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TR-NAVFAC EXWC-SH-2204
DECEMBER 2021

CONFINEDBLAST SOFTWARE USER MANUAL



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14. ABSTRACT This report is a user manual for the ConfinedBlast software tool. ConfinedBlast is a user interface that allows the user to input problems to be analyzed using SHOCK, FRANG, or MUDEMIMP. All three programs analyze different effects resulting from a confined explosion. This manual provides general descriptions of all three of these programs within ConfinedBlast, step by step guidance on how to input data, guidance on interpreting the output data, and example problems for each program. NAVFAC EXWC's verification analysis of the results of each program concludes that the use of ConfinedBlast software produces confined blast effects predictions that are generally conservative and appropriate for use in the design and analysis of facilities intended for protective construction.					
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EXECUTIVE SUMMARY

This report is a user manual for the ConfinedBlast software tool. ConfinedBlast is a user interface that allows the user to input problems to be analyzed using SHOCK, FRANG, or MUDEMIMP. All three programs analyze different effects resulting from a confined explosion. This manual provides general descriptions of all three of these programs within ConfinedBlast, step by step guidance on how to input data, guidance on interpreting the output data, and example problems for each program.

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ACRONYMS AND ABBREVIATIONS

DDESB	Department of Defense Explosives Safety Board
EXWC	Engineering and Expeditionary Warfare Center
MUDEMIMP	Multiple Debris Missile Impact Simulation
NAVFAC	Naval Facilities Engineering Command
NCEL	Naval Civil Engineering Laboratory
NFESC	Naval Facilities Engineering Service Center
SI	International System of Units
TP	Technical Paper
TNT	Trinitrotoluene
UFC	Unified Facilities Criteria
US	United States Customary Units

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TABLE OF CONTENTS

1.0	GENERAL INFORMATION.....	14
1.1	Introduction.....	14
1.2	SHOCK.....	14
1.3	FRANG.....	14
1.4	MUDEMIMP.....	15
2.0	CONFINEDBLAST ANALYSIS OPTIONS.....	16
2.1	ConfinedBlast Unit Selection.....	16
2.2	ConfinedBlast Analysis Selection.....	16
3.0	INPUT DATA.....	18
3.1	General Information.....	18
3.2	Run Title and Units – ALL.....	18
3.3	Computation Engine.....	20
3.4	Room Data.....	22
3.5	Charge Data.....	27
3.6	Target Data.....	28
3.7	MUDEMIMP General Data.....	36
3.8	MUDEMIMP Distribution Functions Input.....	36
3.9	MUDEMIMP Default Overrides Input.....	40
4.0	OUTPUT DATA.....	42
4.1	Text Results—ALL.....	42
4.2	Graphical Results—ALL.....	45
5.0	EXAMPLE PROBLEMS.....	46
5.1	SHOCK Example 1.....	46
5.2	SHOCK Example 2.....	47
5.3	FRANG Example 1.....	48
5.4	FRANG Example 2.....	48
5.5	MUDEMIMP Example 1.....	49
5.6	MUDEMIMP Example 2.....	50
6.0	CONFINEDBLAST CODE VERIFICATION AND THEORETICAL BASIS.....	52
6.1	SHOCK 2.0.....	52
6.2	FRANG 2.0.....	52
6.3	MUDEMIMP 2.0.....	52
7.0	REFERENCES.....	55

LIST OF APPENDICES

APPENDIX A GLOSSARY.....	A-1
APPENDIX B FRANG VERIFICATION STUDY	B-1
APPENDIX C MUDEMIMP COMPARISON STUDY	C-1

LIST OF TABLES

Table 4-1. Descriptions of ConfinedBlast Text Output Data Files.....	42
Table 4-2. Descriptions of ConfinedBlast Graphical Output Data Files	45
Table B-1. Parameters of Confined Explosions in EMRTC Test Series [2]	B-3
Table B-2. Parameters of Test Series Examined in PEC Gas Model Study [6]	B-3
Table C-1. Fragment Distribution Functions	C-4
Table C-2. Default Overrides.....	C-5
Table C-3. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-5
Table C-4. Fragment Distribution Functions	C-5
Table C-5. Default Overrides.....	C-6
Table C-6. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-6
Table C-7. Fragment Distribution Functions	C-6
Table C-8. Default Overrides.....	C-7
Table C-9. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-7
Table C-10. Fragment Distribution Functions	C-7
Table C-11. Default Overrides.....	C-8
Table C-12. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-8
Table C-13. Fragment Distribution Functions	C-9
Table C-14. Default Overrides.....	C-9
Table C-15. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-10
Table C-16. Fragment Distribution Functions	C-10
Table C-17. Default Overrides.....	C-10
Table C-18. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-11
Table C-19. Fragment Distribution Functions	C-11
Table C-20. Default Overrides.....	C-11
Table C-21. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-12
Table C-22. Fragment Distribution Functions	C-12
Table C-23. Default Overrides.....	C-12
Table C-24. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-13
Table C-25. Fragment Distribution Functions	C-14
Table C-26. Default Overrides.....	C-14
Table C-27. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-15
Table C-28. Fragment Distribution Functions	C-15
Table C-29. Default Overrides.....	C-15

Table C-30. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-16
Table C-31. Fragment Distribution Functions.....	C-16
Table C-32. Default Overrides.....	C-16
Table C-33. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-17
Table C-34. Fragment Distribution Functions.....	C-17
Table C-35. Default Overrides.....	C-17
Table C-36. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-18
Table C-37. Fragment Distribution Functions.....	C-19
Table C-38. Default Overrides.....	C-19
Table C-39. Output Comparison between TP-13 and MUDEMIMP Version 2.....	C-20
Table C-40. Fragment Distribution Functions.....	C-21
Table C-41. Default Overrides.....	C-21
Table C-42. Output Comparison between Example A and MUDEMIMP Version 2.....	C-22
Table C-43. Fragment Distribution Functions.....	C-23
Table C-44. Default Overrides.....	C-23
Table C-45. Output Comparison between Example B and MUDEMIMP Version 2.....	C-24
Table C-46. Fragment Distribution Functions.....	C-25
Table C-47. Default Overrides.....	C-25
Table C-48. Output Comparison between Example C and MUDEMIMP Version 2.....	C-26
Table C-49. Fragment Distribution Functions.....	C-27
Table C-50. Default Overrides.....	C-27
Table C-51. Output Comparison between Example D and MUDEMIMP Version 2.....	C-28
Table C-52. Fragment Distribution Functions.....	C-29
Table C-53. Default Overrides.....	C-29
Table C-54. Output Comparison between Example E and MUDEMIMP Version 2.....	C-30
Table C-55. Fragment Distribution Functions.....	C-31
Table C-56. Default Overrides.....	C-31
Table C-57. Output Comparison between Example F and MUDEMIMP Version 2.....	C-32
Table C-58. MUDEMIMP Comparison Summary.....	C-34

LIST OF FIGURES

Figure 2-1 ConfinedBlast Launcher Unit System Selection Interface.....	16
Figure 2-2. ConfinedBlast Analysis Selection Drop-Down Menu.....	17
Figure 3-1. ConfinedBlast Run Title and Units Input Menu.....	19
Figure 3-2. Overpressure Computation Engine Selection.....	21
Figure 3-3. SHOCK Room Data Input Menu.....	22
Figure 3-4. FRANG Room Data Input Menu.....	24
Figure 3-5. SHOCK/FRANG Room Data Input Menu.....	26
Figure 3-6. SHOCK, SHOCK/FRANG Charge Data Input Menu.....	27
Figure 3-7. SHOCK Reduced Area/ Panels / Point Loads Input Menu.....	29
Figure 3-8. FRANG Frangible Panels Input Menu.....	31
Figure 3-9. SHOCK/FRANG Reduced Area/ Panels Input Menu.....	33
Figure 3-10. SHOCK/FRANG Reduced Area/ Panels Frangibility Input Menu.....	34

Figure 3-11. SHOCK, SHOCK/FRANG Surfaces to be Analyzed Input Menu	35
Figure 3-12 MUDEMIMP General Data Input Menu	36
Figure 3-13. MUDEMIMP Mass Distribution Input Menu.....	37
Figure 3-14. MUDEMIMP Launch Velocity Distribution Input Menu	38
Figure 3-15. MUDEMIMP Launch Angle Distribution Input Menu	38
Figure 3-16. MUDEMIMP Drag Coefficient Distribution Input Menu	39
Figure 3-17. MUDEMIMP Drag Area Factor Distribution Input Menu	39
Figure 3-18. MUDEMIMP Default Overrides Input Menu.....	41
Figure B-1. Comparison between Peak Gas Pressures Published in the UFC 3-340-02, Change 2 and Predicted by FRANG 2.0	B-5
Figure B-2. Comparisons of Figure 2-154 in TM-5-1300 and UFC 3-340-02 Showing Similar Values for Scaled Panel Weights of 0.3 psf/lbs ³	B-7
Figure B-3. Distribution of Differences between UFC-Provided and FRANG-Predicted Values for Scaled Gas Impulse	B-9
Figure B-4. Considered Scenario Parameters in Verification Run on FRANG Multiple Panel Analysis.....	B-10
Figure C-1. MMP Input File.....	C-3

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1.0 GENERAL INFORMATION

1.1 Introduction

ConfinedBlast is a user interface that allows the user to input problems to be analyzed using SHOCK, FRANG, or MUDEMIMP. All three programs analyze effects resulting from an explosion within a confined space, such as a storage room. ConfinedBlast improves upon previous versions of these programs in three key areas. Firstly, previous versions required the user to enter in the data using text files format with predetermined positions for each input that were difficult to follow for users unfamiliar with the format. Secondly, previous versions ran in MS-DOS format, which poses compatibility issues with newer operating systems that do not support this format. Lastly, output files had to be accessed from a folder and opened up separately, whereas the new interface allows the user to open up and view each output within the ConfinedBlast user interface, allowing the user to more efficiently move through the various output files and compare results.

Note that while versions of the underlying software within ConfinedBlast (i.e. SHOCK, FRANG and MUDEMIMP) have been endorsed by the Department of Defense Explosives Safety Board (DDESB), ConfinedBlast was never submitted to the DDESB for approval. Previous versions of ConfinedBlast have been distributed among the explosive safety community; however, none of those versions were officially endorsed for use by the DDESB. The version of ConfinedBlast (ConfinedBlast v5.0) described in this user manual is the first version of the software to be submitted to the DDESB for approval in designs in accordance with UFC 3-340-02 [1].

1.2 SHOCK

SHOCK is a program that analyzes the impact of an explosive blast on a blast surface such as a wall, resulting in impulse and pressure values for the surface in question. These blast surfaces may be bounded by reflecting surfaces. The essential input for this program are the dimensions of the blast surface, the number and location of the reflecting surfaces, the location and dimensions of the surface to be analyzed, and the weight and location of the charge. SHOCK will then calculate the impulse and pressure due to the incident blast wave and the reflected waves from the specified reflecting surfaces. The maximum average pressure from each incident and reflected wave and the total average impulse from the sum of all the waves are calculated and displayed. The impulse duration on the blast surface is also calculated and displayed.

1.3 FRANG

FRANG is a program that analyzes the gas pressure inside a confined space such as a room generated by an internal explosion. The resulting calculations account for the increased blast load caused by the “trapping” effect of a frangible panel on gas pressure inside a room while it blows off and away from its opening. The

pressures remain inside the room for a longer time than they would without a cover. Room dimensions, frangible panel dimensions, covered and uncovered vent areas, availability of venting around frangible panel perimeter, panel unit surface weight, initial recessed depth of the panel, shock impulse on the panel, presence or absence of gravity load on the panel, the analysis time step size and charge weight all need to be input by the user. The output includes the pressure versus time history, panel displacement, velocity and acceleration, the effective area of the covered vent, gas duration, peak gas pressure and the total gas impulse.

1.4 MUDEMIMP

The MUDEMIMP simulation computer program was developed to calculate conservative estimates of the maximum and hazardous debris distances from an accidental detonation within an explosives material operations building. The user must determine expected debris mass, velocity, launch angle, drag coefficient, and drag area, along with the appropriate distribution for each of these parameters in accordance with guidance provided in DDESB TP-13. These parameters provide the input for the MUDEMIMP software, along with values for debris density, break-up pattern, wall thickness (if applicable) ambient environmental conditions, initial debris location, fragment shape factor and whether the debris will ricochet or roll. The output includes trajectory and impact range for debris, launch/flight characteristics, and a debris missile impact histogram of the accumulated number of hazardous debris missiles within 600 ft² ground surface area at various impact ranges. The debris safety distance can then be easily determined from the histogram by applying the DDESB debris hazard guidelines.

Note that the guidance in TP-13 includes additional parameters on the scenarios that may be considered using the methodology outlined in that report. These parameters include maximum charge weight, minimum standoffs, material types, and additional constraints. These parameters are not utilized by the calculations in the MUDEMIMP software, and are not considered in its assessment. The user is responsible for ensuring compliance with TP-13 guidance if using that methodology for calculation of hazardous debris distances.

2.0 CONFINEDBLAST ANALYSIS OPTIONS

2.1 ConfinedBlast Unit Selection

- Upon launching ConfinedBlast Launcher, select appropriate application based on desired units, as shown in Figure 2-1. Available options are:
 - Launch US: input and output values calculated in imperial units (feet, feet per second, pounds, pounds per square inch, etc.)
 - Launch SI: input and output values calculated in metric units (meters, meters per second, kilograms, kilopascals, etc.)

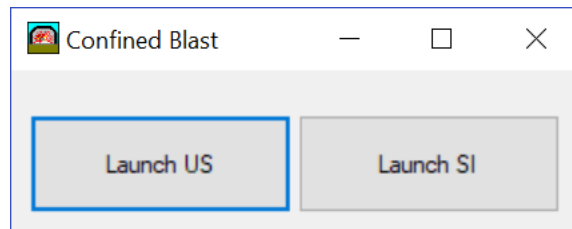


Figure 2-1 ConfinedBlast Launcher Unit System Selection Interface

2.2 ConfinedBlast Analysis Selection

- Click drop-down at top of program interface next to 'Analysis:' as shown in Figure 2-2. Available options are:
 - SHOCK: calculate internal shock pressure loading parameters.
 - FRANG: calculate internal gas pressure loading parameters.
 - MUDEMIMP: calculate debris trajectories and safety distance.
 - SHOCK/FRANG: calculate both internal shock and gas pressure in the same program run.

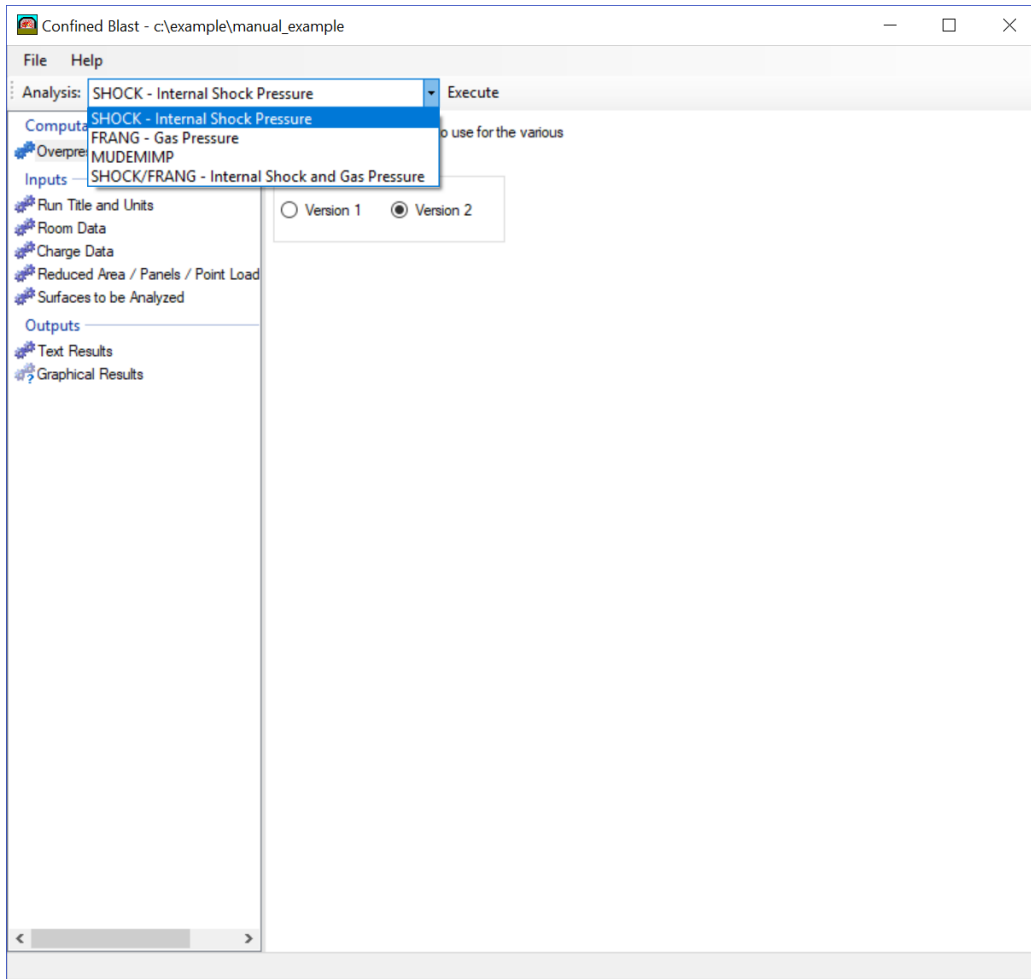


Figure 2-2. ConfinedBlast Analysis Selection Drop-Down Menu

3.0 INPUT DATA

3.1 General Information

- Each general input category needs to be selected, even if the information is not updated (see Figure 3-1). This sends the related input information to the input data file that is read by the program.
- After each input page title listed below, the program(s) that page applies to is listed in all caps (i.e. SHOCK, FRANG, MUDEMIMP, or SHOCK/FRANG).

3.2 Run Title and Units – ALL

- Input screen shown in Figure 3-1.
- Enter in a title and date for the analysis to be run.
- A title must be entered for each run.
- The user can also add a brief comment to record specific details regarding the problem to be analyzed.

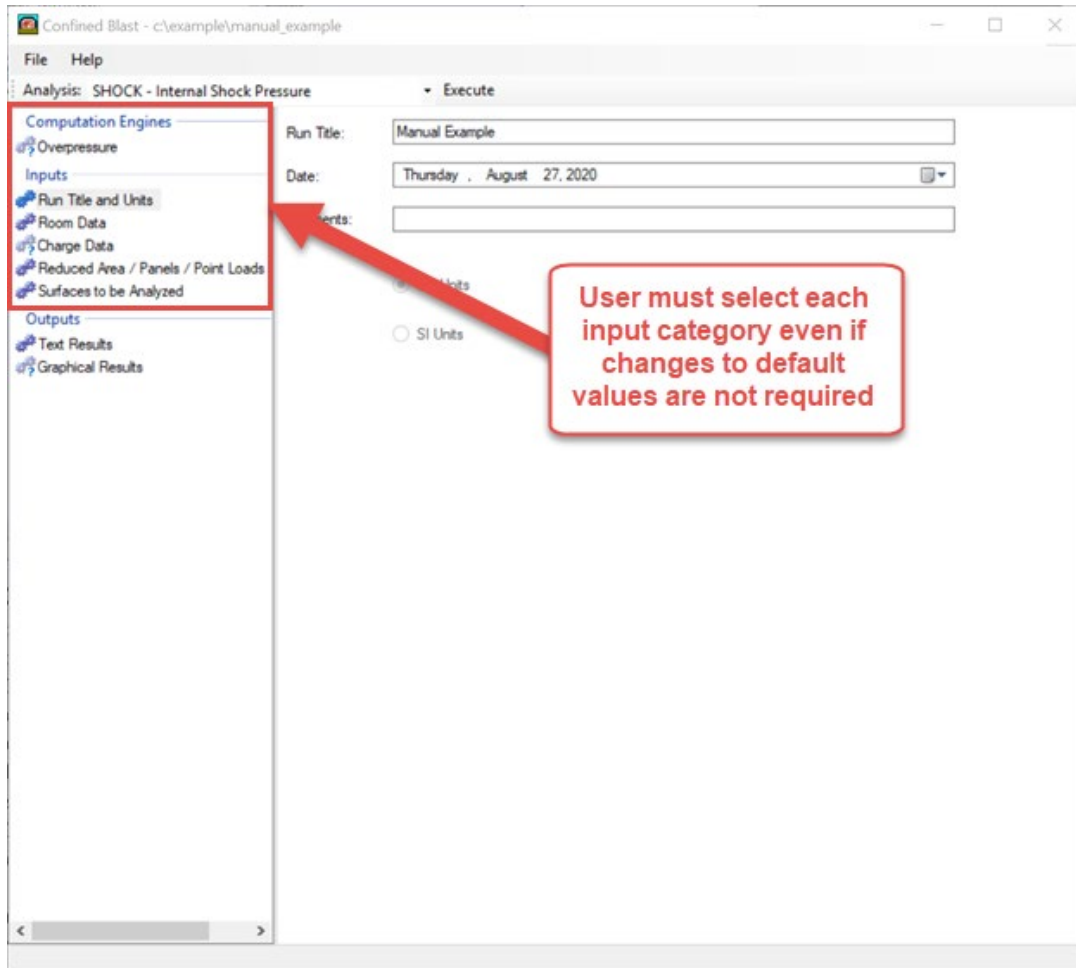


Figure 3-1. ConfinedBlast Run Title and Units Input Menu

3.3 Computation Engine

- Overpressure: when running SHOCK or SHOCK/FRANG, select ‘Overpressure’ under ‘Computation Engine’ from left hand menu options (Figure 3-2). Although the option appears in both SHOCK and FRANG analysis selections, the selection of computation engine only affects the results generated by the SHOCK program. See Section 6.1 of this report for additional information on the computational differences between Version 1 and Version 2.
- When running FRANG only, Overpressure Computation Engine must still be selected even though input value selected does not affect FRANG results. User may leave selection at default.
- Debris: there is an input category in the MUDEMIMP analysis module for Debris Computation engine (select ‘Debris’ under ‘Computation Engine’). However, no user input is required as only one option is available.
- Shock Computation Engine Version 2 should be selected for consistency with methodologies outlined in UFC 3-340-02, “Structures to Resist the Effects of Accidental Explosions” [1].
- Shock Computation Engine Version 1 may be selected to perform legacy calculations for comparison with previously completed analyses. For additional details on Shock Computation Engine Version 1, the user is referred to Reference [2].

