouflet is formed
- Crater Radius
- Maximum Soil Ejecta Distance
- Maximum Fragment Distance
- Buried Equivalent K328 Overpressure Distance (the distance at which overpressure is 0.066 psi)
- Non-Essential Personnel Distance
- Buried Equivalent K24 Overpressure Distance (the distance at which overpressure is 2.3 psi)

- Overpressure at Non-essential Personnel Distance
- Overpressure at a User-entered Distance.

The original versions of the BEM, published in 1998, were executable FORTRAN programs. In these FORTRAN programs, the necessary values were input into BEM in an interactive mode and the results were written to an output file. The fragment weight, exit velocity and exit angle were then used as input to a separate trajectory program such as TRAJ<sup>Ref 6</sup> to calculate the maximum fragment distance. Beginning with version 6 (BEMv6) and TP 16 rev 3<sup>Ref 2</sup>, the tool was transitioned to an Excel-based software and has addressed both burial in soil and burial in water. Also beginning with BEMv6, a simplified trajectory code method was included in the tool to eliminate the need to run a separate trajectory program outside of the BEM.

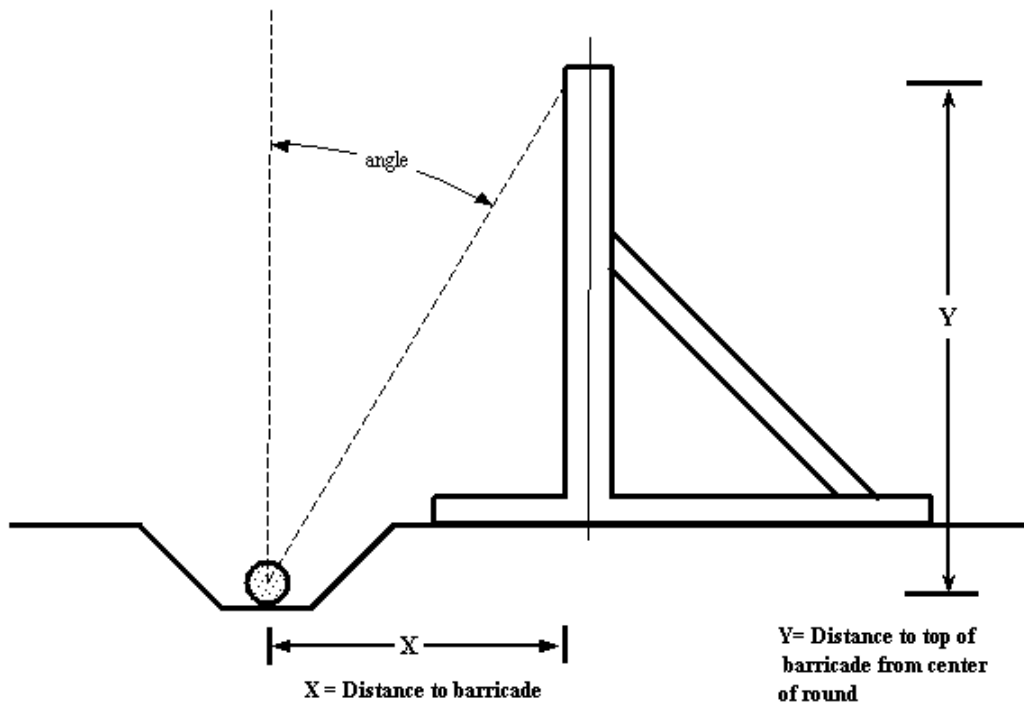
With each revision of TP 16, changes are made to the munition items listed in the drop-down menu to incorporate the latest updates to the Fragmentation Database. Beginning in version 7.0 (BEMv7) a new user interface was developed to consolidate input fields into a single region and add the buried equivalent K24 overpressure distance output field. Version 7.1 (BEMv7.1) was released to correct errors found in the built-in trajectory code method which resulted in non-conservative results. Version 7.2 (BEMv7.2) is under development to incorporate new Fragmentation Database (released May 2018) items and to increase the fidelity of the built-in trajectory code method.

