Ballistics

User Tutorial for the Ballistics Tool

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Institute for Software Integrated Systems
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1.0 Purpose

The Ballistics Analysis tool analyzes the performance of a design against a variety of ballistic threats. The system imposes suites of shotlines against the design assembly and provides a report of the expected penetration depth of the projectile through the layers of the design geometry intersected by the shotline. Three tiers of analysis are supported to give flexibility in choosing between computation time and analysis fidelity.

Tier 1 is a very fast running model (on the order of microseconds) that scales historical results of ballistic testing against the layers of material encountered in the design.

Tier 2 is a fast running model (on the order of milliseconds) that performs simplified physics-based analysis of the penetration of the projectile through the material layers.

Tier 3 is a long running (on the order of hours) hydrocode calculation that employs CTH, a 3rd party solver, to evaluate the detailed motion of the projectile and interactions with materials and boundaries.

The following diagram illustrates the concept for the three ballistic tiers. Tier 1 is the top row, tier 2 is the middle row, and tier 3 is the bottom. The width of wedge represents the amount of uncertainty in the analysis. The higher tiers decrease the amount of uncertainty while increasing the amount of computation time required for the analysis routines.

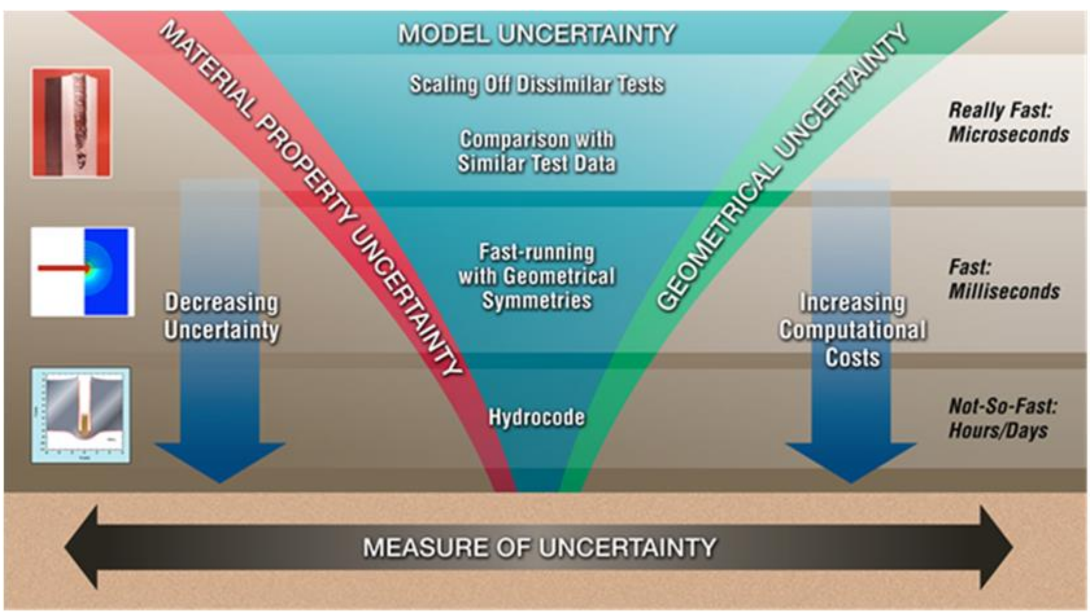

Figure 1: Ballistic Tiers

While you are able to select between tier 1 and tier 2, it is unlikely that you will see much difference in the overall run time of the system since, for larger models, the time is dominated by the time required to load and compute the intersections of the shotlines with the model.

1.1 Requirements Tested

Crew and vehicle survivability in the context of ballistic penetration of the vehicle.

1.2 Required Components

There must be at least one component in the system under test; however, this component can be of any type.