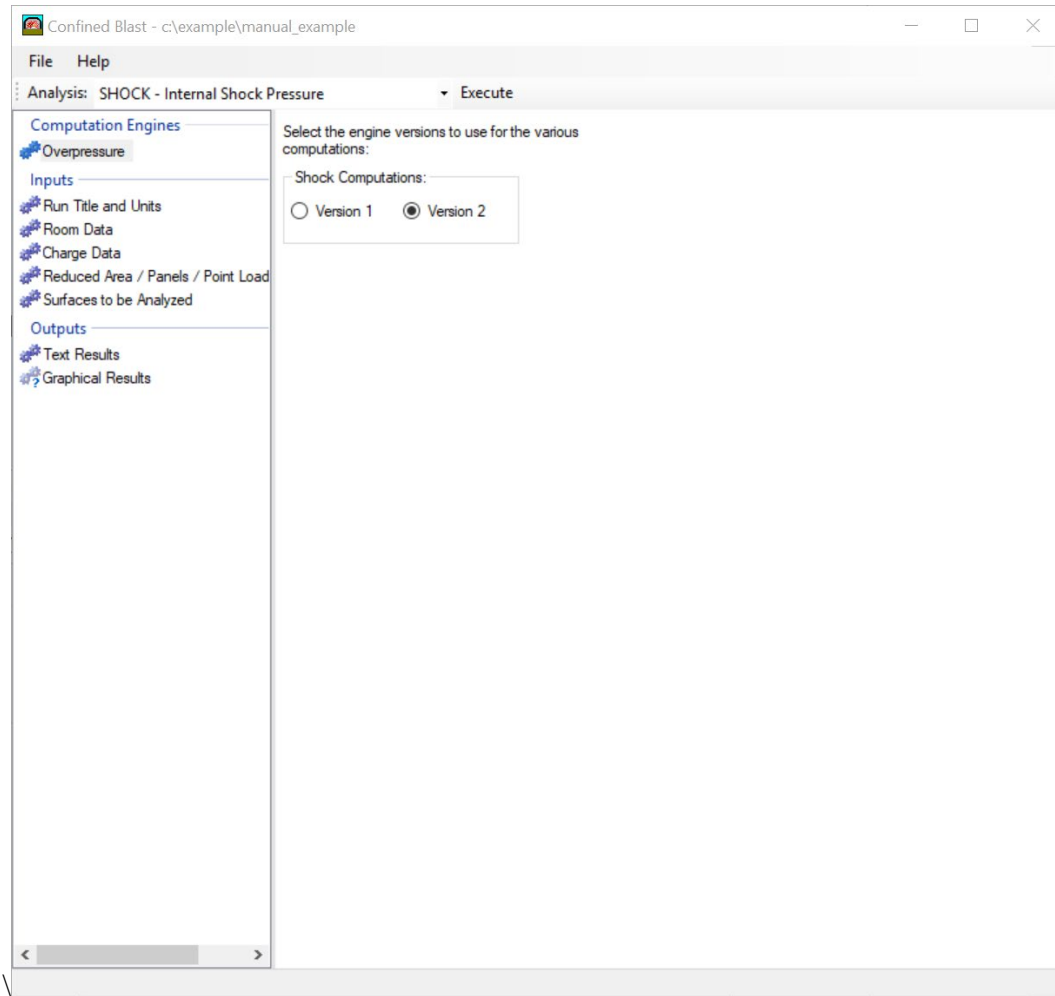


Figure 3-2. Overpressure Computation Engine Selection

3.4 Room Data

3.4.1 Room Data – SHOCK

- Input screen shown in Figure 3-3.
- Enter room dimensions as defined in the figure.
- Select the reflecting surfaces to determine which of them will reflect blast pressures. All room surfaces that are not initially open should be selected as reflecting surfaces. Surfaces that are frangible (per the definition established in UFC 3-340-02 [1] Section 2-14.2.2) may have their reflected pressures and impulses reduced, per guidance in that section; this calculation must be performed by the user. The effect of openings in reflecting surfaces is conservatively neglected by the software.

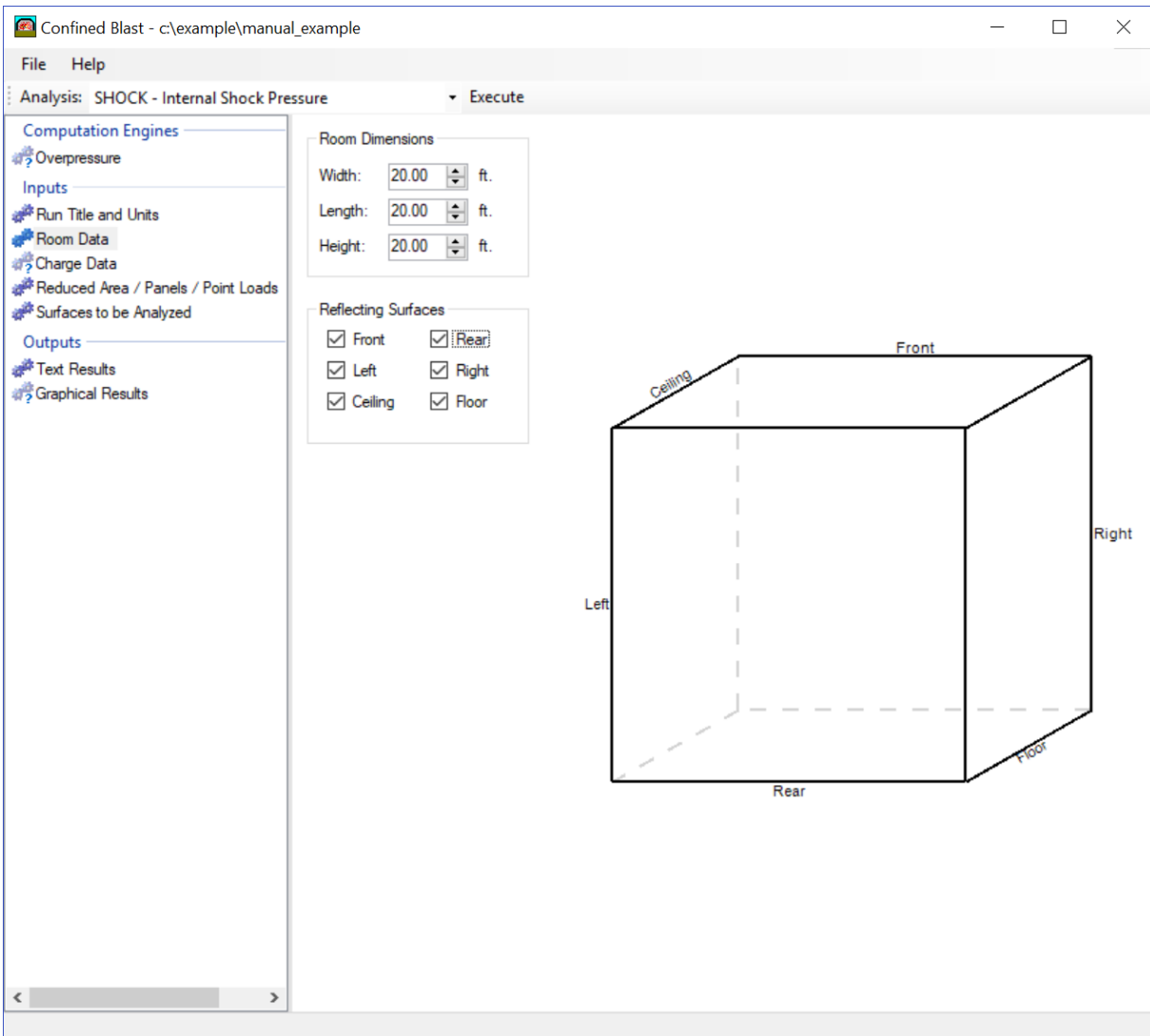


Figure 3-3. SHOCK Room Data Input Menu

3.4.2 Room Data – FRANG

- Input screen shown in Figure 3-4.
- Enter in the room dimensions.
- Enter in the charge weight.
- The charge weight must meet the following criteria:
 - o The ratio of the charge weight divided by the room volume must be greater than 0.001 and less than 2.0 lbs/ft³: $0.001 < W/V < 2.0$
 - o The ratio of the reduced reflected shock impulse divided by the cube root of the charge weight must be less than 2000.0 psi-ms/lbs^{1/3}:
 $i_r/W^{1/3} < 2000.0$
 - o The ratio of the frangible panel surface weight divided by the cube root of the charge weight must be less than 300.0 psf/lbs^{1/3}: $M/W^{1/3} < 300.0$
- If the charge weight exceeds these parameters, FRANG (in the .FS0 output file) will display a warning noting the violation (e.g. “W/V = .0005 < .001”) and a declaration that “Calculated IG/W**(1/3) may be less than actual value”.
- Enter the initial open vent area.
- Vents that are uncovered have a constant area.
- FRANG will reject a problem if the initial open vent area is set to zero and no frangible panels are included. A room with no vents can be simulated by specifying a very small initial open vent area or an extremely heavy frangible panel.
- Select one of the six options for the print flag—from every 100th line to every line. This will determine how often the output prints the data from the time steps.
- Enter in the time step. Default and recommended time step is 0.001 ms.
- The time steps determine how often a calculation is made. As this number increases, the time to complete the run decreases while the accuracy decreases.
- FRANG calculates α , the exponential decay constant for the gas pressure.
- If it cannot calculate this value, a warning message will be displayed saying, “Warning—Alpha not accurate.”
- This message will be displayed for each time step where α cannot be calculated. If this occurs more than 10% of the time steps, the FRANG results are inaccurate and should not be used.
- If α becomes a problem (which typically occurs when small charge weights are detonated in large rooms), engineering judgment must be used to make conservative assumptions.
- If the ratio of the change in gas pressure to peak gas pressure is greater than 0.5% in a time step— $DP/PG > 0.5\%$ —a warning message appears and the time step size must be reduced.

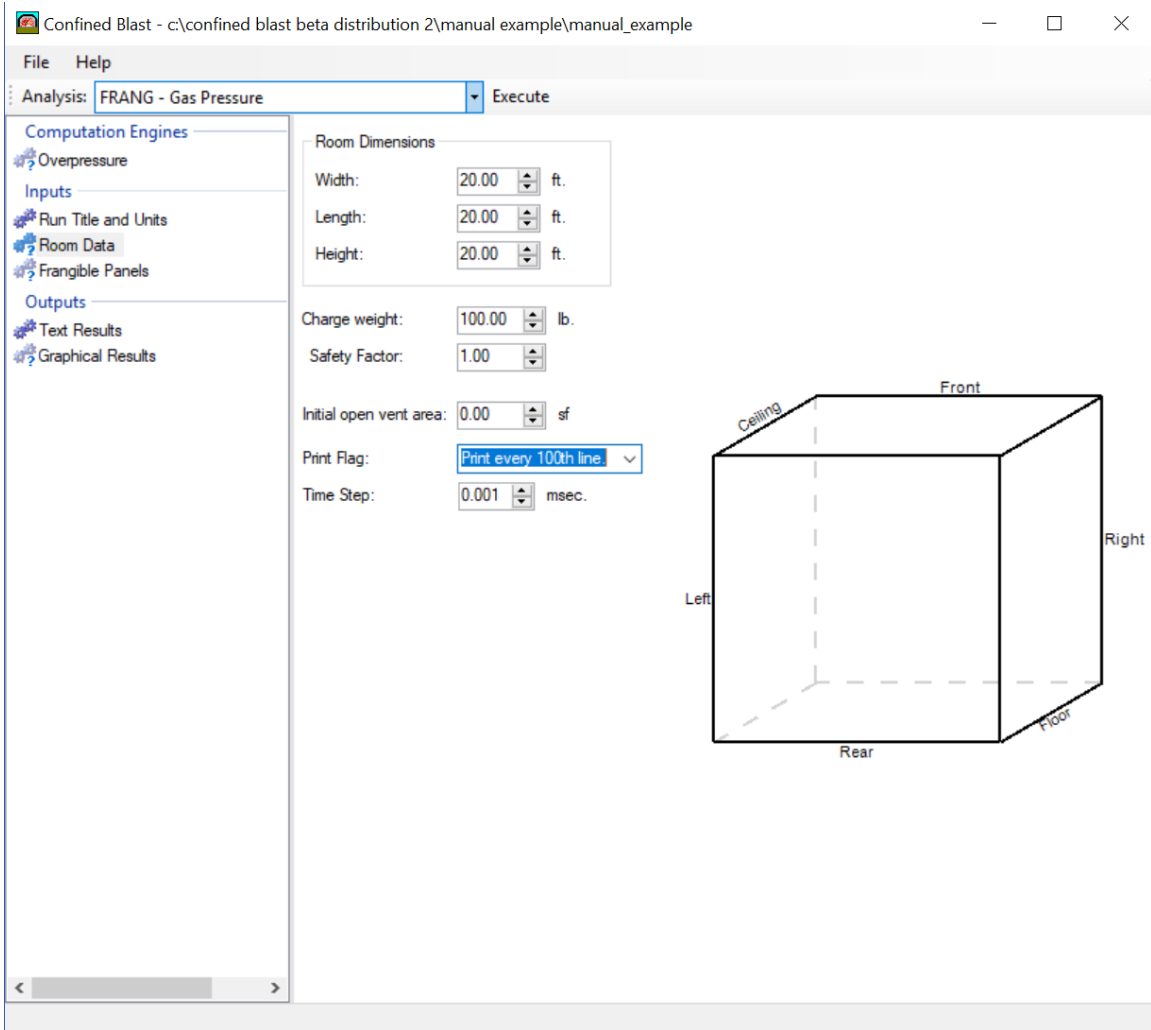


Figure 3-4. FRANG Room Data Input Menu

3.4.3 Room Data – SHOCK/FRANG

- Input screen shown in Figure 3-5.
- Enter in the room dimensions.
- Enter in initial open vent area.
- Vents that are uncovered have a constant area.
- FRANG will reject a problem if the initial open vent area is set to zero and no frangible panels are included. A room with no vents can be simulated by specifying a very small initial open vent area or an extremely heavy frangible panel.
- Select one of the six options for the print flag—from every 100th line to every line. This will determine how often the output prints the data from the time steps.
- Enter in the time step. Default and recommended time step is 0.001 ms.
- The time step determines how often a calculation is made. As this number increases, the time to complete the run decreases while the accuracy decreases.
- Select the reflecting surfaces to determine which of them will reflect blast pressures. All room surfaces that are not initially open should be selected as reflecting surfaces. Surfaces that are frangible (per the definition established in UFC 3-340-02 [1] Section 2-14.2.2) may have their reflected pressures and impulses reduced, per guidance in that section; this calculation must be performed by the user. The effect of openings in reflecting surfaces is conservatively neglected by the software.

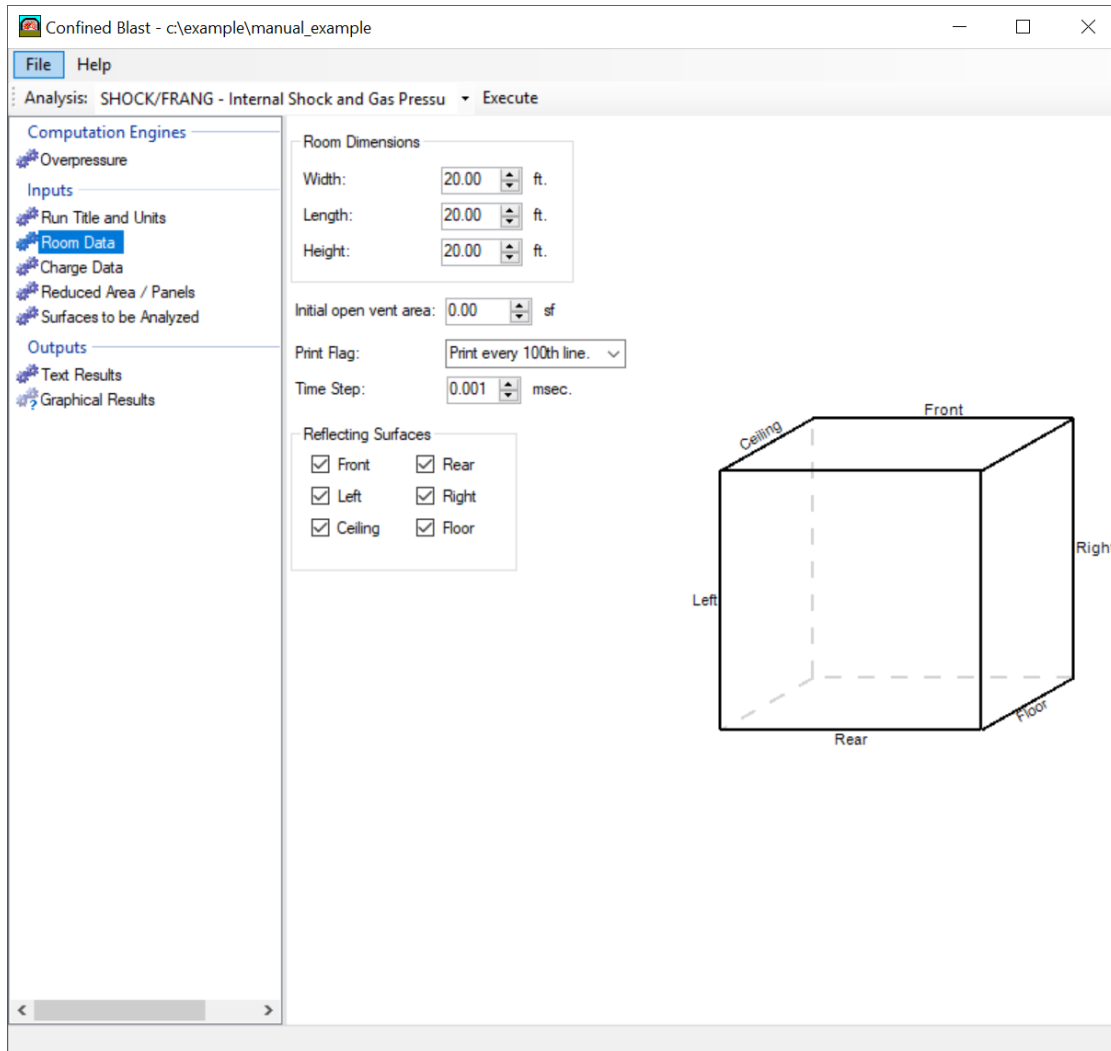


Figure 3-5. SHOCK/FRANG Room Data Input Menu

3.5 Charge Data

3.5.1 Charge Data – SHOCK, SHOCK/FRANG

- Input screen shown in Figure 3-6.
- SHOCK code automatically assumes a spherical charge.
- Indicate the position of the charge with respect to its distance from the floor, front wall, and left wall, as shown on the figure seen at the bottom of the screen. These distances are assumed to be to the centroid of the charge.
- Scaled distance to any surface must be greater than 0.2 and less than 100 $\text{ft}/\text{lbs}^{1/3}$
- If the charge weight exceeds these parameters, SHOCK (in the .SS0 output file) will display a warning noting the violation and a declaration that “Calculated pressure and impulse may be less than actual value”.