The BEM is most useful when the munition item cannot be safely detonated on the ground surface due to the large fragmentation and/or overpressure distance required. The BEM can be used in a case-by-case scenario to determine the required depth of burial to mitigate the required separation distance to the area which can be controlled or to eliminate the fragmentation and overpressure effects completely by forming a camouflet. The BEM can be used for burials of items below the earth's surface or for determination of a minimum required thickness of soil to pile on top of the munition in order to safely detonate the item. The BEM can be a useful tool for both Military Munitions Response (MMR) type activities as well as for research development testing and evaluation (RDT&E) activities. The BEM should be used cautiously for RDT&E activities because the burial of the munition may alter results of the planned test or impede data collection in some scenarios.

The methodologies utilized within the BEM are discussed in detail in Chapter 6 of Technical Paper 16. The user manual for the GEQ is provided in Chapter 9 of TP 16. Due to the inclusion of United States munition data, the BEM is a Distribution D document and is authorized only for release to Department of Defense (DoD) and US DoD Contractors only for Administrative Operational Use.

### **Barricade Angle Calculator (BACv1.3)**

The Barricade Angle Calculator (BAC) was developed and published as part of Technical Paper 16 revision 3<sup>Ref 2</sup> to automate the process of determining the size/location of a barricade to limit the range of fragments to a pre-determined value. Consider the situation depicted in Figure 1. For a given munition and type of initiation, the limiting departure angle that would allow fragments to reach the entered range is computed. Based on this departure angle, either the distance to the barricade or its height is calculated.



**Figure 1. Barricade Angle Location**

The user selects properties of the munition item(s) to be detonated. Then enters the available distance (i.e., fragment distance) and either the known distance between the munition item(s) and the barricade or the known barricade height. The BAC then uses a series of trajectory code data tables to look up the required launch angle to limit fragment throw distance to a value less than the entered available distance. Finally, simple geometry is used with the launch angle to determine either the distance to the barricade or the barricade height.

There have been very few changes to the tool since its original release in 2009. With each revision of TP 16, changes are made to the munition items listed in the drop-down menu to incorporate the latest updates to the Fragmentation Database. Version 1.3 (BACv1.3) was released to correct errors found in the built-in trajectory code method which resulted in non-conservative results. Version 1.4 (BACv1.4) is under development to incorporate new Fragmentation Database (released May 2018) items and to increase the fidelity of the built-in trajectory code method. The Navy has also funded future updates to the BAC to develop a means for using the BAC to mitigate

Hazardous Fragment Distance (HFD) in addition to MFD-H. These updates have been developed in a BETA version and are currently being reviewed and validated.

The BAC is most useful to RDT&E activities who need the flexibility to manage their operations within a given QD arc. RDT&E activities cannot predict the full extent of their operations when planning their facilities. The BAC can aid in providing maximum operational flexibility to RDT&E activities by permitting the activity to build a custom barricade for each test scenario. When the munition item cannot be safely detonated in the open within the approved quantity distance (QD) arcs, the BAC can be used to determine the barricade geometry in order to contain fragments within a specified distance. The BAC can also be a useful tool for Military Munitions Response (MMR) type activities as they frequently use barricading to dispose of an item in place when the item is unsafe to move. Unfortunately, the BAC can only provide a cross-sectional barricade geometry solution due to the complexity and variability of PES and ES locations in plan view. A plan-view geometry analysis should always be performed in addition to utilizing the BAC to ensure the fragmentation risks are properly mitigated.

The methodologies utilized within the BAC are based solely in geometry and thus are only briefly discussed in Chapter 9 of Technical Paper 16. The user manual for the BAC is also provided in Chapter 9 of TP 16. Due to the inclusion of United States munition data, the BAC is a Distribution D document and is authorized only for release to Department of Defense (DoD) and US DoD Contractors only for Administrative Operational Use.

### **Modified Pseudo Trajectory Normal Calculator (MPTNC v1.1)**

The Modified Pseudo Trajectory Normal Calculator (MPTNC) was developed to speed the process of determining Hazardous Fragment Distance (HFD) based on test data. When fragments and debris from a munition test are collected via a method to record location and mass, the data can be used to empirically derive a HFD. Unlike the other software associated with TP 16, the methodologies used in this software are not discussed in TP 16. The methodologies used in the MPTNC are detailed in Technical Paper 21 (TP 21)<sup>Ref 8</sup> and the TB700-2<sup>Ref 9</sup>. Because there is currently no software as part of the TP 21 package, the decision was made to incorporate the MPTNC software into TP16.