2.0 Procedures

2.1 Tool Installation and Checkout

Run the SwRI AVM Tools installer and accept the default settings. This will install the tools into C:\SwRI-AVM-Tools. The tools need to be installed there rather than under the more typical Program Files directory because temporary files are written to directories under the installation directory and it is not needed, nor desirable, to run the blast and ballistics tools with administrator privileges.
In addition to the SwRI AVM Tools, LS-PrePost, a free program from Livermore Software will be installed using its standard installer. These files are installed under the Program Files directory. LS-PrePost is a pre- and post- processor program designed to be used with LS-Dyna, the solver used for tier 3, 4, and 5 of the blast pipeline. The output from all 5 tiers of the blast pipeline can be viewed using LS-PrePost.
If you wish to test the installation of the ballistics portion of the SwRI AVM Tools, you can start up a cmd shell (cmd.exe) or a cygwin shell and run the following command:

```
C:\SwRI-AVM-Tools\ballistics.exe  C:\SwRI-AVM-
Tools\Examples\double_v_aluminum\BallisticConfig.json
```

This will run a Tier 2 ballistics computation on a Meta-generated hull that has been included with the tool installation. A lot of text will then scroll by as the pipeline operates on the test design included with the tools. You will know that the tool is installed and operating correctly if the output ends with text similar to the following:

```
writing results to:  C:\SwRI-AVM-
Tools\Examples\double_v_aluminum\BallisticConfig_sl_geo_res.json
ELAPSED TIME: XXXXXXX Seconds
Time Loading: XXXXXXX  Seconds
Time Intersections: XXXXXXX Seconds
Time Shotlines: XXXXXXX Seconds
Total Shots:  200
Total Intersections:  884
Total Kills:  42
Total Perforations:  102
============== Running Shotline Viewer =================
```

The pipeline then launches the Shotline Viewer program to view the results. A window similar to Figure 2 should appear on your screen:

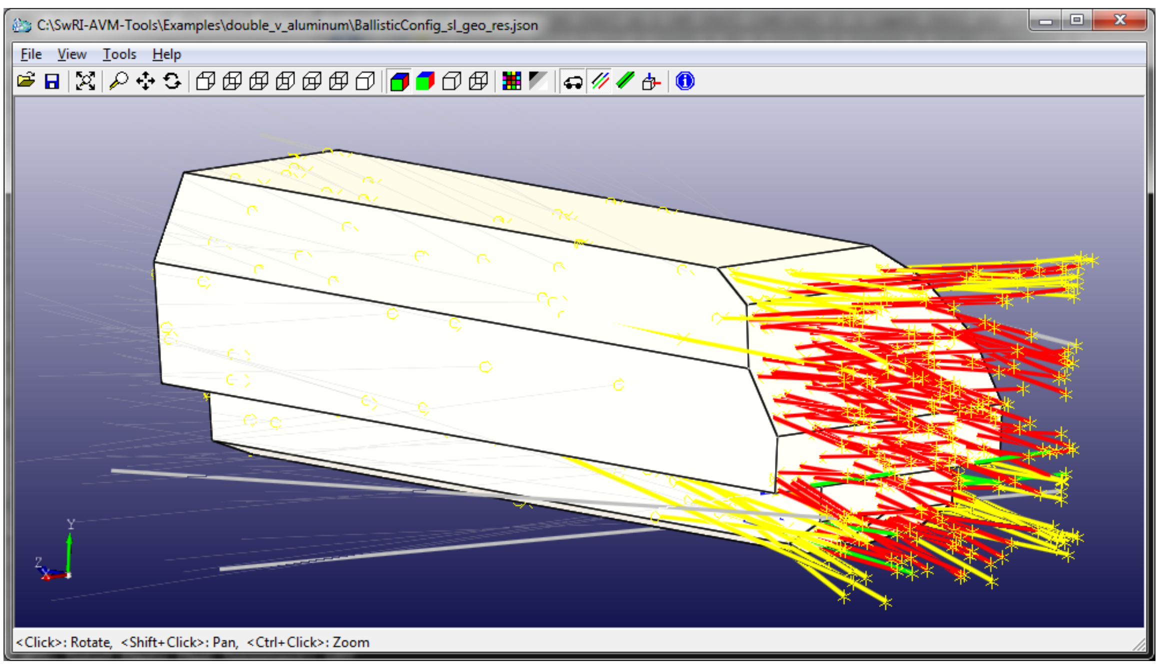

Figure 2: Shotline Viewer

To 3D rotate the view, hold down the Ctrl key and click-and-drag the right mouse button.