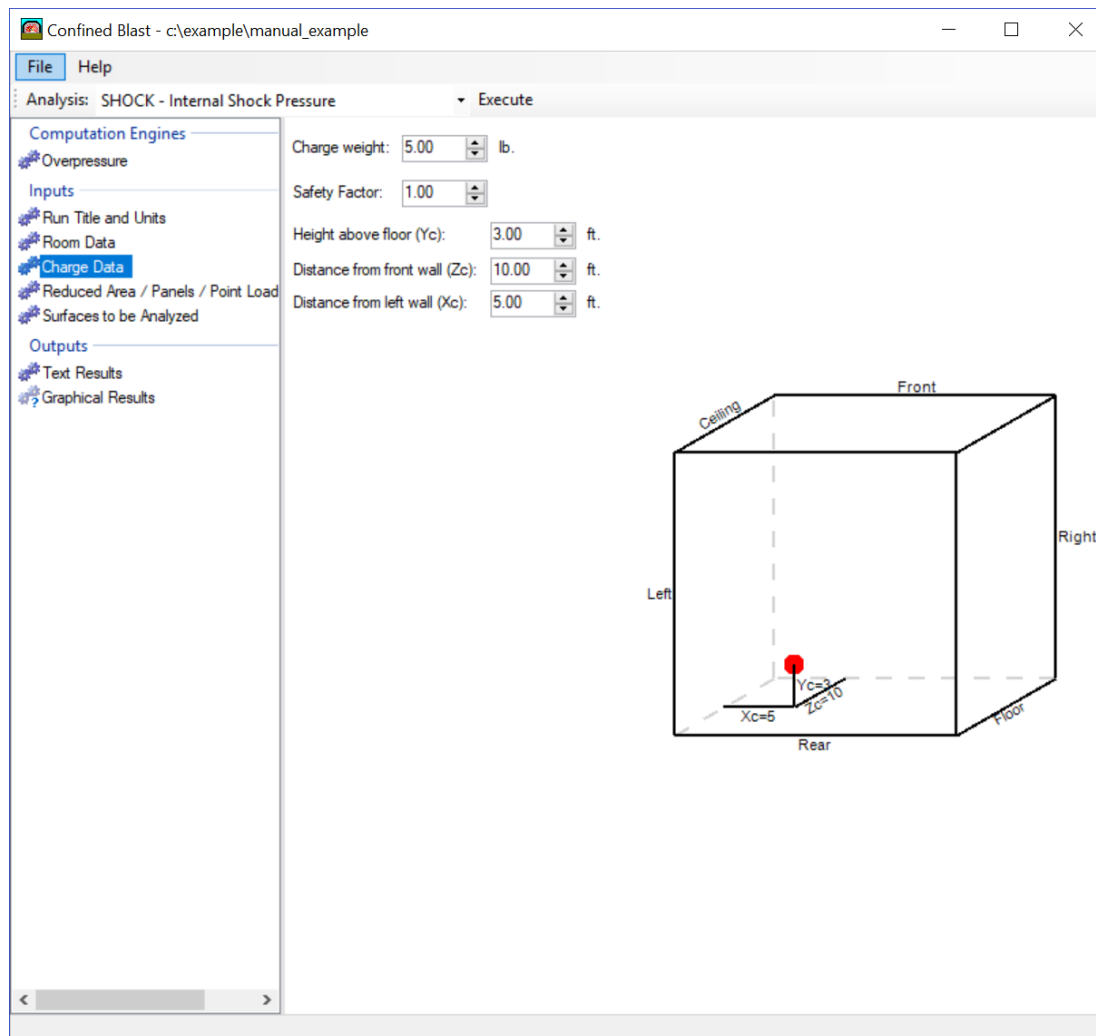


Figure 3-6. SHOCK, SHOCK/FRANG Charge Data Input Menu

3.6 Target Data

3.6.1 SHOCK Reduced Area/ Panels/ Point Loads

- Input menu shown in Figure 3-7.
- Select number of desired reduced area, point, or panel calculations (maximum of 5).
- Select the surface where it is located.
- Select Reduced Area/Panel if average impulse and pressure loadings are desired on an area located on one of the surfaces. Can be useful for doors, windows, etc.
- Reduced areas can also be a point.
- Define corner coordinate of panel according to local origin shown in the on-screen graphic.
- Define Height and Width of panel as shown in the figure.
- Local origin is defined based on an observer looking at load wall from inside the structure as shown in on-screen graphic.
- These coordinates are compared with the coordinates of the blast surface grid, with the grid points nearest being used to define the reduced area.

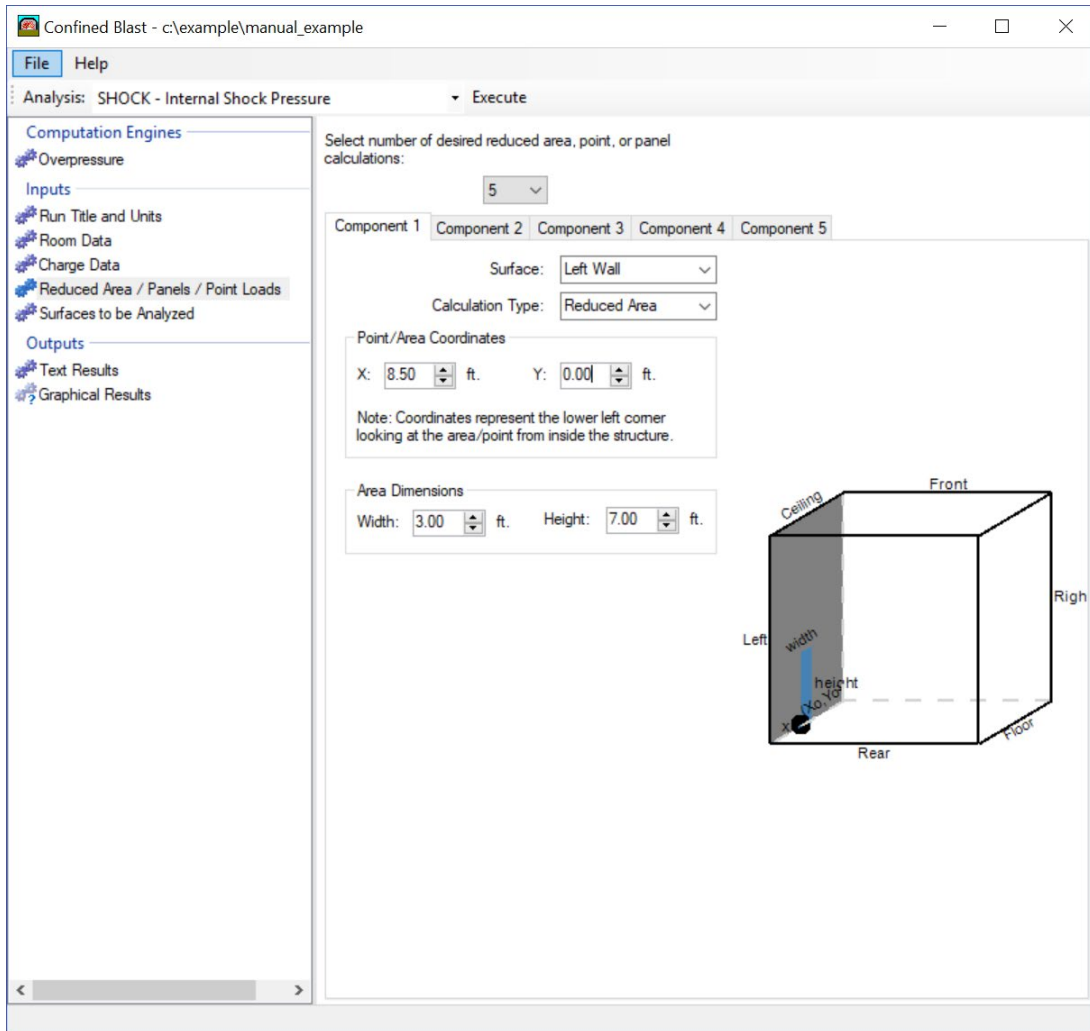


Figure 3-7. SHOCK Reduced Area/ Panels / Point Loads Input Menu

3.6.2 FRANG Frangible Panels

- Input menu shown in Figure 3-8.
- Select the number of frangible panels (maximum of 5).
- Frangible panels are exterior surfaces designed to break loose and blow away quickly enough to limit the effects of an explosion inside the room.
- FRANG will reject a problem if the initial open vent area is set to zero and no frangible panels are included. A room with no vents can be simulated by specifying a very small initial open vent area or an extremely heavy frangible panel.
- FRANG requires that the frangible panel weight be greater than zero if the covered vent area is greater than zero. If this weight is entered in as zero, FRANG will change it to 0.00001.
- A vent without a covering panel can be analyzed by setting the initial open vent area equal to the vent area and inputting no frangible panels.
- For each area or panel:
 - o Select the surface where it is located.
 - o Select the height and width of the area or panel.
 - o Define corner coordinate of panel according to local origin shown in the figure.
 - o Local origin is defined based on an observer looking at load wall from inside the structure.
 - o Enter in the recessed depth. FRANG accounts for the additional time required to displace the panel by the amount of recessed depth before venting can begin.
 - o Enter in the surface weight.
 - o Enter in the initial velocity. This entry may be used if the initial panel velocity is calculated by the user. However, it is recommended that this value be left at zero, in which case the software will calculate the initial velocity of the panel based on the applied impulse.
 - o Enter in the impulse load of the reduced area or panel. This impulse load is used to calculate the initial velocity of the frangible panel, if that value is not input by the user (i.e. the initial velocity is left as zero). If the user inputs an initial velocity for the panel, the impulse load on the panel is not used in the software's calculations. If no value is input for the impulse load, the software will calculate the panel velocity based on the gas pressure acting on the panel.
 - o Select Apply Gravity as appropriate (e.g. for panels located in the roof of a room).
 - o Select whether the top, bottom, right, and/or left edges will act as vents. For most scenarios, all edges should be assumed to act as vents.

However, in some scenarios, external features may prevent venting along a given panel edge, e.g. frangible panels at ground level should be assumed not to vent along their bottom edge.

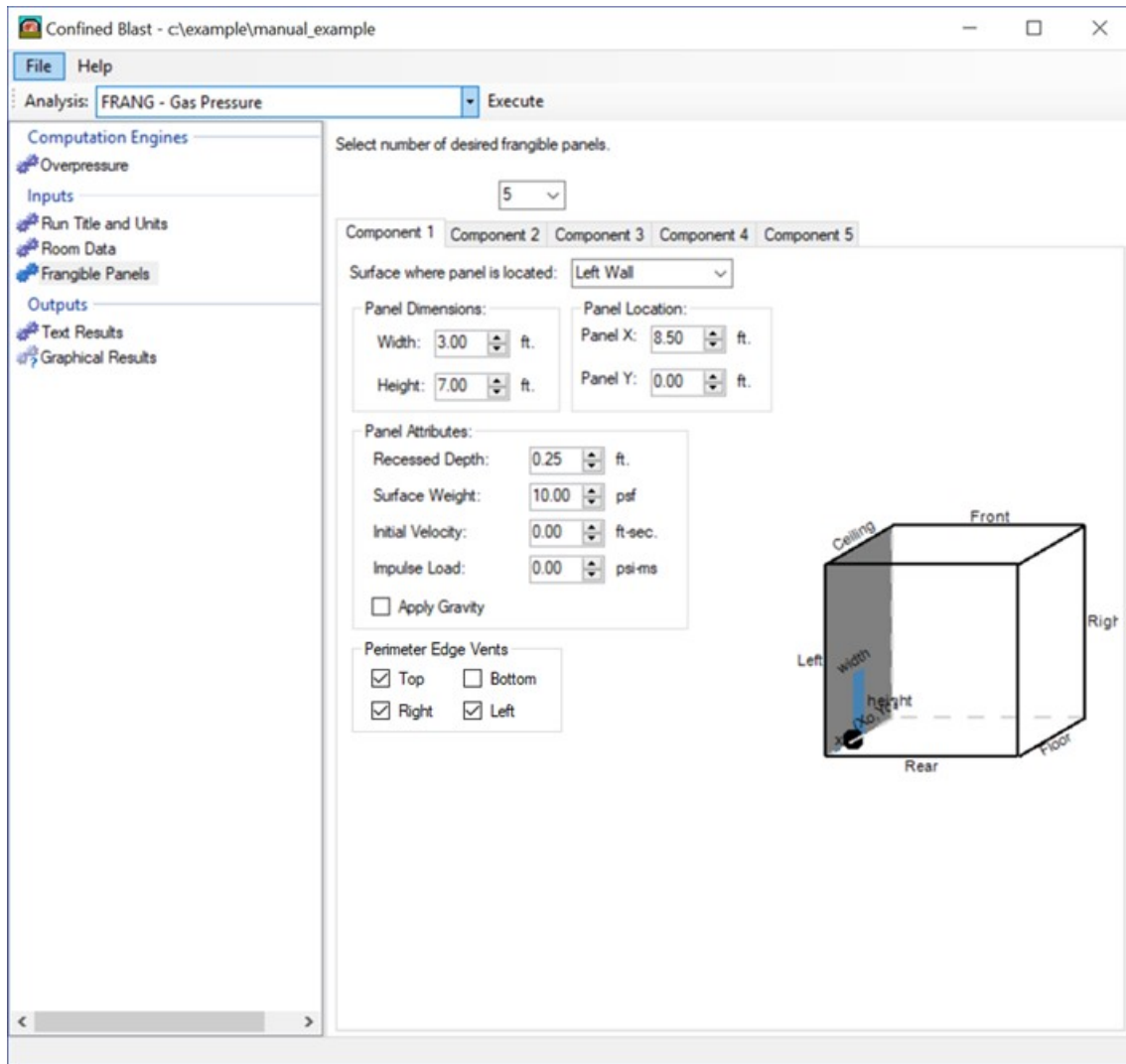


Figure 3-8. FRANG Frangible Panels Input Menu

3.6.3 SHOCK/FRANG Reduced Area Panels

- Input menu shown in Figure 3-8.
- Select number of desired reduced area, point, or panel calculations (maximum of 5).
- Select the surface where it is located.
- Select Reduced Area/Panel if average impulse and pressure loadings are desired on an area located on one of the surfaces. By default, frangibility for these panels is turned off (i.e. panels are assumed not to displace away from surface).
- Define corner coordinate of panel according to local origin shown in the on-screen graphic.
- Define Height and Width of panel as shown in the figure.
- Local origin is defined based on an observer looking at load wall from inside the structure as shown in on-screen graphic.
- These coordinates are compared with the coordinates of the blast surface grid, with the grid points nearest being used to define the reduced area.
- To turn on frangibility for a given panel, select and enable 'Frangibility' checkbox as shown in Figure 3-10.
- Enter frangible panel input data for each area or panel:
 - o Enter in the recessed depth. FRANG accounts for the additional time required to displace the panel by the amount of recessed depth before venting can begin.
 - o Enter in the surface weight.
 - o Enter in the initial velocity. This entry may be used if the initial panel velocity is calculated by the user. However, it is recommended that this value be left at zero, in which case the software will calculate the initial velocity of the panel based on the applied impulse.
 - o Enter in the impulse load of the reduced area or panel. This impulse load is used to calculate the initial velocity of the frangible panel, if that value is not input by the user (i.e. the initial velocity is left as zero). If the user inputs an initial velocity for the panel, the impulse load on the panel is not used in the software's calculations. If the impulse load is left at zero, the software will automatically apply the impulse load calculated in the SHOCK software to the frangible panel.
 - o Select Apply Gravity as appropriate (e.g. for panels located in the roof of a room).
 - o Select whether the top, bottom, right, and/or left edges will act as vents. For most scenarios, all edges should be assumed to act as vents. However, in some scenarios, external features may prevent venting along a given panel edge, e.g. frangible panels at ground level should be assumed not to vent along their bottom edge.

- Thickness and effective mass inputs are not used by the software. Entries are left to ensure compatibility with needed file formats. User should leave entries at default values