A modified pseudo trajectory normal analysis assumes that at a given distance from a detonation, personnel will be hazarded by all fragments which land at that distance and a third of all fragments landing beyond that distance. The process outlined in the TB 700-2 for analysis of the data is labor intensive and requires multiple sorts of the data set. If any of the analysis parameters are changed, the dataset must be resorted prior to completing the analysis. The MPTNC uses Excel-based macros to sort the data set quickly and perform the remaining analyses.

The MPTNC was first published in 2012 with TP 16 revision 4<sup>Ref 3</sup>. There haven't been any significant changes to the tool though there have been multiple versions released as bugs and compatibility issues were found across the various DoD Services and computing systems. In

general, the user is unlikely to notice any of the changes between versions. The most recent version is version 1.1 (MPTNCv1.1) published as part of the TP 16 rev 5<sup>Ref 1</sup> package.

The MPTNC is most useful when trying to determine the HFD based on test data. The tool has significantly automated a labor intensive process which previously required the user to evaluate hundreds to thousands of lines of data by hand. Problems using the MPTNC are less a result of the tool and more a result of the methodology outlined in TB 700-2. The TB 700-2 includes a recommendation that masses smaller than 100 gm be ignored in the analysis. Unfortunately, for some items, the 100 gm minimum size is larger than the maximum fragment size. Additionally, the TB 700-2 recommends radial distance increments of 60 m or 200 ft. Because the method for determination of HFD requires multiple groupings of fragments at various distances, using this distance increment for smaller munitions can yield no results. (Note that the default distance increment for the MPTNC is 50 ft to alleviate this problem.) Because the user will likely have to adjust or ignore fragment mass requirements, distance increments, and look at test data from multiple sectors, the method isn't as standardized as many other fragment analysis methods. This can yield vastly different results which are not entirely repeatable. The benefit of the MPTNC is that the output repeats the analysis conditions. If the same data and inputs are entered, the user should be able to generate repeatable results for a given data set.

The methodologies utilized within the MPTNC are discussed in detail in Technical Paper 21<sup>Ref 8</sup> and the TB 700-2<sup>Ref 9</sup>. The user manual for the MPTNC is provided in Chapter 9 of TP 16<sup>Ref 1</sup>. Because the MPTNC contains no munition specific data, the MPTNC is a Distribution A document and is approved for public release.

### **Jacobs-Roslund Calculator (JRC v1.2)**

The Jacobs-Roslund Calculator (JRC) was developed to speed the process of determining if sympathetic detonation due to fragmentation is likely or unlikely for cased items. When a detonation occurs, fragments from the donor munition can impact other exposed munitions causing the exposed items to sympathetically detonate. This type of analysis is based on the fragment weight of the donor munition and the case thickness and explosives sensitivity of the exposed munition. This analysis procedure only considers propagation by fragmentation. It is well established that propagation due to overpressure is extremely difficult to achieve therefore, sympathetic detonation due to overpressure is typically ignored.

Using the methods described in TP 16<sup>Ref 1</sup>, the JRC compares the fragment energy generated from the user-selected donor item to the munition case and explosive properties of every munition in the fragmentation database as well as any user-entered donor items. For each munition in the Fragmentation Database, the JRC displays a "yes" or "no" value in response to the question "Does the donor item cause propagation to the exposed item?" This comparison is made assuming both intentional and unintentional detonations for each database munition as an exposed item.

The JRC was first published in 2012 with TP 16 revision 4<sup>Ref 3</sup>. Multiple revisions have been made to the JRC to update the munition items listed in the drop-down menu and used as exposed items

in order to incorporate the latest updates to the Fragmentation Database. The original version of the tool (JRCv1.0) displayed only exposed munitions which resulted in propagation. Beginning with version 1.1 (JRCv1.1) and TP 16 rev 5<sup>Ref 1</sup>, all exposed munition items have been displayed. Version 1.2 (JRCv1.2) is soon to be released to incorporate new Fragmentation Database (released May 2018) items and to add the ability for the user to filter the exposed munition list to show only items of interest using any one of the following selections:

- All Items
- All Propagation
- All Non-Propagation
- Intentional Detonation Propagation
- Intentional Detonation Non-propagation
- Unintentional Detonation Propagation
- Unintentional Detonation Non-Propagation

The JRC is most useful when planning storage scenarios or evaluating the risks associated with two concurrent operations. The JRC can be used to determine a maximum credible event (MCE), leading to the determination of the net explosive weight used for determining quantity distance (NEWQD) or eliminating the need to increase fragmentation distances when multiple rounds are present.