To zoom the view, hold down the Ctrl key and click-and-drag the left mouse button. The shotlines are color coded according to the following scheme:

- A Green shotline does not intersect a part marked as "Critical"
- A Green shotline turns to Blue at the point where the projectile stopped.
- A Yellow shotline intersects a "critical" part but the projectile stopped before perforating the critical part.
- A Yellow shotline turns to Orange at the point where it was stopped.
- A Red shotline perforates a "critical" part, representing a Kill, and turns to Black at the point of the kill.

2.2 Running "Predefined Shotline Suite" Ballistics Analysis on the MSD

This tutorial will demonstrate the steps required to run a ballistics simulation of a "predefined shotline suite" on the MSD.

2.2.1 Step 1: Set Up Test Folder

Create a top-level **Testing folder** if one is not already created. In the GME Browser, insert a new **Testing subfolder** within the top-level Testing folder and name it "Ballistics Test."
Within the Ballistics TestBench subfolder, insert a new **BallisticTestBench** model and name it "Ballistics TestBench, Predefined SL".
Open "Ballistics TestBench, Predefined SL" by double-clicking it in the GME Browser.

2.2.2 Step 2: Insert Design Space Reference

Copy/Paste As Reference... the MyMassSpringDamper design container into the Ballistics Test window.
When prompted, select **TopLevelSystemUnderTest**.

2.2.3 Step 3: Predefined Shotline Suite Ballistic Test Bench Requirements

The ballistic test bench for a predefined shotline suite has the following components:

- Ballistic target you are shooting at (e.g. MSD)
- Predefined Ballistic Suite (Figure 3)

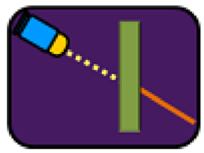

Figure 3: PredefinedBallisticSuite Part

- Metric entries for "Crew_Survivability_Score" and "Vehicle_Survivability_Score"
- Reference to CAD Workflow definition
- Reference plane (Figure 4)

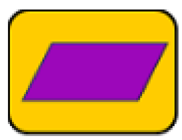

Figure 4: ReferencePlane Part

2.2.4 Step 3a: Select the Predefined Ballistic Suite

Within the Part Browser, find the "PredefinedBallisticSuite" part and Drag/Drop it into the test bench window.
In order for the simulation to run, the Name of the predefined shotline suite must be supplied.

Highlight the PredefinedBallisticSuite and fill out the information so that the Name field under the Object Inspector matches the following figure.