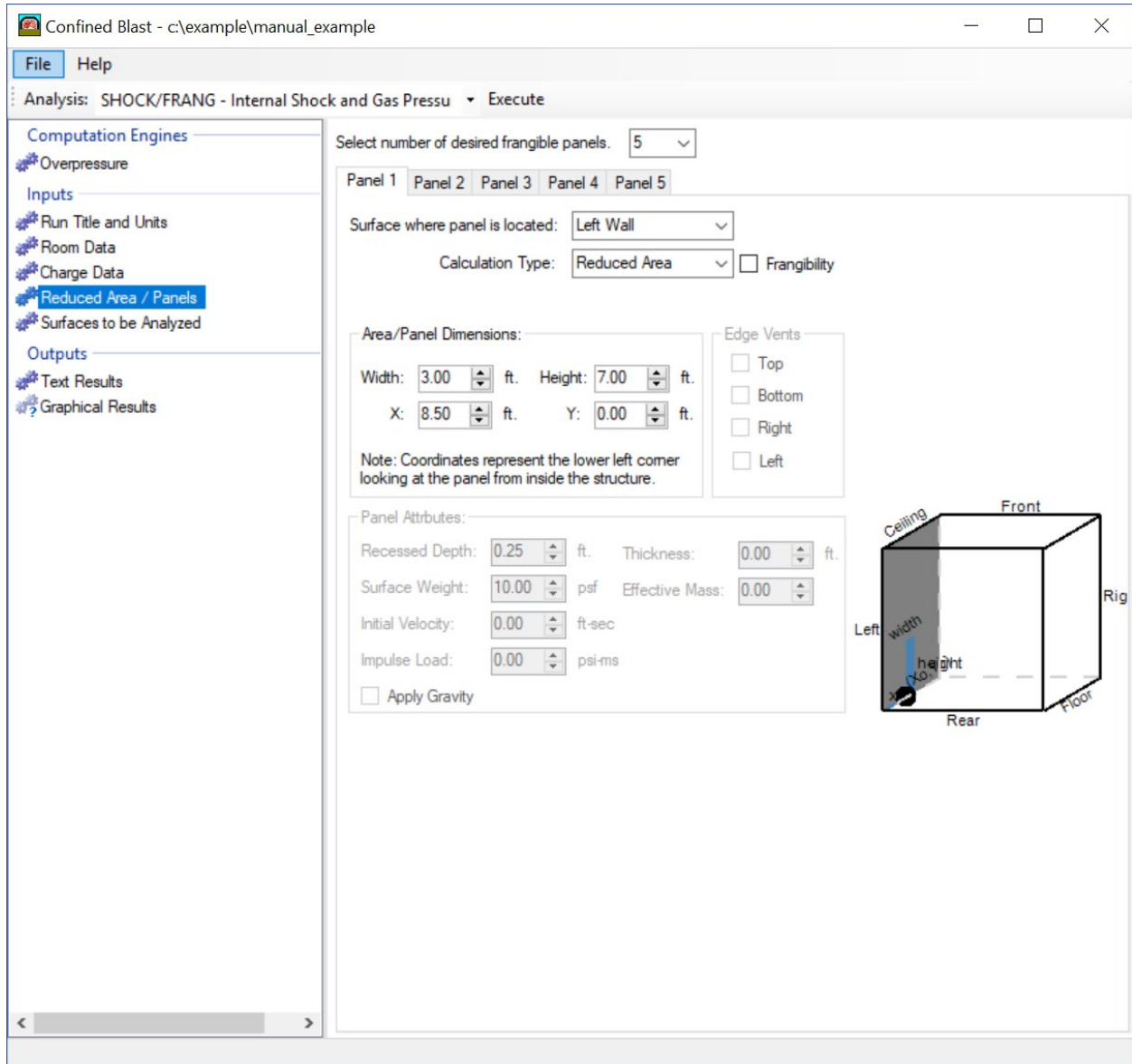


Figure 3-9. SHOCK/FRANG Reduced Area/ Panels Input Menu

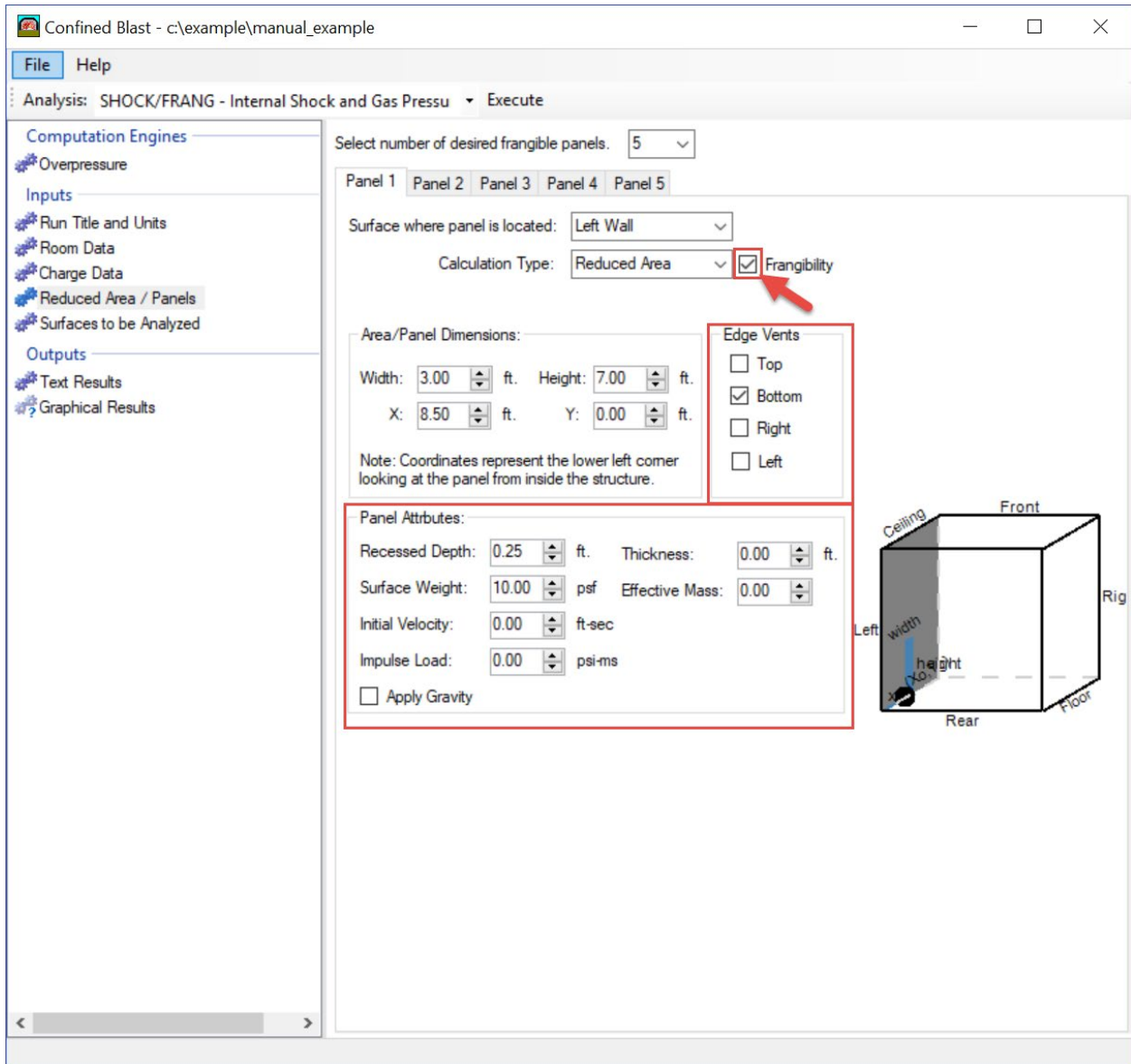


Figure 3-10. SHOCK/FRANG Reduced Area/ Panels Frangibility Input Menu

3.6.4 SHOCK, SHOCK/FRANG Surfaces to be Analyzed

- Input menu shown in Figure 3-11.
- Select each surface for which SHOCK and/or FRANG overpressure calculations are desired.
- For a SHOCK or SHOCK/FRANG analysis, once the previous step is completed, user may execute analysis by clicking 'Execute'.

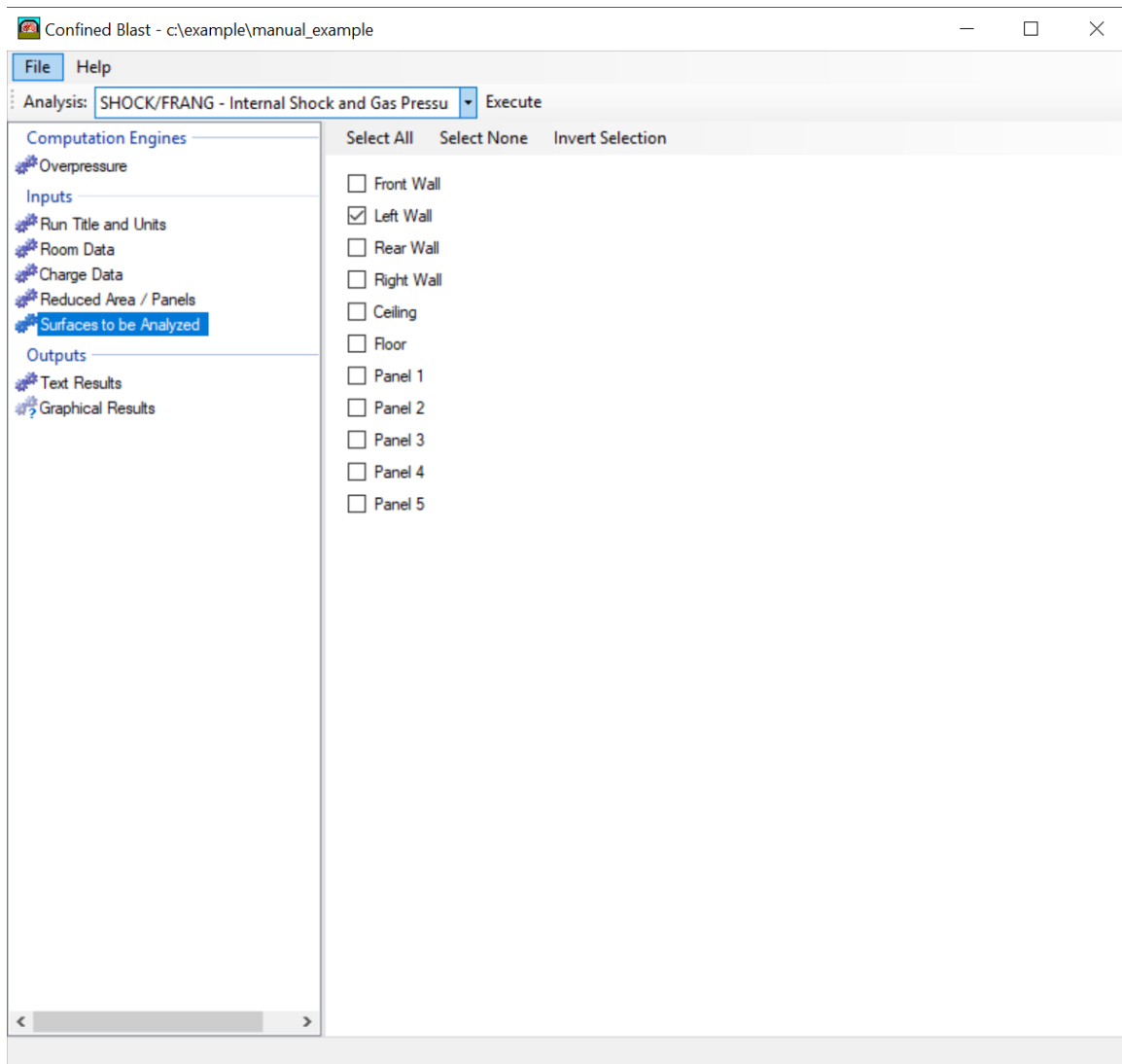


Figure 3-11. SHOCK, SHOCK/FRANG Surfaces to be Analyzed Input Menu

3.7 MUDEMIMP General Data

- Input Screen Shown in Figure 3-12:
 - o Random Monte Carlo Simulations: Total number of debris trajectories calculated by the MUDEMIMP software. Recommended value is 5,000.
 - o Total Effective Destroyed Mass: Weight of the total destroyed mass analyzed by the software
 - o Critical Kinetic Energy: Minimum kinetic energy for a given debris to be considered a hazardous fragment. Default value of 58 ft-lbs reflects current criteria.
 - o Initial Random Seed: Used to generate random parameter distributions. Recommend user use default value of 14555568.0
 - o Trajectory Output Data Required: Select box to produce detailed trajectory data for each MUDEMIMP simulation. Note: the selection of this option significantly increases the size of the produced output files and the runtime of the software, potentially leading to run-time errors.

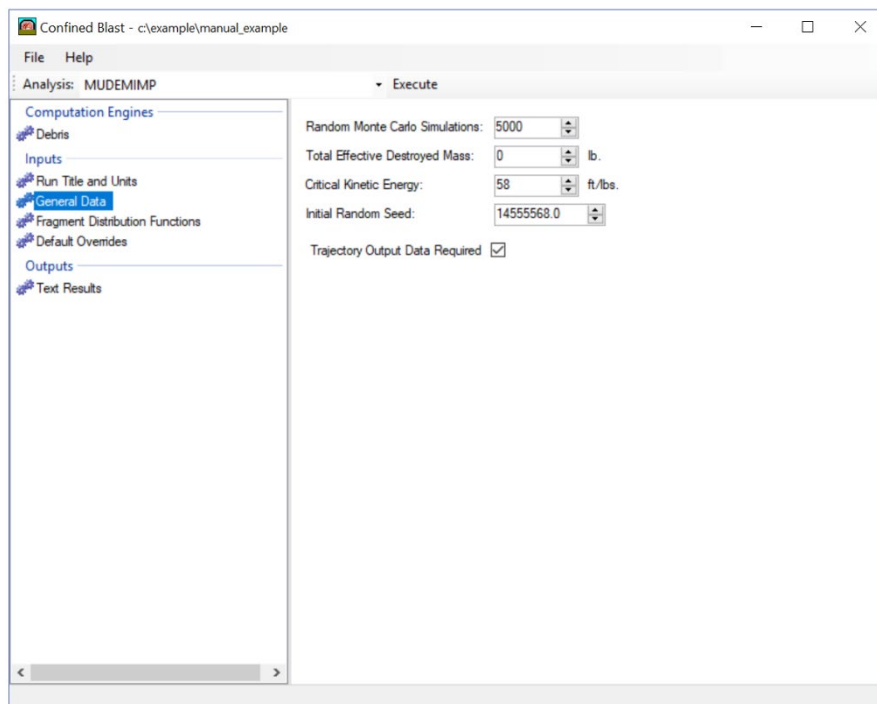


Figure 3-12 MUDEMIMP General Data Input Menu

3.8 MUDEMIMP Distribution Functions Input

- For a MUDEMIMP analysis, enter input data for the five distributions required as follows:
 - o Mass distribution input (Figure 3-13).

- Launch Velocity distribution input (Figure 3-14).
 - Launch Angle distribution input (Figure 3-15).
 - Drag Coefficient distribution input (Figure 3-16).
 - Drag Area Factor distribution input (Figure 3-17).
- The distribution types should be determined in accordance with Department of Defense Explosives Safety Board (DDESB) Technical Paper 13 [3].
 - Available distribution types are Exponent, Uniform, Normal, or Constant.
 - For Exponent distributions, enter average value.
 - For Uniform distributions, enter maximum and minimum values.
 - For Normal distributions, enter average and standard deviation values.
 - For Constant distributions, enter average value.