The methodologies utilized within the JRC are discussed in detail in Chapter 8 of Technical Paper 16. The user manual for the JRV is provided in Chapter 9 of TP 16. Due to the inclusion of United States munition data, the JRC is a Distribution D document and is authorized only for release to Department of Defense (DoD) and US DoD Contractors only for Administrative Operational Use.

### **Stacked Munition Article Calculator (SMAC v1.0)**

The Stacked Munition Article Calculator (SMAC) was first published in 2014 to provide a means for determining the Hazardous Fragment Distance (HFD) from stacks of munition items. The US Army Technical Center for Explosives Safety (USATCES) funded the development of the methodology when they needed a way to quantify fragmentation risks for purposes of briefing commanders. The tool was based on a late 1990s software called HFSTACK (Hazardous Fragments from a Stack) but strictly followed the methods described in TP 16 rev 4<sup>Ref 3</sup> and NATO AASTP 1<sup>Ref 10</sup>. The methods for SMAC were later incorporated into TP 16 rev 5<sup>Ref 1</sup>.

Using the methodology outlined in TP 16 rev 5<sup>Ref 1</sup>, SMAC permits the user to select a munition item, select the munition orientation, and enter the stack geometry (i.e., number of munitions on the side a top). SMAC then outputs the HFD for the entered stack configuration. Additionally, SMAC displays the Maximum Fragment Distance Horizontal (MFD-H) for the stack of items and provides required thicknesses of various materials to prevent perforation.

There has only been one published version of SMAC. However, periodic updates to the software are expected in the future to incorporate the latest updates to the Fragmentation Database. In fact,



version 1.1 (SMACv1.1) is currently under development to incorporate new Fragmentation Database (released May 2018) items.

SMAC is most useful for predicting test data and quantifying fragmentation hazards from stacks of munitions. The tool can be used for siting activities involving stacks of munitions possibly providing a lesser distance than those tabulated in the DoD 6055.09-M<sup>Ref 11</sup>. Additionally, SMAC can be used to determine the thickness of barricades or engineering controls necessary to prevent fragment perforation. Care should be taken when using SMAC to ensure that the entered numbers of items on the side and top of the stack include all items and not just the items visible in cross-section. SMAC does not have the ability to determine HFD from a stack of mixed munitions. However, running the full stack configuration for each munition item present and taking the largest value will be conservative.

The methodologies utilized within SMAC are discussed in detail in Chapters 3 and 5 of Technical Paper 16<sup>Ref 1</sup>. The user manual for SMAC is provided in Chapter 9 of TP 16<sup>Ref 1</sup>. Due to the inclusion of United States munition data, the JRC is a Distribution D document and is authorized only for release to Department of Defense (DoD) and US DoD Contractors only for Administrative Operational Use.

## **References**

1. "Methodologies for Calculating Primary Fragment Characteristics," DDESB Technical Paper No. 16, revision 5, 15 September 2016.
2. "Methodologies for Calculating Primary Fragment Characteristics," DDESB Technical Paper No. 16, revision 3, 1 April 2009.
3. "Methodologies for Calculating Primary Fragment Characteristics," DDESB Technical Paper No. 16, revision 4, 2 August 2012.
4. DOE/TIC-11268, "A Manual for the Prediction of Blast and Fragment Loadings on Structures", Feb 1992.
5. Crull, Michelle, "Buried Explosion Module (BEM): A Method For Determining The Effects Of Detonation Of A Buried Munition," HNC-ED-CS-S-97-7-Revision 1, January 1998.
6. Montanaro, Paul E., "TRAJ—A Two Dimensional Trajectory Program for Personal Computers," Minutes of the 24th DoD Explosives Safety Seminar, August 1990.
7. "Methodologies for Calculating Primary Fragment Characteristics," DDESB Technical Paper No. 16, revision 1, 1 December 2002.
8. "Procedures for the Collection, Analysis, and Interpretation of Explosion-Produced Debris, Revision 1" DDESB Technical Paper No. 21, 22 October 2007.
9. "Department of Defense Ammunition and Explosives Hazard Classification Procedures", TB 700-2, Headquarters Departments of the Army, the Navy, and the Air Force, 5 January 1998.
10. AASTP 1 "Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives", May 2010.
11. DoD 6055.09-M "DoD Ammunition and Explosives Safety Standards", Volumes 1-8, 12 March 2012.