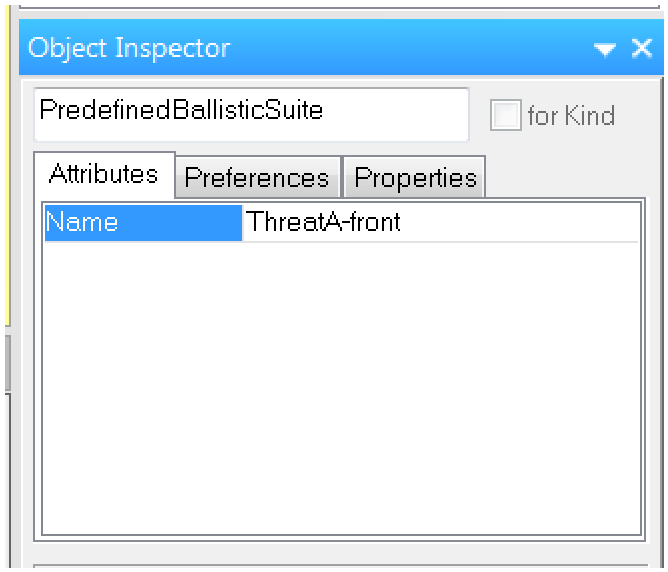

Figure 5: Object Inspector for PredefinedBallisticSuite

This is the necessary information required for the simulation to run.
The following table lists the available shotline suites by threat and direction. Scoring is only performed on the '-all' shotline suites. The others are included to facilitate analysis. The details on the specific threats are not included in this documentation; however, in general, the severity of the threat increases with the rank of the alphabetic identifier, meaning that threat "J" is generally more severe than threat "A". The artillery threats are specially chosen threat properties, such as length, diameter, material, and velocity, that represent a typical fragment from an artillery round at a nearby standoff. This is referred to in the literature as a Fragment Simulating Projectile, or FSP.

Conventional Projectiles:

All	Front	Rear	Left	Right	Top
ThreatA-all	ThreatA-front	ThreatA-rear	ThreatA-left	ThreatA-right	ThreatA-top
ThreatB-all	ThreatB-front	ThreatB-rear	ThreatB-left	ThreatB-right	ThreatB-top
ThreatC-all	ThreatC-front	ThreatC-rear	ThreatC-left	ThreatC-right	ThreatC-top
ThreatD-all	ThreatD-front	ThreatD-rear	ThreatD-left	ThreatD-right	ThreatD-top
ThreatE-all	ThreatE-front	ThreatE-rear	ThreatE-left	ThreatE-right	ThreatE-top
ThreatF-all	ThreatF-front	ThreatF-rear	ThreatF-left	ThreatF-right	ThreatF-top
ThreatG-all	ThreatG-front	ThreatG-rear	ThreatG-left	ThreatG-right	ThreatG-top
ThreatH-all	ThreatH-front	ThreatH-rear	ThreatH-left	ThreatH-right	ThreatH-top
ThreatI-all	ThreatI-front	ThreatI-rear	ThreatI-left	ThreatI-right	ThreatI-top
ThreatJ-all	ThreatJ-front	ThreatJ-rear	ThreatJ-left	ThreatJ-right	ThreatJ-top
ThreatK-all	ThreatK-front	ThreatK-rear	ThreatK-left	ThreatK-right	ThreatK-top
ThreatL-all	ThreatL-front	ThreatL-rear	ThreatL-left	ThreatL-right	ThreatL-top

Artillery Simulating Projectiles:

All	Front	Rear	Left	Right	Top
ThreatAA-all	ThreatAA-front	ThreatAA-rear	ThreatAA-left	ThreatAA-right	ThreatAA-top
ThreatAB-all	ThreatAB-front	ThreatAB-rear	ThreatAB-left	ThreatAB-right	ThreatAB-top

2.2.5 Step 3b: Reference Plane

Locate the ReferencePlane part in the Part Browser and Drag/Drop it into the Ballistics TestBench window.
Select the part and ensure that under the Attributes tab in the Object Inspector that its Type is specified as "Ground".

2.2.6 Step 3c: Tier

Select the "BallisticTestBench, Predefined SL" under the Testing folder in the GME Browser.
Select the Tier in the Object Inspector Window. Tier 1, 2 and 3 are currently supported.