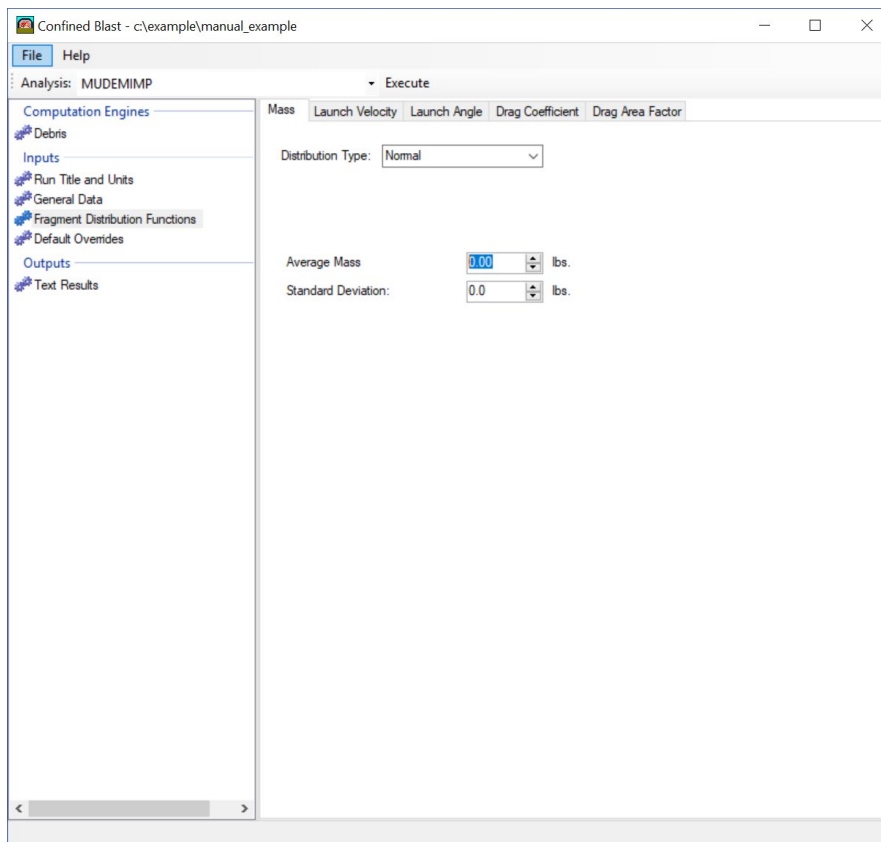


Figure 3-13. MUDEMIMP Mass Distribution Input Menu

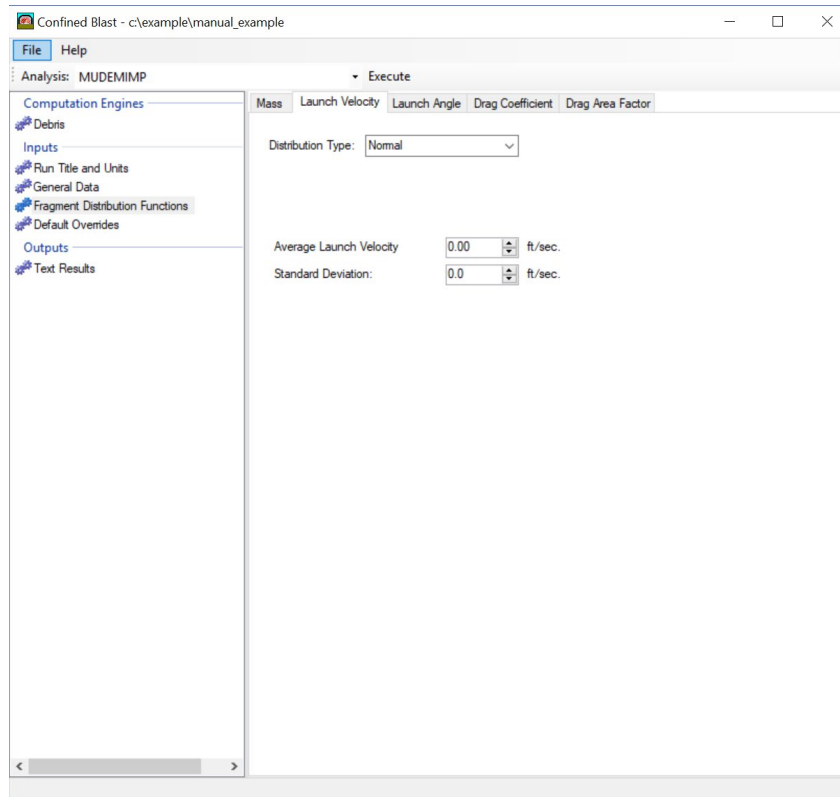


Figure 3-14. MUDEMIMP Launch Velocity Distribution Input Menu

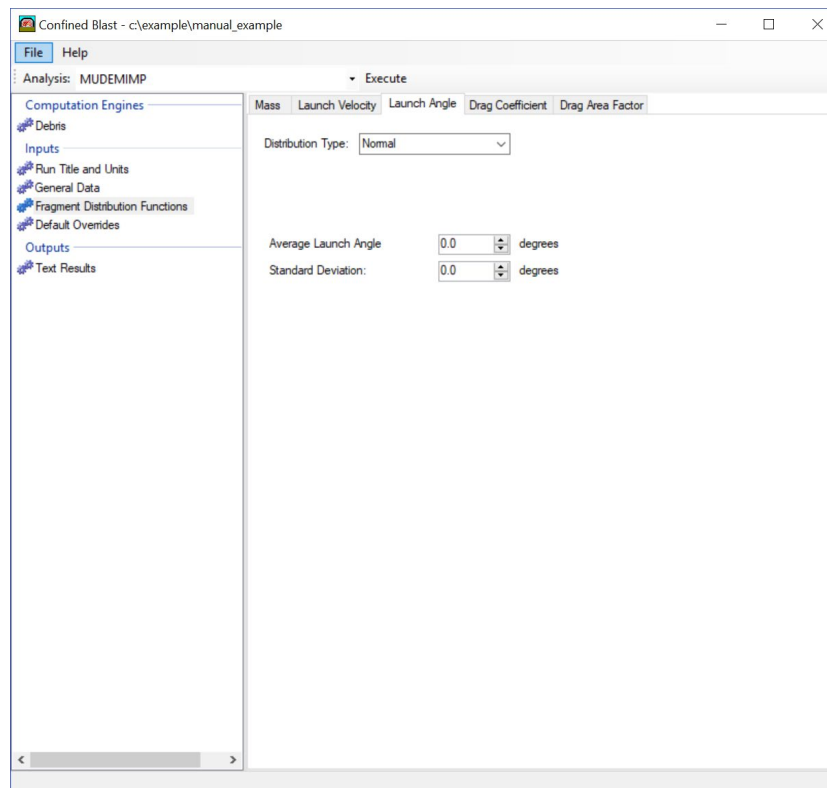


Figure 3-15. MUDEMIMP Launch Angle Distribution Input Menu

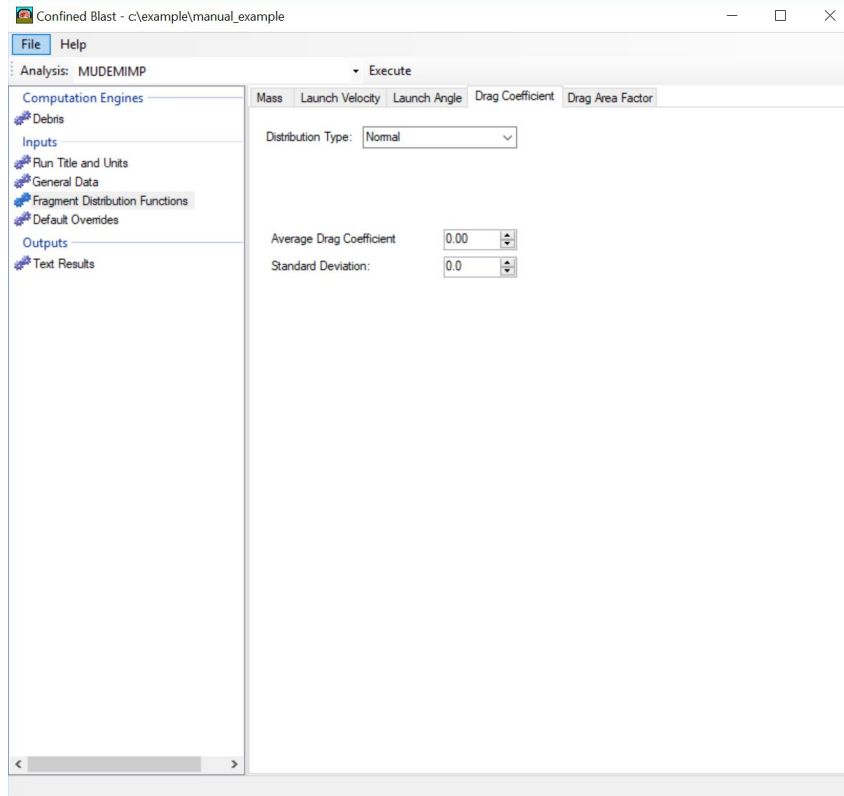


Figure 3-16. MUDEMIMP Drag Coefficient Distribution Input Menu

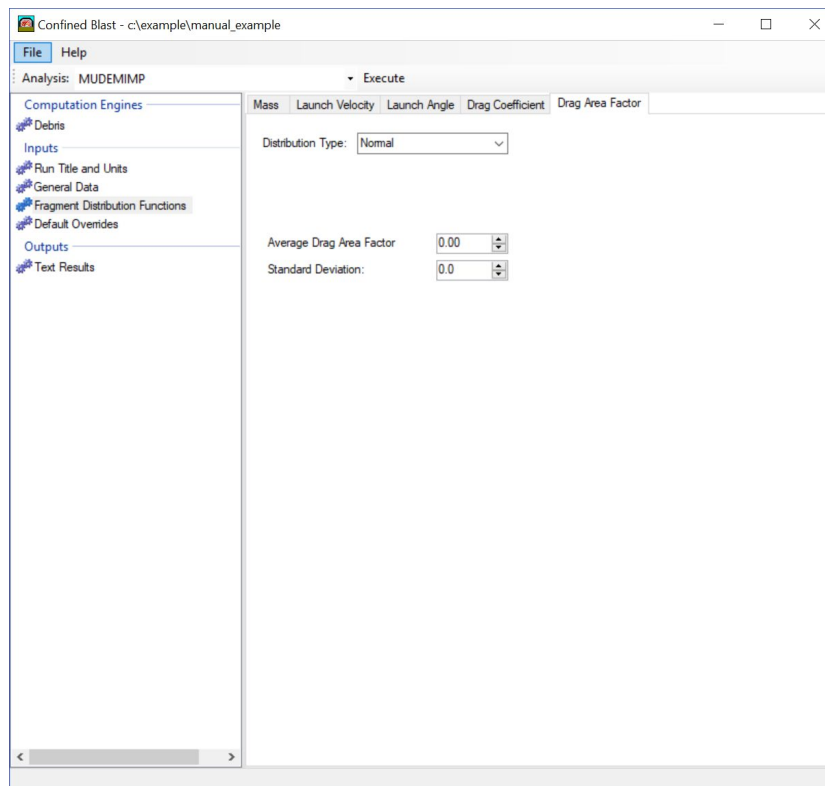


Figure 3-17. MUDEMIMP Drag Area Factor Distribution Input Menu

3.9 MUDEMIMP Default Overrides Input

- Input menu shown in Figure 3-18.
- Verify and/or enter values for desired overrides in MUDEMIMP analysis. The user should refer to TP-13 [3] for guidance on values to use for the default overrides to conduct hazardous fragment analyses. However, for ease of use, values that are commonly edited by the user are summarized below:
 - (1-D) Debris Material Density: Input material density of analyzed fragments.
 - (7-BKUP) Breakup Factor: Indicates whether material is expected to breakup along three dimensions (such as with concrete or plaster walls, which also fragment through their thickness), or two dimensions (such as with masonry walls or metal panels, which typically only fracture along their transverse dimensions).
 - (8-IRIC) Ricochet Factor: User is recommended to select “Include Empirical Roll” for analysis compliant with TP-13 methodology. However, MUDEMIMP can also predict response to first impact of fragments if “First Impact Distance Only” is selected. “Include FRAGHAZ Logic” can produce unrealistic values and is not recommended for use; option is left within the code for comparison with legacy calculations.
 - (10-L) Wall/Shell Thickness (Masonry): Input thickness of masonry wall, metal panel, etc. if “2-Dimensional” is selected for (7-BKUP).
 - (12-Y) Initial Vertical Fragment Coordinate: Input initial height of fragment (typically charge height for close-in loading, mid-height of the wall for far-range loading, or height of the roof for roof fragments).
 - (19-GRIDL) Effective Destroyed Width: Input effective destroyed width of wall for determination of fragment “collection bins”. Typically equal to full width of wall (for far-range loading) or diameter of assumed destroyed “disk” of wall (for close-in loading) See TP-13 [3] for full methodology of GRIDL calculation.
- It is recommended that the user does not update the other default override values to ensure compliance with TP-13 methodologies.
- For a MUDEMIMP analysis, once the previous step is completed, user may execute analysis by clicking ‘Execute’.

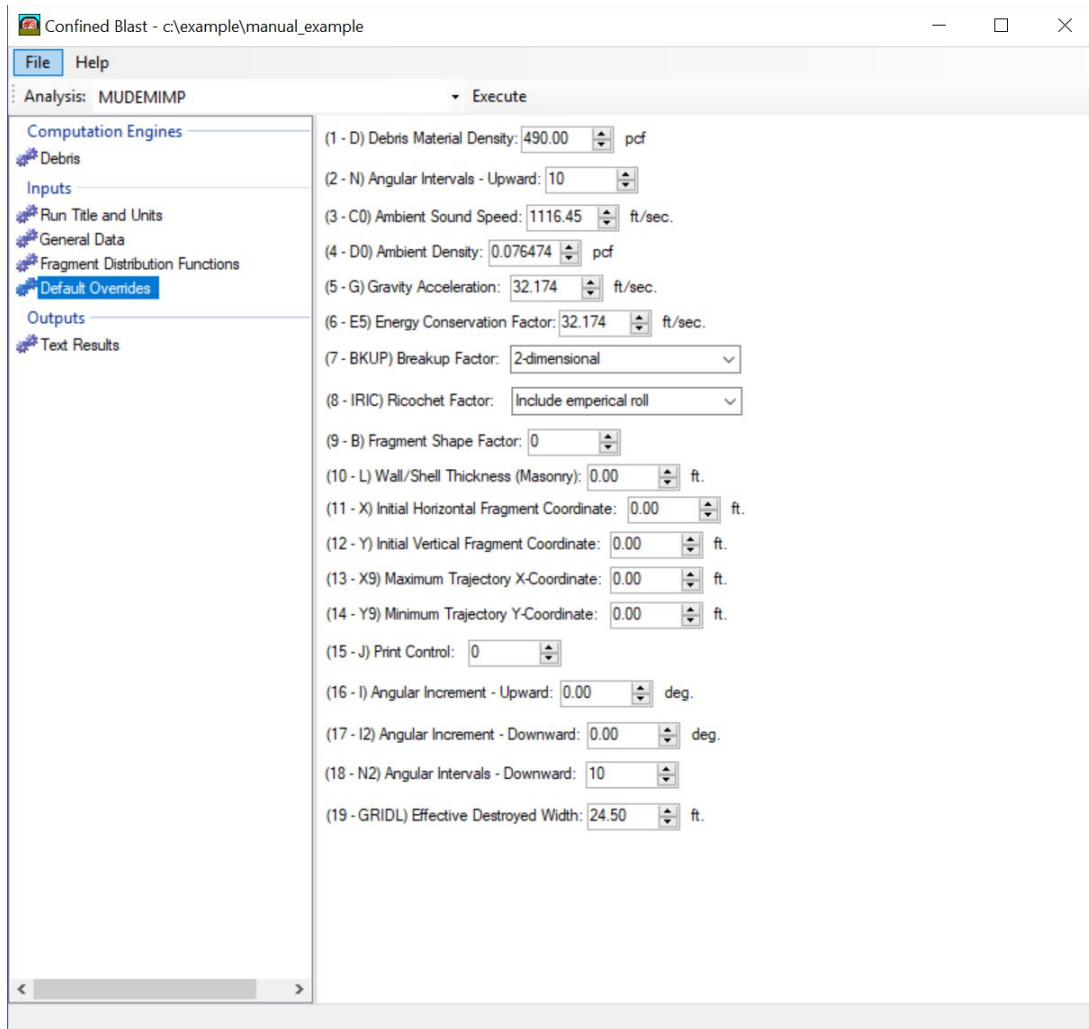


Figure 3-18. MUDEMIMP Default Overrides Input Menu

4.0 OUTPUT DATA

4.1 Text Results—ALL

- Single-clicking on the graphical file displays the result in the lower right window of ConfinedBlast. Double-clicking on the text file brings up the file in a new window using Word Pad. Descriptions of ConfinedBlast text output files are provided in Table 4-1.

Table 4-1. Descriptions of ConfinedBlast Text Output Data Files

Text Results Filename	Program File is Applicable to	File Description
DP1	MUDEMIMP	Number of hazardous debris vs. distance. This is a MUDEMIMP output file.
DS1	MUDEMIMP	Standard output file for MUDEMIMP, summarizing all input parameters, trajectory data (if trajectory output data is required) and maximum throw distance/critical throw distance. This is a MUDEMIMP output file.
DS2	MUDEMIMP	Small text file showing maximum throw distance and minimum separation distance (i.e. hazardous fragment distance). This is a MUDEMIMP output file
FII	FRANG, SHOCK/FRANG	Total gas impulse inside the structure. This is a FRANG output file.
FNG	FRANG, SHOCK/FRANG	This is the data input file as it is read by FRANG, created from the XPL file. This is a ConfinedBlast output file.
FP1	FRANG, SHOCK/FRANG	A small text file showing the peak gas pressure and duration of pressure inside the structure.
FP2	FRANG, SHOCK/FRANG	A text file showing the pressure-time history and impulse-time history inside the structure.
FP3	FRANG, SHOCK/FRANG	A text file showing the displacement-time history for frangible panels.
FS0	FRANG, SHOCK/FRANG	The standard output file for FRANG. This file is a FRANG output file.
FS1	FRANG, SHOCK/FRANG	A detailed summary of all computations made for this analysis. This file is a FRANG output file.

FS2	FRANG, SHOCK/FRANG	An abbreviated summary of all computations made for this analysis. This file is a FRANG output file.
MMP	MUDEMIMP	ConfinedBlast Output. Data input file for MUDEMIMP.
SCR	MUDEMIMP	MUDEMIMP Output. Miscellaneous output data.
SHK	SHOCK, SHOCK/FRANG	This is the data input file as it is read by SHOCK, created from the XPL file. This is a ConfinedBlast Output file.
SP1	SHOCK, SHOCK/FRANG	Text file showing the pressure, duration, and impulse from the shock load on each structural element. This is a SHOCK output file.
SP2	SHOCK, SHOCK/FRANG	Text file of data showing the shock impulse on each structural surface organized as a grid. This is just raw output data with a full grid printout. This is a SHOCK output file.
SP3	SHOCK, SHOCK/FRANG	Text file of data showing the shock pressure on each structural surface organized as a grid. This is just raw output data with a full grid printout. This is a SHOCK output file.
SS0	SHOCK, SHOCK/FRANG	Standard output file showing the results from the SHOCK analysis in an organized and easy-to-read format. Results include: <ul style="list-style-type: none"> ○ The average pressure and impulse on the blast surface due to the incident wave and the reflected wave off each existing adjacent surface. ○ Note that SHOCK treats the blast surface as the front wall in the analysis and the reflecting surfaces in the results are oriented with respect to that definition. ○ The final pressure result is the maximum of the average pressures on the blast surface from the incident wave or any of the reflected waves.

		<ul style="list-style-type: none"> ○ The final impulse result is the sum of the average impulses on the blast surface from the incident wave and all reflected waves. ○ The results conclude with the impulse duration on the blast surface. <p>This is a SHOCK output file.</p>
SS1	SHOCK, SHOCK/FRANG	<p>Text file of data showing the shock impulse on each structural surface organized as a grid. In this file, the information is organized in a clear and easily read manner.</p> <ul style="list-style-type: none"> ○ This is a compressed printout with results listed for 33 y-coordinates and 9 x-coordinates at a time, limiting each set of results to one page. <p>This is a SHOCK output file.</p>
SS2	SHOCK, SHOCK/FRANG	<p>Text file of data showing the shock pressure on each structural surface organized as a grid. In this file, the information is organized in a clear and easily read manner.</p> <ul style="list-style-type: none"> ○ This is a compressed printout with results listed for 33 y-coordinates and 9 x-coordinates at a time, limiting each set of results to one page. <p>This is a SHOCK output file.</p>
SS3	SHOCK, SHOCK/FRANG	<p>General summary of shock loads on each surface. This is a SHOCK output file.</p>
SUM	FRANG, SHOCK, SHOCK/FRANG, MUDEMIMP	<p>Text file showing a general summary of geometry and material properties for each structural surface and frangible panel. This is a ConfinedBlast output file.</p>
XPL	FRANG, SHOCK, SHOCK/FRANG, MUDEMIMP	<p>A text file showing the input data created from the information the user entered into ConfinedBlast. This is a ConfinedBlast data input file.</p>

4.2 Graphical Results—ALL

Single-clicking on the graphical file displays the result in the lower right window of ConfinedBlast. Double-clicking on the graphical file brings up the file in a new window using Windows Picture and Fax Viewer. Descriptions of ConfinedBlast text output files are provided in Table 4-2.

Table 4-2. Descriptions of ConfinedBlast Graphical Output Data Files

Graphical Results Filename	Program File is Applicable to	File Description
Pressure psi	SHOCK, SHOCK/FRANG	A figure showing the pressure distribution across the indicated SHOCK surface(s).
Impulse psi-ms	SHOCK, SHOCK/FRANG	A figure showing the impulse distribution across the indicated SHOCK surface(s).
Pressure and Impulse Chart	FRANG, SHOCK/FRANG	A chart showing the internal gas pressure-time history.

5.0 EXAMPLE PROBLEMS

5.1 SHOCK Example 1

Input

- Room Data:
 - o Width = 20.00 ft
 - o Length = 20.00 ft
 - o Height = 20.00 ft
 - o Reflecting Surfaces: Front, Left, Right, Ceiling, Floor
- Charge Data:
 - o Charge Weight = 100.00 lbs
 - o Safety Factor = 1.0
 - o Height Above Floor = 5.00 ft
 - o Distance From the Front Wall = 5.00 ft
 - o Distance From the Left Wall = 5.00 ft
- Reduced Area/Panel:
 - o No reduced areas/panels in this problem
- Surfaces to be Analyzed:
 - o Left Wall

Output

- Average SHOCK Pressure Due to Waves Off Reflecting Surfaces:
 - o Floor = 865.8 psi
 - o Left = 0.0 psi
 - o Ceiling = 31.9 psi
 - o Right = 865.8 psi
 - o Opposite = 27.7 psi
- Average SHOCK Impulse on Blast Surface Due to Waves Off Reflecting Surfaces:
 - o Floor = 173.6 psi-ms
 - o Left = 0.0 psi-ms
 - o Ceiling = 55.4 psi-ms
 - o Right = 173.6 psi-ms
 - o Opposite = 70.6 psi-ms
- Average SHOCK Pressure Due to Incident Wave = 1058.2 psi
- Average SHOCK Impulse Due to Incident Wave = 231.5 psi-ms
- Maximum Average SHOCK Pressure on Blast Surface: 1058.2 psi
- Maximum Average SHOCK Impulse on Blast Surface: 704.7 psi-ms
- SHOCK Load Duration on Blast Surface = 1.33 ms

- Scaled Impulses Have Been Divided By $W^{(1/3)} = 4.64$

5.2 SHOCK Example 2

Input

- Room Data:
 - o Width = 16.00 ft
 - o Length = 16.00 ft
 - o Height = 10.00 ft
 - o Reflecting Surfaces: Front, Left, Right, Ceiling, Floor, Rear
- Charge Data:
 - o Charge Weight = 100.00 lbs
 - o Safety Factor = 1.0
 - o Height Above Floor = 5.00 ft
 - o Distance From the Front Wall = 5.00 ft
 - o Distance From the Left Wall = 5.00 ft
- Reduced Area/Panel:
 - o Panel 1
 - Surface Where Panel is Located = Front Wall
 - Calculation Type: Reduced Area
 - Panel Corner Coordinates
 - X = 4.00 ft
 - Y = 4.00 ft
 - Panel Height = 6.00 ft
 - Panel Width = 6.00 ft
- Surfaces to be Analyzed:
 - o Panel 1

Output

- Average SHOCK Pressure Due to Waves Off Reflecting Surfaces:
 - o Floor = 409.3 psi
 - o Left = 407.1 psi
 - o Ceiling = 4914.1 psi
 - o Right = 45.1 psi
 - o Opposite = 60.6 psi
- Average SHOCK Impulse on Blast Surface Due to Waves Off Reflecting Surfaces:
 - o Floor = 157.1 psi-ms
 - o Left = 156.8 psi-ms
 - o Ceiling = 601.9 psi-ms

- Right = 68.6 psi-ms
- Opposite = 101.1 psi-ms
- Average SHOCK Pressure Due to Incident Wave = 3469.6 psi
- Average SHOCK Impulse Due to Incident Wave = 548.3 psi-ms
- Maximum Average SHOCK Pressure on Blast Surface: 4914.1 psi
- Maximum Average SHOCK Impulse on Blast Surface: 1633.7 psi-ms
- SHOCK Load Duration on Blast Surface = 0.66 ms
- Scaled Impulses Have Been Divided By $W^{(1/3)} = 4.64$

5.3 FRANG Example 1

Input

- Room Data:
 - Width = 20.00 ft
 - Length = 20.00 ft
 - Height = 20.00 ft
- Charge Data:
 - Charge Weight = 100.00 lbs
 - Safety Factor = 1.0
- Initial Open Vent Area
 - Vent Area = 16 sf
- Time Step
 - Time step = 0.001 ms
- Reduced Area/Panel:
 - No reduced area/panels in this problem

Output

- Peak Gas Pressure = 113.29 psi
- Total Gas Duration = 582.96 ms
- Total Gas Impulse = 20896.83 psi-ms
- Equivalent Gas Duration (Based on Triangular Pulse) = 368.92 ms

5.4 FRANG Example 2

Input

- Room Data:
 - Width = 16.00 ft
 - Length = 16.00 ft
 - Height = 10.00 ft

- Charge Data:
 - o Charge Weight = 100.00 lbs
 - o Safety Factor = 1.0
- Initial Open Vent Area
 - o Vent Area = 0 sf
- Time Step
 - o Time step = 0.001 ms
- Reduced Area/Panel:
 - o Panel 1
 - Surface where panel is located = Front Wall
 - Panel Width = 8.00 ft
 - Panel Height = 4.00 ft
 - Panel Location (X) = 4.00 ft
 - Panel Location (Y) = 4.00 ft
 - Recessed Depth = 0.00 ft
 - Surface Weight = 25.00 psf
 - Initial Velocity = 0.00 ft/sec
 - Impulse Load = 25 psi-ms
 - Applied Gravity = No
 - Perimeter Vents: Top, Bottom, Left, Right

Output

- Peak Gas Pressure = 244.93 psi
- Total Gas Duration = 220.8 ms
- Total Gas Impulse = 13711.52 psi-ms
- Equivalent Gas Duration (Based on Triangular Pulse) = 111.96 ms

5.5 MUDEMIMP Example 1

Input

- General Data:
 - o Number of Monte Carlo Simulation = 5000
 - o Total Effective Destroyed Mass = 10,440 lbs
 - o Critical Kinetic Energy = 58 ft-lbs
 - o Initial Random Seed = 14555568.0
- Fragment Distribution Functions:
 - o Mass Distribution Type: Exponential
 - o Average Mass = 2.6 lbs
 - o Launch Velocity Distribution Type: Normal

- Average Launch Velocity = 104.00 ft/sec
- Standard Deviation of Launch Velocity = 24.0 ft/sec
- Launch Angle Distribution Type: Normal
- Average Launch Angle = 0.0°
- Standard Deviation of Launch Angle = 1.3°
- Drag Coefficient Distribution Type: Uniform
- Maximum Drag Coefficient = 1.0
- Minimum Drag Coefficient = 2.0
- Drag Area Factor Distribution Type: Constant
- Drag Area Factor = 1.0
- Default Overrides
 - Debris Material Density = 150 pcf
 - Break-up Factor: 3-Dimensional
 - Ricochet Factor: Include empirical roll
 - Wall/Shell Thickness (Masonry) = 1.00 ft
 - Initial Vertical Fragment Coordinate = 2.00 ft
 - Effective Destroyed Width = 9.40 ft
 - Any values not listed are default MUDEMIMP values

Output

- Maximum Throw Distance = 656 ft
- Minimum Separation Distance (Maximum Hazardous Fragment Distance) = 644 ft

5.6 MUDEMIMP Example 2

Input

- General Data:
 - Number of Monte Carlo Simulation = 5000
 - Total Effective Destroyed Mass = 1,872 lbs
 - Critical Kinetic Energy = 58 ft-lbs
 - Initial Random Seed = 14555568.0
- Fragment Distribution Functions:
 - Mass Distribution Type: Exponential
 - Average Mass = 0.8 lbs
 - Launch Velocity Distribution Type: Normal
 - Average Launch Velocity = 1785.00 ft/sec
 - Standard Deviation of Launch Velocity = 416.0 ft/sec
 - Launch Angle Distribution Type: Normal

- Average Launch Angle = 85.0°
- Standard Deviation of Launch Angle = 10.0°
- Drag Coefficient Distribution Type: Constant
- Drag Coefficient = 1.5
- Drag Area Factor Distribution Type: Constant
- Drag Area Factor = 1.0
- Default Overrides
 - Debris Material Density = 36 pcf
 - Break-up Factor: 2-Dimensional
 - Ricochet Factor: Include empirical roll
 - Wall/Shell Thickness (Masonry) = 0.13 ft
 - Initial Vertical Fragment Coordinate = 12.00 ft
 - Effective Destroyed Width = 20.00 ft
 - Any values not listed are default MUDEMIMP values

Output

- Maximum Throw Distance = 488 ft
- Minimum Separation Distance (Maximum Hazardous Fragment Distance) = 439 ft

6.0 CONFINEDBLAST CODE VERIFICATION AND THEORETICAL BASIS

The ConfinedBlast software tool is a user interface that allows the user to easily enter in problems to be analyzed using SHOCK, FRANG, or MUDEMIMP. Each of these programs are fast-running and utilize both empirical data and analytical methods to compute relevant parameters associated with confined blast events. These programs have been developed separately and utilize program specific theory and assumptions to perform their computations. The following sections of this report document efforts to verify that the results of these programs are suitable for use in the design of blast-resistant structures in explosives safety applications by comparing them to 1) results produced by previously approved versions of each respective program, 2) published values for confined blast load prediction, or 3) experimental data produced via physical testing.

6.1 SHOCK 2.0

Reference [4] is the theory manual for the current SHOCK 2.0 computer program. This reference documents the following: 1) the history of development of the SHOCK code, 2) the current theory and assumptions used by SHOCK to calculate the shock pressures and impulses resulting from an explosion in a confined space, 3) a validation study comparing the predictions of the SHOCK 2.0 software with experimental data and the results from the SHOCK 1.0 software, and 4) an appendix for the comparison of the SHOCK 2.0 software with the current UFC 3-340-02 [1] figures for average peak reflected pressure and scaled average unit reflected impulse. Based on the verification studies documented in Reference 43], NAVFAC EXWC concludes that this software produces results that are appropriate for use in calculation of design loads on surfaces for protective construction and explosives safety applications.

6.2 FRANG 2.0

Reference [5] is the theory manual for the FRANG 2.0 computer program. This reference details the history of the development of the FRANG code, as well as the theory and assumptions used by the software to calculate the gas pressure and impulse resulting from an explosion in a confined space. Appendix B of this report documents a verification study NAVFAC EXWC performed on the computer program FRANG 2.0. This study compares FRANG 2.0 confined gas pressure load predictions to experimental data, other available software tools, and published values in UFC 3-340-02 [1] criteria. Based on the verification study documented in Appendix B, NAVFAC EXWC concludes that the FRANG 2.0 software produces predictions for peak gas pressure and impulse that are generally conservative, and appropriate for use in the calculation of gas pressure loads for facilities intended for protective construction.

6.3 MUDEMIMP 2.0

Reference [6] is the theory manual for the first version of MUDEMIMP (version 1.1). MUDEMIMP was developed for the purpose of determining the downrange hazardous distance and dispersion from debris breakup and thus follows the guidance of DDESB TP-13 [3]. The user is referred to TP-13 [3] for additional guidance on how to perform hazardous distance and dispersion analysis due to debris breakup. The version of MUDEMIMP contained in the

ConfinedBlast software package is version 2.0, which features several changes and improvements over version 1.1. These changes and improvements are documented in Reference [7]. As part of the official release of the ConfinedBlast program, which includes the MUDEMIMP version 2.0 software, NAVFAC EXWC has completed a verification study that compares the current version of MUDEMIMP against four example sets provided in TP-13 as well as an additional six examples drawn from previous TP-13 analyses done in-house. This study is documented in Appendix C of this report. Based on the results of this study, NAVFAC EXWC concludes that MUDEMIMP version 2.0 is appropriate and conservative for use in determining hazardous fragment distance in accordance with the procedures outlined in TP-13 [3].

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7.0 REFERENCES

- [1] Department of Defense, "Unified Facilities Criteria 3-340-02: Structure to Resist the Effects of Accidental Explosions," 2014.
- [2] P. Wager and J. Tancreto, "SHOCK User's Manual," Naval Civil Engineering Laboratory, Port Hueneme, CA, 1988.
- [3] "Predicting Building Debris for Quantity-Distance Siting", Technical Paper 13, DOD Explosives Safety Board, April 1991.
- [4] S. Donahue, J. Abraham, C. Stewart, and J. Ayars, "Computer Program SHOCK 2.0 Theory Manual. TR-NAVFAC EXWC-SH-2202," Naval Facilities Engineering and Expeditionary Warfare Center, Port Hueneme, CA, June 2020.
- [5] C. A. Kerrigan, "FRANG 2.0 Theory Manual, TR-NAVFAC ESC-CI-1213," Naval Engineering Service Center, Port Hueneme, CA, 2012.
- [6] Huang, L.C.P., "Theory and Computer Program for the Multiple Debris Missile Impact Simulation (MUDEMIMP)", Naval Facilities Engineering Command, Naval Civil Engineering Laboratory, Program No. Y0995-01-003-331, June 1984.
- [7] Ambrosio, A., Chrostowski, J.D., "MUDEMIMP Modifications Technical Report No. 01-444-05", ACTA. Torrance, CA 2001.

APPENDIX A

GLOSSARY

A.1 Glossary of Terms

- Beam: A structural member typically made from steel or reinforced concrete. It is placed horizontally so that loads run along the length of the member. Typical shapes are I-beams, channels, and T-beams.
- Charge Weight: The TNT weight equivalent of the actual weight of the charge.
- Column: A structural member typically made from steel or reinforced concrete. It is placed vertically so that loads act on the ends of the member. Typical shapes are I-beams, channels, and T-beams.
- Cover: (1) A material placed on top of the main structure wall for protection, aesthetics, etc. (2) The space between the surface of the concrete or masonry and the first reinforcing steel inside.
- Debris Throw: The distance traveled by debris caused by the destruction of portions of the structure due to the blast.
- Distributed Load: A load which is equally spread out over the entire surface of a material.
- Frangible Panel: An exterior surface designed to break loose and blow away quickly enough to limit effects from an explosion inside the room.
- Impulse Load: A pressure loading that occurs over a very small interval of time.
- Initial Open Vent Area: An area in the structure prior to the explosion that vents gas pressure freely.
- Initial Velocity: The initial rate of travel of the reduced area/panel or frangible panel.
- Perimeter Edge Vent: The length of the designated edge(s) of the panel that allows gas pressure to vent.
- Point Load: A load which is concentrated on a single point on the surface of a material.
- Print Flag: During calculations, the lines of calculations that will be displayed are flagged.
- Recessed Depth: The depth to which the reduced area/panel or frangible panel is located in the surface.
- Reduced Area/Panel: An area or panel on the surface(s) of interest that is smaller than the surface itself.
- Reflecting Surface: A surface will reflect the shock impulse, which will affect the adjacent surfaces.
- Ricochet: The situation where a piece of debris will rebound of an adjacent surface.
- Roll: The situation where a piece of debris will roll after impact with the ground following the explosion.

- Shell Thickness: The thickness of the masonry wall.
- Shock Surface: A surface on which a distributed shock load will be applied.
- Surface Weight:
- Time Step: The time increment used in FRANG calculations.

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APPENDIX B
FRANG VERIFICATION STUDY

B.1 INTRODUCTION

FRANG is a software package developed by NAVFAC EXWC (then the Naval Civil Engineering Laboratory, NCEL) for the prediction of gas pressures and impulses due to an explosion in a confined space. The first version of this program (FRANG 1.0) was developed in 1989 [1], based on an experimental test series conducted in the 1980's at the Energetic Materials Research and Testing Center [2]. This software was officially endorsed by the DDESB [3], and later used to develop the curves in the UFC 3-340-02 [4] for prediction of confined blast loads. In 1998, the software was updated to FRANG 2.0 to allow for the modeling of up to five frangible panels (rather than the one panel allowed in FRANG 1.0) [5]. Additional refinements to the FRANG calculation methodology were made during this update; however, the precise nature of these updates is not known and the updated version of the software has not been endorsed by the DDESB.

As part of the official release of the ConfinedBlast program, which includes the FRANG 2.0 software, NAVFAC EXWC undertook an effort to verify the current version of FRANG 2.0 against published values for gas pressure and impulse, so that it may be approved by the DDESB for use by the industry in predicting blast loads in confined spaces.

B.2 VERIFICATION METHODOLOGY

Work has been done to validate the predictions from the FRANG software against the 1984 test series used to develop the initial curve-fit equations; this work has been documented in [5]. Further comparison studies were done against a larger collection of test series in [6], which showed the FRANG software (used via the ConfinedBlast interface) produced generally conservative results, with comparable accuracy to other available software (the BlastX software [7], and a proposed spreadsheet solver developed by PEC called GAS-BLAST). However, both studies were limited to available experimental data, within relatively narrow parameter bounds (Summarized in Table B-1 and Table B-2 below). In order to obtain greater confidence in the ability of the FRANG 2.0 software to predict confined gas loads, there was a desire to perform additional verification of the program against a more complete data set, with a wider array of input parameters. To the author's knowledge, there is no such experimental data set, so the verification of FRANG was instead conducted comparing its predictions to published values in the UFC 3-340-02 criteria, which cover a broad range of room, explosive charge, and panel properties. This verification is limited to the FRANG 2.0 version of the software; for ease of readability, this version will be referred to as simply "FRANG" for the remainder of this appendix.

Table B-1. Parameters of Confined Explosions in EMRTC Test Series [2]

Parameters	Bounds
Room Volume (sf)	450
Explosive Weight (lbs)	2 - 27
Scaled Vent Area	0.1 - 1
Scaled Panel Weight (psf/lbs ^{1/3})	0 - 40

Table B-2. Parameters of Test Series Examined in PEC Gas Model Study [6]

Parameters	Bounds
Charge Weight-to-Volume Ratio (lbs/ft ³)	0.005 - 1.0
Scaled Vent Area	0.0 - 1.0
Scaled Panel Weight (psf/lbs ^{1/3})	2 - 75
Scaled Recessed Depth (ft/lbs ^{1/3})	0.01 - 1.0

The UFC criteria provide figures for estimation of the peak gas pressure and scaled gas impulse in a room subjected to a partially confined explosion. These properties are presented on separate graphs (Figure 2-152 for peak gas pressure, and Figures 2-153 through 2-164 for scaled gas impulse), as a function of different parameters (with gas pressure dependent on charge weight-to-volume ratio, and gas impulse primarily dependent on the scaled vent area). Thus, verification of the FRANG algorithm was conducted as two independent efforts, which are detailed separately in the discussions below.

B.3 PREDICTION OF PEAK GAS PRESSURE

B.3.1 VERIFICATION SCENARIOS

To compare the predicted peak gas pressure from the FRANG software against the UFC criteria, explosive scenarios were developed and run in the FRANG software for every data point provided in Figure 2-152. The prediction of the peak gas pressure (in both the FRANG software and the UFC criteria) is solely a function of the ratio of the explosive charge weight to the room volume (in lbs/ft³). However, the FRANG software requires input of all parameters in absolute values.

Thus, an initial “seed” variable must be chosen for the FRANG input values, from which the other values can be derived. An initial volume of 100 ft³ was selected as the seed variable, with the charge weights then calculated based on the weight-to-volume ratios used in the UFC curve. Additional FRANG runs were conducted using different seed variables (i.e. assuming a charge weight of 1 lb, with the volume calculated based on that number) and with different scaled vent areas, which showed identical results to the 100 ft³ scenarios. Thus, it was confirmed that the FRANG results are solely dependent on the charge weight-to-volume ratio, and the conclusions below are based on the results from the 100-ft³ set of runs.

B.3.2 VERIFICATION RESULTS

The prediction of peak gas pressure from FRANG shows close agreement with the values in UFC Figure 2-152 at low charge weight-to-volume ratios, with disparities of less than 5% for ratios below 0.01 lbs/ft³ (corresponding to gas pressures between approximately 1 and 100 psi). However, the current method for calculating gas pressure in FRANG is based on figure 9 from NCEL TR828, which has limited data at higher charge weight-to-volume ratios. This figure was updated in the TM 5-1300 (and later the UFC 3-340-02) to incorporate additional test data. Thus, the predictions in FRANG show lower agreement at these ratios, over-predicting the UFC-listed gas pressure by up to 28% between 0.1 and 1.0 lbs/ft³, and under-predicting the UFC-listed gas pressure by up to 27% above 1.0 lb/ft³ (See **Error! Reference source not found.**). As the controlling peak pressure in a room will typically be governed by shock loading rather than gas loading, this disparity is deemed unlikely to cause significant errors in most typical load cases. However, NAVFAC EXWC suggests updating the FRANG software to reflect the data in the more current UFC figure.

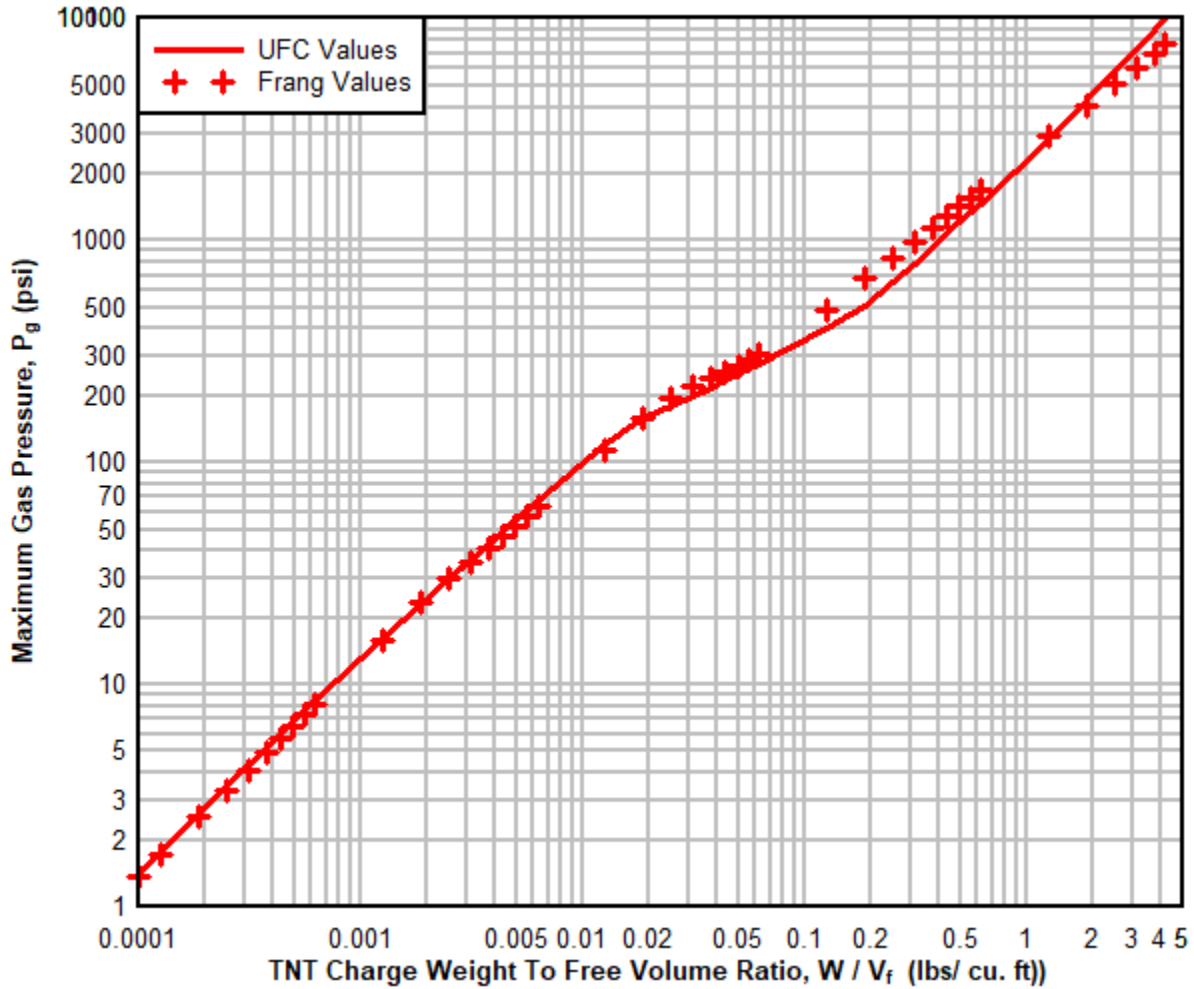


Figure B-1. Comparison between Peak Gas Pressures Published in the UFC 3-340-02, Change 2 and Predicted by FRANG 2.0

B.4 PREDICTION OF SCALED IMPULSE

B.4.1 SELECTION OF VERIFICATION SCENARIOS

To compare the predicted scaled gas impulse from the FRANG software to the UFC criteria, explosive scenarios were developed and run in the FRANG software for every data point provided in UFC figures 2-152 and 2-164. These results are dependent on a number of different parameters: the scaled vent area ($A/V^{2/3}$), the charge weight-to-volume ratio (W/V), the scaled panel weight ($W_f/W^{1/3}$) and the scaled panel impulse ($i/W^{1/3}$). As with the peak gas pressures, these parameters are all relative values, rather than absolute values as is required for input into the FRANG software. Thus, creation of an explosive scenario in FRANG requires selection of a “seed” variable, from which the other values are derived.

Notably, unlike the peak gas pressure, the calculation of scaled gas impulse in FRANG is scale-sensitive. The explosive scenarios derived from an assumption of a 1000-lb charge weight will produce different results than those based on a 1-lb charge weight, or those based on a 100-ft³

room, even if the scenarios have identical relative values, and thus would produce the same results based on the UFC figures. NAVFAC EXWC has concluded that this discrepancy is accurate to the true behavior of the system, as the venting of gasses from the room is dependent on a number of properties that scale at different rates: for instance, initial room venting is based on the perimeter of the panel (which scales linearly) while later room venting is a function of the panel area (which scales quadratically). The lack of additional parameters in the UFC figures to capture this effect is concluded to be due to a desire for simplicity in the presented figures, rather than an endorsement that such parameters do not affect the results.

As the UFC criteria does not discuss intended bounds for the values used in its figures, comparison between the FRANG software and UFC curves is difficult, given the disparity in scaling effects. To provide further confidence in the results of the verification effort, multiple batch runs were prepared, based on initial parameters derived from the test series used in the previous validation effort, i.e., a batch run was developed based on the 450-ft³ test chamber volume; another run was based on the 27-lb explosive used in some tests; etc. From these initial values, the other scenario parameters (panel area, panel impulse, etc.) were all determined based on the relative values specified in the UFC figures. The panel perimeters were determined based on their area, assuming a square panel for all scenarios. The panels were also assumed to have no recessed depth, and assumed located on the sidewalls of the room, meaning gravity would not affect their response. The scenarios were all run using a time-step of .001 ms. While the batch runs developed based on the different initial values all produced different results for predicted scaled gas impulse, their predictions relative to those of the UFC figures demonstrated similar overall trends. Thus, the discussion of their consistency with the UFC predictions will consider all the runs as a whole, as the overall conclusions are similar across the various runs.

Notably, two of the UFC figures (Figures 2-154 and 2-155) list different values for the sixth curve for scaled panel weight: the legend indicates a scaled panel weight of 0.03 psf/lbs^{1/3}, rather than 0.3, as in all the other figures. Examination of Figures 2-154 and 2-155 in TM 5-1300 [8] (the predecessor to the UFC 3-340-02) suggests that this is merely a typo, as those curves list a scaled panel weight of 0.3 psf/lbs³, and show similar data points (See Figure B-2**Error! Reference source not found.**). Thus, for the purposes of this verification effort, the scenarios were run assuming a 0.3 scaled panel weight for all figures.

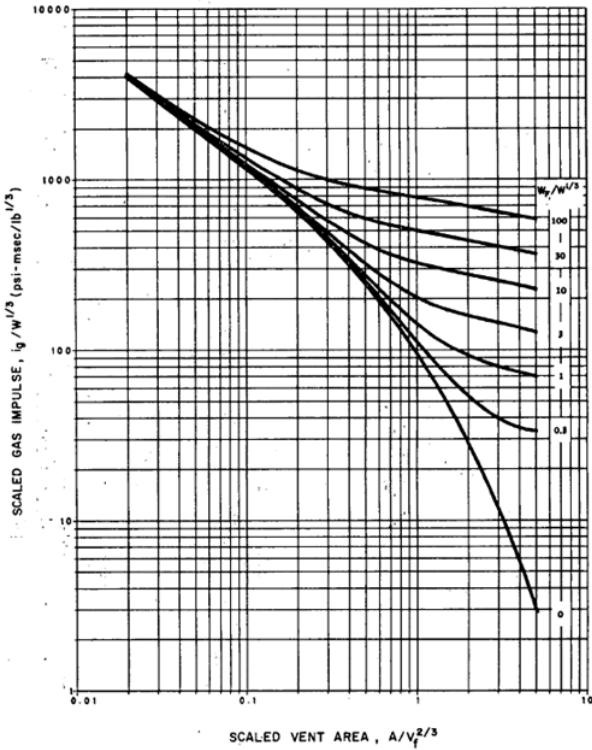


Figure 2-154 Scaled gas impulse ($W/V_f = 0.002$, $i_r/W^{1/3} = 100$)

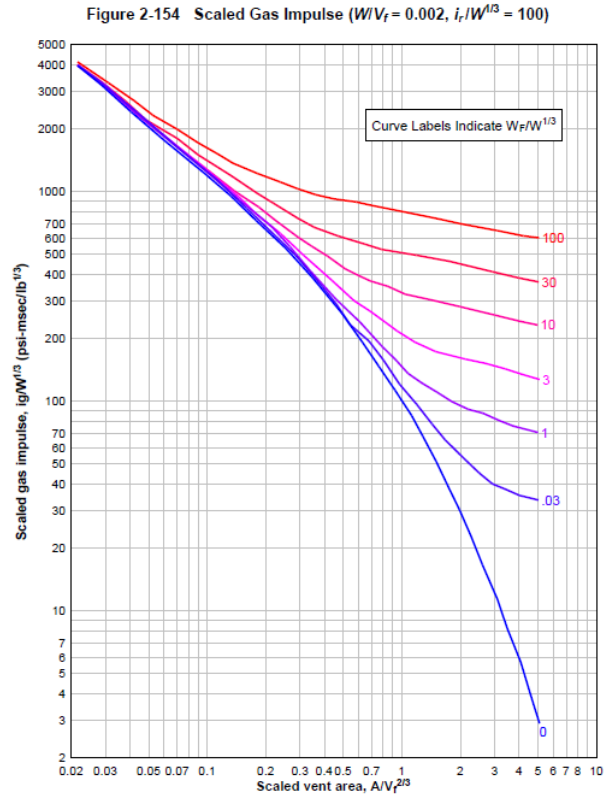


Figure B-2. Comparisons of Figure 2-154 in TM-5-1300 and UFC 3-340-02 Showing Similar Values for Scaled Panel Weights of 0.3 psf/lbs³

B.4.2 FILTERING OF NON-CRITICAL SCENARIOS

The predictions in the FRANG software show good agreement with the UFC curves in high impulse scenarios, with discrepancies between the two methods typically less than 10%. However, the methods show much greater disparities in low-impulse scenarios (i.e. with larger, lighter-weight panels). These scenarios are also the scenarios that show greatest disagreement between the different “seed” variables in the FRANG calculations. Thus, it is concluded that the discrepancies between the FRANG predictions and UFC-presented values are likely in large part due to the differences in scale between the explosive scenarios used in the FRANG runs, and those used to derive the UFC values.

Given this result, it is likely not practical to perform accurate comparison between the predictions from FRANG and the UFC figures at low gas impulses, as the results seem to be highly sensitive to parameters not listed in the UFC criteria. However, the authors conclude comparison in such scenarios is of lesser importance than the higher-impulse scenarios. In the scenarios with large, lightweight panels, the room behaves similarly to a fully-vented scenario, where the gas impulse is limited. In such scenarios, the response is likely to be heavily dominated by the shock loading from the explosive charge. To reflect this, a filter was applied to the batch runs, excluding those results where the shock impulse on the frangible panel was larger than the predicted gas impulse for the room. While such scenarios could still experience minor effects from gas impulse (as the impulse on the panel may exceed the impulse on other walls due to charge location, and a shock-

related impulse is typically shorter than a comparable magnitude gas impulse), the effect is limited. Additionally, FRANG over-predicted the UFC values in a significant majority of the excluded scenarios. Thus, in the limited explosive scenario where these low gas impulses occur and are significant to the structural response, the use of the FRANG software to predict loading is concluded to be generally conservative.

B.4.3 VERIFICATION RESULTS

Discussion of verification results (and the included figures) is based upon the FRANG batch run with a “seed” parameter of a 450-ft³ room volume. The batch run also assumes square panels, no recessed depth, and no gravity acting on the panels. For the scenarios considered “critical” per the previous section, FRANG showed good agreement with the UFC-provided values, with approximately 87% of cases within 5% of the UFC predictions (See Figure B-3). In approximately 3% of cases, FRANG showed disagreements of more than 10%, but these errors were generally conservative, with FRANG overpredicting the UFC values. Recreation of all UFC 3-340-02 figures with the results from the FRANG verifications study included are provided at the end of this appendix.

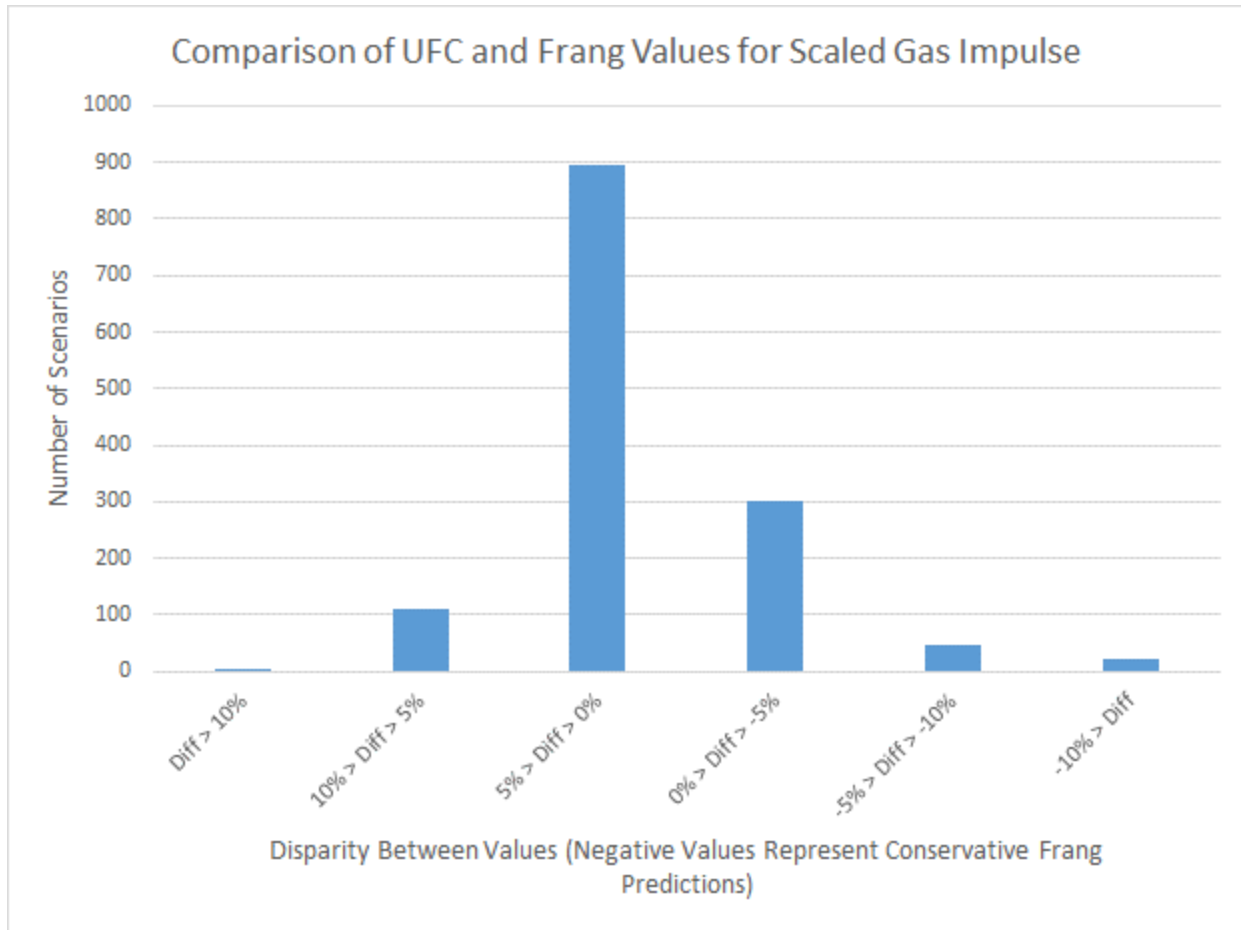


Figure B-3. Distribution of Differences between UFC-Provided and FRANG-Predicted Values for Scaled Gas Impulse

Identifying specific trends in the discrepancies between FRANG and the UFC values is difficult, as most of the parameters are interrelated. FRANG demonstrated generally increasing conservatism at lower panel weights, higher panel areas, and greater panel impulses, all of which lead to lower gas impulses; thus it is unclear which (if any) of those factors contribute to the disparity in values, or if they simply share a non-causal correlation. Given this uncertainty, as well as the inherent uncertainty in comparison to the UFC values (which are based on unknown initial parameters), no firm conclusion can be drawn regarding trends in the relative predicted impulses of FRANG and the UFC-provided values. Nevertheless, given the high agreement shown between the two methods in critical, high gas-impulse scenarios, NAVFAC EXWC feels FRANG shows sufficient accuracy to endorse it for use in predicting gas impulses from a confined explosion.

B.5 MULTI-PANEL ANALYSIS

The update of the FRANG software to version 2.0 included the ability to model multiple frangible panels in an explosive scenario. Unfortunately, to NAVFAC EXWC's knowledge, there is no published experimental or analytical data set examining the gas pressure loading of rooms with multiple frangible panels, and thus direct validation of the software is not possible. There still existed a need to verify that the updated software was calculating results in accordance with its underlying assumptions. The venting of gasses allowed by a frangible panel is assumed solely to be dependent on the charge density and available vent area, which is a function of panel weight, impulse, recessed depth, area and perimeter. Thus, multiple frangible panels of identical weight, impulse, depth, and identical total area and perimeter (along with identical area-to-perimeter ratios) should result in identical predicted gas impulses. To confirm this, a set of FRANG simulations was run examining the predicted gas impulse in a variety of explosive scenarios, considering the upper and lower bounds of FRANG's recommended accuracy limits (based on the limits of the scenarios tested in the experimental test series). A list of the considered FRANG parameters is presented in Figure B-4 below.

Parameters	Bounds
Charge Weight (lbs)	2, 27
Charge Weight-to-Volume Ratio (lbs/ft ³)	0.001, 0.1, 2
Scaled Panel Impulse (psi-ms/lbs ^{1/3})	10, 150, 2000
Scaled Panel Weight (psf/lbs ^{1/3})	1, 20, 300
Scaled Panel Area	0.1, 1
Number of Panels	1,2,3,4,5

Figure B-4. Considered Scenario Parameters in Verification Run on FRANG Multiple Panel Analysis

For each of these scenarios, simulations were run predicting the gas impulse under 1, 2, 3, 4 and 5 frangible panels, with identical panel areas and perimeter divided between all panels (i.e., each of the panels in the 5-panel scenario had $\frac{1}{5}$ the area and $\frac{1}{5}$ the perimeter of the panel in the 1-panel scenario). The results from these simulations showed that the results between scenarios with different numbers of panels differed by less than 0.1% in all cases. These differences are attributed to rounding errors in the division of properties between panels, and the study is concluded to have confirmed that FRANG is modeling multiple-panel scenarios in a manner consistent with its underlying assumptions. While there are still uncertainties in the true blast loading of multiple-

panel scenarios, further verification of the FRANG software is dependent on the use of experimental testing or high-end analytical simulation to develop a data set for comparison.

B.6 CONCLUSIONS

This appendix has documented a series of verification efforts to confirm that the FRANG 2.0 software predicts gas pressure and impulse loads due to an explosion in a confined space in a manner consistent with UFC criteria, so that it may be incorporated into the official release of the ConfinedBlast software. This study showed that FRANG software calculates blast loads similar to those presented in the UFC for the majority of critical blast scenarios that a designer is likely to encounter in practice. However, FRANG does show reduced accuracy outside of certain bounds of input parameters. In addition to the bounds on charge weight-to-volume ratio, scaled panel impulse, and scaled panel weight discussed in reference [5] (based on the limits of the test series), FRANG was shown to possess poor agreement with UFC values for peak gas pressures at charge weight-to-volume ratios above 0.1 lbs/ft³, and designers should exercise caution when using FRANG in such scenarios. While the software does show some disagreement with UFC-provided values at low gas impulses, this is concluded to be due to limits on the number of input parameters in the UFC figures, and not an indication of poor accuracy in the FRANG software.

Based on this study, NAVFAC EXWC concludes that the FRANG software produces predictions for peak gas pressure and impulse that are generally conservative, and appropriate for use in the calculation of gas pressure loads for facilities intended for protective construction. EXWC also concludes that the software is suitable for use in the design of structures compliant with UFC 3-340-02 criteria. However, there are potential areas for improvement to the methods within FRANG, and additional refinement of the software based on recent and ongoing experimental testing is recommended.

B.7 APPENDIX B REFERENCES

- [1] Naval Civil Engineering Laboratory, "FRANG Users Manual," Naval Civil Engineering Laboratory, Port Hueneme, CA, 1989.
- [2] M. Beyer, "Test Data Report - Effect of Frangible Covers on Internal Loads, TM 51-86-16," Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1986.
- [3] DDESB, *Memorandum: Approval for Use of Computer Codes, "SHOCK" and "FRANG"*, Alexandria, VA: Department of Defense Explosives Safety Board, July 26, 1993.
- [4] Department of Defense Explosives Safety Board, "Structures to Resist the Effect of Accidental Explosions, UFC 3-340-02," Unified Facilities Criteria, Alexandria, VA, 2008.
- [5] C. A. Kerrigan, "FRANG 2.0 Theory Manual, TR-NAVFAC ESC-CI-1213," Naval Engineering Service Center, Port Hueneme, CA, 2012.
- [6] C. Oswald, "Development of an Enhanced Gas Pressure Model," Protection Engineering Consultants, San Antonio, TX, 2017.
- [7] J. R. Britt, D. E. Ranta and C. E. Joachim, "BlastX Code, Version 4.2, User's Manual, ERDC/GSL TR-01-2," US Army Engineer Research and Development Center, Geotechnical and Structures Laboratory, March 2001.
- [8] "Structures to Resist the Effects of Accidental Explosions, TM-5-1300," Department of the Army, Navy and Air Force, Washington, D.C., 1990.

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APPENDIX C
MUDEMIMP COMPARISON STUDY

C.1 INTRODUCTION

Multiple Debris Missile Impact Simulation (MUDEMIMP) is a software package originally developed by the Naval Civil Engineering Laboratory (NCEL), which changed its name to the Naval Facilities Engineering Service Center (NFESC) and now NAVFAC EXWC, for determining the downrange hazardous distance and dispersion from debris breakup. The first version of MUDEMIMP (version 1.1) was endorsed as a software module within the dispersion prediction software DISPRE as a siting tool for explosives material and handling facilities in November 1990 by both U.S. Department of Energy (DOE) and U.S. Department of Defense Explosives Safety Board (DDESB). The methods and tools are described in DDESB Technical Paper (TP) No. 13 [1]. Upon distribution of MUDEMIMP version 1.1, many improved versions of the software were ultimately developed to address inconsistent results in the software, as well as the poorly-written nature of the underlying source code. The multiple modified versions of MUDEMIMP beyond version 1.1, coupled with the instability of some of these software versions, were identified as problematic. In 2001, NFESC sponsored ACTA to develop a version of MUDEMIMP labeled MMP1c [2], which includes a few major changes. The major changes include 1) a new and reliable path-independent trajectory algorithm, and 2) a stable and accurate bounce ricochet model for flat and uneven terrain. This ACTA-developed version of MUDEMIMP was based on a version of MUDEMIMP (labelled MMP1a) which had already undergone multiple revisions since its original endorsement by the DDESB. This ACTA-developed version of the software was used as the basis for the version of MUDEMIMP included in the ConfinedBlast software. However, there are some minor differences between the MUDEMIMP version 2.0 software in ConfinedBlast and the source code presented in the ACTA report [2].

As part of the official release of the ConfinedBlast program, which includes the MUDEMIMP version 2.0 software, NAVFAC EXWC undertook an effort to compare the current version of MUDEMIMP against four example sets provided in TP-13 as well as an additional six examples provided from previous TP-13 analyses done in-house. Based on the results of this comparison study, MUDEMIMP version 2.0 is endorsed by NAVFAC EXWC, and EXWC concludes that the software is suitable for determining hazardous fragment distance in accordance with the procedures outlined in TP-13.

C.2 COMPARISON METHODOLOGY

Comparison between the recorded results of all example problems and the MUDEMIMP version 2.0 outputs was completed. Utilizing the example input files (MMP file), a replicated input could be generated into MUDEMIMP version 2.0 allowing for consistency throughout the comparison study. The MMP file provides the inputs read by the MUDEMIMP version 2.0 software, which generate various output files such as the SUM file. The SUM file is an output file, where the maximum range and cumulative risk critical distance, which is equivalent to the hazardous

fragment distance, are reported. These two outputs were used to compare against the examples provided.

C.3 COMPARISON OF EXAMPLES

To compare both inputs and outputs of MUDEMIMP version 2.0 against the examples provided, an input file is needed to be run in the MUDEMIMP version 2.0 software for each scenario. These inputs were provided in-house from a previous TP-13 analysis and also from the TP-13 appendix. The input files are as seen in the following format:

```

1,1
5000,10440,0,58,NONE,14555568
Example Problem No. 1
Friday, August 14, 2020

Mudemimp Run from direct User Input
FT      LBS      SEC      FT-LBS
MASS    EXPONENT  2.60
VELOCITY NORMAL    104.00    24.00
ANGLE   NORMAL    0.00     1.30
COF     UNIFORM    1.00     2.00
KFACTOR CONSTANT  1.00
END
1 150
7 3
8 1
10 1
12 2
19 -9.4
90      DIRECTION OF TERRAIN PROFILE FROM NORTH
X TERRAIN POINT, ALTITUDE OF TERRAIN POINT, SOIL TYPE
10      0      2
50      0      2
300     0      2
1000    0      2
-1,-1,-1,-1,-1,-1,-1

```

Figure C-1. MMP Input File

All highlighted components of the MMP file require a manual input from the user. Cross referencing Figure C-1 and Table C-1 and Table C-2, we can see which input values correlates with a function. For the mass parameter in Figure C-1, an exponential density is chosen due to the material being either concrete or masonry. A normal distribution is chosen for the initial velocity and would only be constant if a beam (or other single fragment scenario) was being analyzed.

Following suit, the initial trajectory uses a normal distribution and is only a constant distribution when a beam is being analyzed. The drag coefficient uses a uniform distribution due to a 3-dimensional breakup factor being chosen in MUDEMIMP. Other options include a constant distribution for a 2-dimensional breakup or for beams, which both yield different constant values. In Figure C-1, on the second line, the nomenclature “none” would appear as “output” if the trajectory output data box were to be used. Note that checking the trajectory output data box would increase the duration in runtime. Examples 1-4 represent the example sets in TP-13 while the following six examples, Example A - F, were from previous TP-13 analyses done in-house. The last six example sets were provided with the needed MUDEMIMP input parameters (stored in a DAT file) and output (OUT file) files in order to conduct the comparison. After inputting the information provided by TP-13’s MMP file and the in-house DAT files into MUDEMIMP, various text outputs are generated. The SUM file provided the necessary fragment distances for comparison. This process is repeated for all 10 example sets and the comparison is summarized in Table C-58.

C.3.1 EXAMPLE 1

Surfaces 1 and 2

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-1. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	10440 lbs
Mass – Exponent	Average Mass: 2.6 lbs
Launch Velocity – Normal	Average Launch Velocity: 104 ft/sec Standard Deviation: 24 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.00 Min: 1.00
Drag Area Factor – Constant	1.00

Table C-2. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.00 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	9.4 ft

Table C-3. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	616 ft	644 ft
Maximum Range	632 ft	656 ft

Surface 3 and 4

Table C-4. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	3600 lbs
Mass – Exponent	Average Mass: 2.6 lbs
Launch Velocity – Normal	Average Launch Velocity: 52 ft/sec Standard Deviation: 12 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.00 Min: 1.00
Drag Area Factor – Constant	1.00

Table C-5. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	1-Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.0 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	5.5 ft

Table C-6. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	190 ft	187 ft
Maximum Range	195 ft	192 ft

Surface 5

Table C-7. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	1872 lbs
Mass – Exponent	Average Mass: 0.8 lbs
Launch Velocity – Normal	Average Launch Velocity: 1785 ft/sec Standard Deviation: 416 ft/sec
Launch Angle – Normal	Average Launch Angle: 85 degrees Standard Deviation: 10 degrees
Drag Coefficient – Constant	1.50
Drag Area Factor – Constant	1.00

Table C-8. Default Overrides

Parameter	Value
(1-D) Debris Material Density	36 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.13 ft
(12-Y) Initial Vertical Fragment Coordinate	12.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-9. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	430 ft	439 ft
Maximum Range	483 ft	488 ft

Surface 6

Table C-10. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	1
Total Effective Destroyed Mass	319 lbs
Mass – Constant	319 lbs
Launch Velocity – Constant	111 ft/sec
Launch Angle – Constant	85.0 degrees
Drag Coefficient – Constant	1.80
Drag Area Factor – Constant	1.00

Table C-11. Default Overrides

Parameter	Value
(1-D) Debris Material Density	490 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.2 ft
(12-Y) Initial Vertical Fragment Coordinate	12.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-12. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Range	62 ft	62 ft

C.3.2 EXAMPLE 2

Surfaces 1 and 2

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-13. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	1800 lbs
Mass – Exponent	Average Mass: 2.6 lbs
Launch Velocity – Normal	Average Launch Velocity: 17 ft/sec Standard Deviation: 3.9 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.00 Min: 1.00
Drag Area Factor – Constant	1.00

Table C-14. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.00 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	3.9 ft

Table C-15. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	33 ft	29 ft
Maximum Range	33 ft	30 ft

Surface 3 and 4

Table C-16. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	1800 lbs
Mass – Exponent	Average Mass: 2.6 lbs
Launch Velocity – Normal	Average Launch Velocity: 16 ft/sec Standard Deviation: 3.6 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.00 Min: 1.00
Drag Area Factor – Constant	1.00

Table C-17. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.00 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	3.9 ft

Table C-18. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	29 ft	17 ft
Maximum Range	30 ft	27 ft

Surface 5

Table C-19. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	1872 lbs
Mass – Exponent	Average Mass: 0.8 lbs
Launch Velocity – Normal	Average Launch Velocity: 550 ft/sec Standard Deviation: 128 ft/sec
Launch Angle – Normal	Average Launch Angle: 85 degrees Standard Deviation: 10 degrees
Drag Coefficient – Constant	1.50
Drag Area Factor – Constant	1.00

Table C-20. Default Overrides

Parameter	Value
(1-D) Debris Material Density	36 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.13 ft
(12-Y) Initial Vertical Fragment Coordinate	12.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-21. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	330 ft	329 ft
Maximum Range	353 ft	353 ft

Surface 7

Table C-22. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	1
Total Effective Destroyed Mass	118 lbs
Mass – Constant	118 lbs
Launch Velocity – Constant	677 ft/sec
Launch Angle – Constant	0 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-23. Default Overrides

Parameter	Value
(1-D) Debris Material Density	33 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.17 ft
(12-Y) Initial Vertical Fragment Coordinate	2.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-24. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Range	808 ft	808 ft

C.3.3 EXAMPLE 3

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-25. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	7920 lbs
Mass – Exponent	Average Mass: 0.29 lbs
Launch Velocity – Normal	Average Launch Velocity: 800 ft/sec Standard Deviation: 187 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-26. Default Overrides

Parameter	Value
(1-D) Debris Material Density	120 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.0625 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	17.5 ft

Table C-27. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	1654 ft	1660 ft
Maximum Range	1773 ft	1773 ft

Surface 2 - 4

Table C-28. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	15480 lbs
Mass – Exponent	Average Mass: 2.6 lbs
Launch Velocity – Normal	Average Launch Velocity: 132 ft/sec Standard Deviation: 31 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.00 Min: 1.00
Drag Area Factor – Constant	1.00

Table C-29. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.00 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	11.5 ft

Table C-30. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	926 ft	900 ft
Maximum Range	974 ft	925 ft

Surface 5

Table C-31. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	800 lbs
Mass – Uniform	Max: 160 lbs Min: 40 lbs
Launch Velocity – Normal	Average Launch Velocity: 863 ft/sec Standard Deviation: 201 ft/sec
Launch Angle – Normal	Average Launch Angle: 90 degrees Standard Deviation: 10 degrees
Drag Coefficient – Constant	1.50
Drag Area Factor – Constant	1.00

Table C-32. Default Overrides

Parameter	Value
(1-D) Debris Material Density	490 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.0048 ft
(12-Y) Initial Vertical Fragment Coordinate	12.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-33. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	90 ft	66 ft
Maximum Range	264 ft	266 ft

Surface 6

Table C-34. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	1
Total Effective Destroyed Mass	319 lbs
Mass – Constant	319 lbs
Launch Velocity – Constant	111 ft/sec
Launch Angle – Constant	90 degrees
Drag Coefficient – Constant	1.8
Drag Area Factor – Constant	1.0

Table C-35. Default Overrides

Parameter	Value
(1-D) Debris Material Density	490 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.2 ft in
(12-Y) Initial Vertical Fragment Coordinate	12.0 ft
(19-GRIDL) Effective Destroyed Width	20.0 ft

Table C-36. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Range	12.5 ft	0 ft

C.3.4 EXAMPLE 4

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-37. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	7920 lbs
Mass – Exponent	Average Mass: 0.29 lbs
Launch Velocity – Normal	Average Launch Velocity: 287 ft/sec Standard Deviation: 67 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-38. Default Overrides

Parameter	Value
(1-D) Debris Material Density	120 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.0625 ft
(12-Y) Initial Vertical Fragment Coordinate	2.00 ft
(19-GRIDL) Effective Destroyed Width	17.5 ft

Table C-39. Output Comparison between TP-13 and MUDEMIMP Version 2

	TP-13	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	709 ft	713 ft
Maximum Range	714 ft	713 ft

C.3.5 EXAMPLE A

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-40. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	2260 lbs
Mass – Exponent	Average Mass: 1.25 lbs
Launch Velocity – Normal	Average Launch Velocity: 271.6 ft/sec Standard Deviation: 63.4 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.0 Min: 1.0
Drag Area Factor – Constant	1.0

Table C-41. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.667 ft
(12-Y) Initial Vertical Fragment Coordinate	6.0 ft
(19-GRIDL) Effective Destroyed Width	23.0 ft

Table C-42. Output Comparison between Example A and MUDEMIMP Version 2

	Example A (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	1852 ft	1538 ft
Maximum Range	2882 ft	1991 ft

C.3.6 EXAMPLE B

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-43. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	1251 lbs
Mass – Exponent	Average Mass: 1.389 lbs
Launch Velocity – Normal	Average Launch Velocity: 351.0 ft/sec Standard Deviation: 82.0 ft/sec
Launch Angle – Normal	Average Launch Angle: 90.0 degrees Standard Deviation: 10.0 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-44. Default Overrides

Parameter	Value
(1-D) Debris Material Density	30 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	1.67 ft
(12-Y) Initial Vertical Fragment Coordinate	17.458 ft
(19-GRIDL) Effective Destroyed Width	19.0 ft

Table C-45. Output Comparison between Example B and MUDEMIMP Version 2

	Example B (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	238 ft	245 ft
Maximum Range	285 ft	289 ft

C.3.7 EXAMPLE C

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-46. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	500 lbs
Mass – Exponent	Average Mass: 0.556 lbs
Launch Velocity – Normal	Average Launch Velocity: 143.0 ft/sec Standard Deviation: 33.0 ft/sec
Launch Angle – Normal	Average Launch Angle: 90.0 degrees Standard Deviation: 10.0 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-47. Default Overrides

Parameter	Value
(1-D) Debris Material Density	12 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.167 ft
(12-Y) Initial Vertical Fragment Coordinate	17.458 ft
(19-GRIDL) Effective Destroyed Width	19.0 ft

Table C-48. Output Comparison between Example C and MUDEMIMP Version 2

	Example C (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	67 ft	66 ft
Maximum Range	94 ft	95 ft

C.3.8 EXAMPLE D

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-49. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	770 lbs
Mass – Uniform	Min: 16 lbs Max: 64 lbs
Launch Velocity – Normal	Average Launch Velocity: 226.0 ft/sec Standard Deviation: 53.0 ft/sec
Launch Angle – Normal	Average Launch Angle: 95.4 degrees Standard Deviation: 10.0 degrees
Drag Coefficient – Constant	1.5
Drag Area Factor – Constant	1.0

Table C-50. Default Overrides

Parameter	Value
(1-D) Debris Material Density	490 pcf
(7-BKUP) Breakup Factor	2-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.00408 ft
(12-Y) Initial Vertical Fragment Coordinate	19.08 ft
(19-GRIDL) Effective Destroyed Width	22 ft

Table C-51. Output Comparison between Example D and MUDEMIMP Version 2

	Example D (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	55 ft	77 ft
Maximum Range	159 ft	178 ft

C.3.9 EXAMPLE E

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-52. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	15348 lbs
Mass – Exponent	Average Mass: 2.5 lbs
Launch Velocity – Normal	Average Launch Velocity: 61.0 ft/sec Standard Deviation: 14.0 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.0 Min: 1.0
Drag Area Factor – Constant	1.0

Table C-53. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.083 ft
(12-Y) Initial Vertical Fragment Coordinate	3.0 ft
(19-GRIDL) Effective Destroyed Width	11.4 ft

Table C-54. Output Comparison between Example E and MUDEMIMP Version 2

	Example E (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	257 ft	255 ft
Maximum Range	259 ft	255 ft

C.3.10 EXAMPLE F

Surface 1

Variables that are not listed below use the default MUDEMIMP parameters.

Table C-55. Fragment Distribution Functions

Functions	Quantity
Random Monte Carlo Simulations	5000
Total Effective Destroyed Mass	565 lbs
Mass – Exponent	Average Mass: 1.25 lbs
Launch Velocity – Normal	Average Launch Velocity: 99.5 ft/sec Standard Deviation: 23.2 ft/sec
Launch Angle – Normal	Average Launch Angle: 0.0 degrees Standard Deviation: 1.3 degrees
Drag Coefficient – Uniform	Max: 2.0 Min: 1.0
Drag Area Factor – Constant	1.0

Table C-56. Default Overrides

Parameter	Value
(1-D) Debris Material Density	150 pcf
(7-BKUP) Breakup Factor	3-dimensional
(8-IRIC) Ricochet Factor	Include Empirical Roll
(10-L) Wall/Shell Thickness (Masonry)	0.667 ft
(12-Y) Initial Vertical Fragment Coordinate	12.75 ft
(19-GRIDL) Effective Destroyed Width	23 ft

Table C-57. Output Comparison between Example F and MUDEMIMP Version 2

	Example F (HIS File)	MUDEMIMP Version 2
Maximum Cumulative Hazardous Distance	449 ft	455 ft
Maximum Range	592 ft	613 ft

C.4 SUMMARY

Table C-58 highlights all example scenario's hazardous fragment distance and maximum fragment distance as well as percentage differences. The percent differences are color coded to show whether MUDEMIMP version 2.0 was more conservative (green) or less conservative (red). In most cases, the discrepancy between TP-13/in-house examples and MUDEMIMP show little to no disagreement with each other. MUDEMIMP would output values that are slightly conservative or unconservative, with the exception of a few scenarios. Example 2, Surface 1/2, has a difference of 12.12% for hazardous fragment distance and 9.09% for maximum distance. Example 2, Surface 3/4, has a difference of 41.38% in hazardous fragment distance and 10% for maximum distance when compared to the TP-13 values. Example A has a difference of 20.42% in hazardous fragment distance and 44.75% for maximum distance. Lastly, Example D has a difference of 28.57% in hazardous fragment distance and 10.67% for maximum distance. All the example's discrepancies are concluded to be due to one or more of the following factors: 1) a modification in the empirical roll logic prior to ACTA's modification, made to include additional test data not available at the time of MUDEMIMP's initial writing and address unrealistic predictions noted in the original algorithm, 2) an introduction of the DGRIDL parameter for measurement of debris density, 3) an improved, more stable trajectory algorithm and/or 4) a removal of an override of high launch angles in the original MUDEMIMP software.

Full details of the changes to the roll methodology are not available. ACTA's final report mentions unrealistic roll values being produced in some scenarios in MUDEMIMP version 1.0. This can be seen prominently in Example A, where one of the simulated debris first impacted at 250 ft, and subsequently rolls to 2300 ft, which is inconsistent with typical observed debris behavior. Further checking on this theory, Example 2 Surface 3/4 was rerun with roll disabled and the maximum range decreased to 9.94 ft (65.72% difference) from 17 ft, indicating that the maximum fragment range is highly dependent on this roll model. This same theory can be tested through Example 2, Surface 1/2, when roll is disabled the maximum range decreased to 10.68 ft (67.64%) from 30 ft. This shows that roll plays a large part in generating the larger hazardous fragment distances in several of the original TP-13 results. As the new roll model is based on a more complete data set, NAVFAC EXWC concludes the disparity between the three versions is likely indicative of improved accuracy of the software's methodology.

Additional minor discrepancies are seen in hazardous fragment distance and max fragment distance due to the different fragment density model being used in the MUDEMIMP version 1.1 and 2.0. MUDEMIMP version 2.0 runs on ACTA's new fragment density model which calculates the hazardous debris density differently by introducing a unique parameter, DGRIDL, which is the incremental sector depth. Both DGRIDL and GRIDL parameters are used in MUDEMIMP version 2.0 to calculate the trapezoidal area which is divided into the cumulative number of debris landing within, or passing through each segment to determine the debris density. It is also important to note that DGRIDL is set to a default value of 2.45 in MUDEMIMP. In MUDEMIMP version 1.1, GRIDL is used for the trapezoidal area to calculate for the debris density. Example D is a case where the values may be influenced by the implementation of DGRIDL, but only partially attribute to the large discrepancy present. The implementation of DGRIDL allows for more sectors to be generated, due to shorter sector increments, which led to having slightly more conservative estimations of debris density in each trapezoidal area being produced as shown in the comparison

between TP-13 example problems, in-house example problems, and MUDEMIMP version 2.0 values.

One additional scenario with a significant disagreement is Example 3, Surface 6, which has a 100% difference. However, investigation of the scenario (i.e. a single fragment thrown at a 90° launch angle with no horizontal velocity) indicates that MUDEMIMP version 2.0 is producing the correct value and MUDEMIMP version 1.1 producing a value of 12.5 ft is incorrect as engineering judgment would indicate the fragment should exhibit no lateral movement. An old version of MUDEMIMP would run a process that converted any angle within one degree of 90 degrees to 89 degrees, to prevent instabilities in the previous trajectory-based algorithm, which had issues in such scenarios, where the fragment’s angle would shift instantaneously from a positive 90-degree angle to a negative 90-degree angle at its peak. This adjustment of the initial launch angle is the reason why a hazardous fragment distance other than zero was produced by the version of MUDEMIMP used in TP-13. The range of 0 ft. predicted by MUDEMIMP version 2.0 is correct, and not concluded to be indicative of any inaccuracy in the software’s methodology. This may also contribute to Example D’s discrepancy, as its high launch angle would lead to a number of simulations where the angle was increased to avoid stability problems associated with the old trajectory model. The improved and more stable trajectory-based algorithm can account for most of the discrepancy, but as previously stated, DGRIDL may also contribute to a portion of the discrepancy for this scenario.

It is important to note, although there are discrepancies between the varying versions of MUDEMIMP, a factor of safety of 1.3 is applied to the net explosive weight and a final safety factor of 1.3 is applied to the debris distance to account for uncertainties in the model and real-world scenarios. The final safety factor should only be applied to distances predicted for concrete and masonry debris and not for ductile material debris covered by the model.

Table C-58. MUDEMIMP Comparison Summary

INPUT FILE	TP-13		MUDEMIMP 2.0		EXAMPLE HIS FILE		PERCENT DIFFERENCE	
	Haz Frag Dist (ft)	Max Dist (ft)	Haz Frag Dist (ft)	Max Dist (ft)	Haz Frag Dist (ft)	Max Dist (ft)	Haz Frag Dist (%)	Max Dist (%)
Ex. 1 Surface 1/2	616	632	644	656			4.55	3.80
Ex. 1 Surface 3/4	190	195	187	192			1.58	1.54
Ex. 1 Surface 5	430	483	439	488			2.09	1.04
Ex. 1 Surface 6		62		62				0
Ex. 2 Surface 1/2	33	33	29	30			12.12	9.09
Ex. 2 Surface 3/4	29	30	17	27			41.38	10.00

Ex. 2 Surface 5	330	353	329	353			0.30	0
Ex. 2 Surface 6		808		808				0
Ex. 3 Surface 1	1654	1773	1660	1773			0.36	0
Ex. 3 Surface 2-4	926	974	900	925			2.81	5.03
Ex. 3 Surface 5	90	264	66	266			26.67	0.76
Ex. 3 Surface 6		12.5		0				100
Ex. 4 Surface 1	709	714	713	713			0.56	0.14
Ex. A			1538	1991	1852	2882	20.42	44.75
Ex. B			245	289	238	285	2.86	1.38
Ex. C			66	95	67	95	1.52	0
Ex. D			77	178	55	159	28.57	10.67
Ex. E			255	255	257	259	0.78	1.57
Ex. F			455	613	449	592	1.32	3.43

C.5 CONCLUSION

NAVFAC EXWC has compared the outputs of the MUDEMIMP version 2.0 software with outputs provided in the 10 example problem sets, and has found there is reasonable agreement with the DDESB-approved version of MUDEMIMP. Additionally, further examination by NAVFAC EXWC suggests the major disparities are concluded to be due to the revision of the software's empirical roll logic based on additional test data, the change to DGRIDL, and the removal of the 90 degree angle overwrite. A factor of safety of 1.3 is to be applied to distances predicted for concrete and masonry debris and this is intended to capture the uncertainty in the results and provide a hazardous fragment distance to be used for exposed site (ES) siting. NAVFAC EXWC concludes the revisions to the software accounts for additional test data and can account for more scenarios. NAVFAC EXWC also concludes that ACTA's new implementation of the trajectory model is an improvement to the algorithm, which is more stable and reasonable than was previously. Given the agreement between MUDEMIMP and the example sets, NAVFAC EXWC concludes that the software produces an improved simulation of debris dispersion and endorses the use of MUDEMIMP version 2.0 for calculation of hazardous fragment distances for protective construction analysis.

C.6 APPENDIX C REFERENCES

- [1] DDESB, "TP 13 Prediction of Debris for Quantity Distance Siting," Department of Defense Explosives Safety Board, Alexandria, VA, 1991.
- [2] Al Ambrosio & Jon D. Chostowski, "MUDEMIMP Modifications Technical Report No. 01-444-05," ACTA, Torrance, CA, 2001.

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