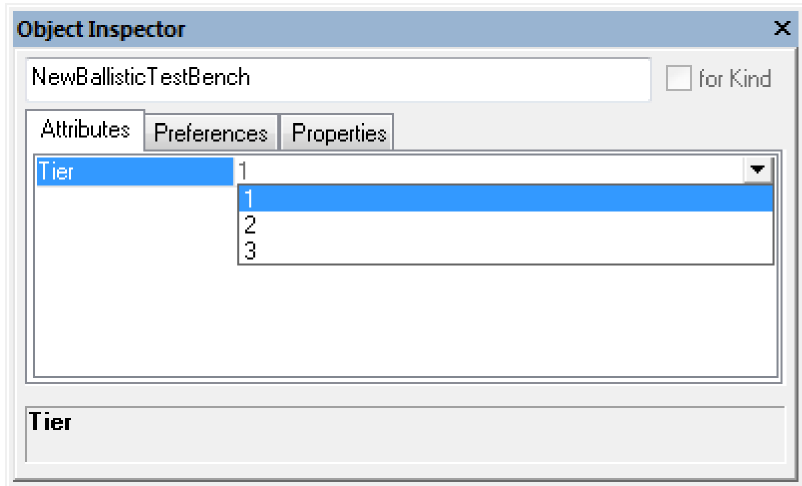

Figure 6: Tier selection in Object Inspector Window

2.2.7 Step 3d: Critical Components

The approach to scoring is centered around the concept of critical components. The user can either choose to employ the default "distance-to-the-next-intersection" heuristic for determining critical components. Or the user can manually select components to identify as critical. If any components are manually marked as critical, the heuristic is not used. Only the manually identified components are considered critical.

The default heuristic is that when a part is perforated, meaning the shot exits the part, if the distance to the next intersection is greater than 30 cm (about 12 inches), the shot is considered to have entered the crew region and is marked as a kill. The number of shotlines resulting in a kill is the key factor in the determination of the crew survivability score.

The approach for mobility kills slightly different. A table containing a probability of mobility kill associated with each class of component is used to estimate which shots were likely to result in a mobility kill. Each mobility-related component that is impacted by a shot will detract from the mobility score. This algorithm is not fully implemented as of release 27. The intention is have it in place for mid-gamma.

To manually designate critical components:

1. Open the design space referenced as the "TopLevelSystemUnderTest" in the test bench.
2. Copy/Paste as Reference the component to be designated as a critical component. When prompted, select Critical Component.
3. In the object inspector, designate the type of critical component.

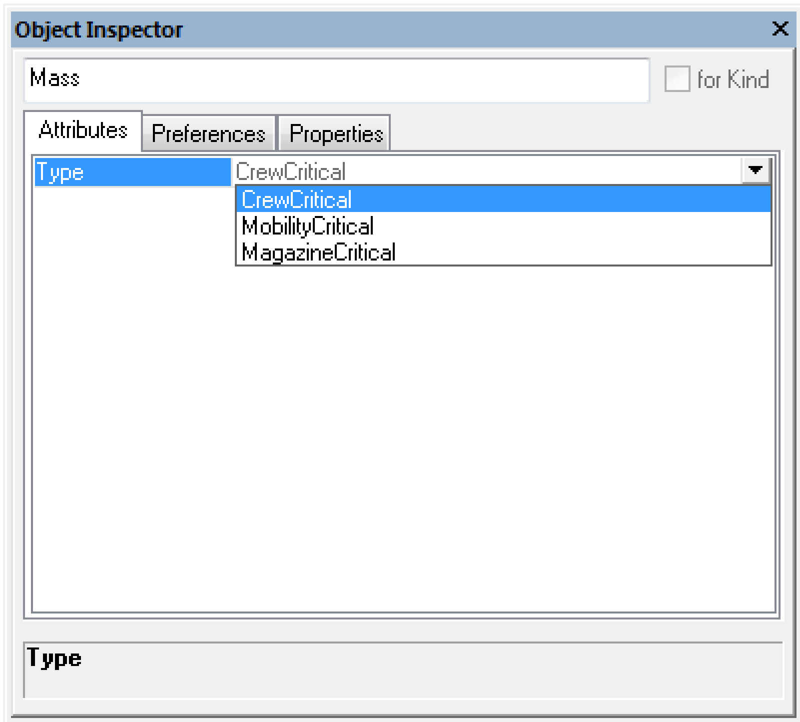

Figure 7: Critical component type selection in Object Inspector

2.2.8 Step 3e: Add Reference to CAD Workflow definition

Define a CAD workflow definition and paste a reference to the CAD workflow into the test bench. See Chapter 6 Step 8 of the MSD tutorial for more information.

2.2.9 Step 4: Add Requested Metrics

Add two metric elements to the test bench. Name them "Crew_Survivability_Score" and "Vehicle_Survivability_Score". Note that scores are only provided when running one of the "all" predefined shotline suites.
Your ballistics test bench is now set up.
Your screen should now resemble Figure 8:

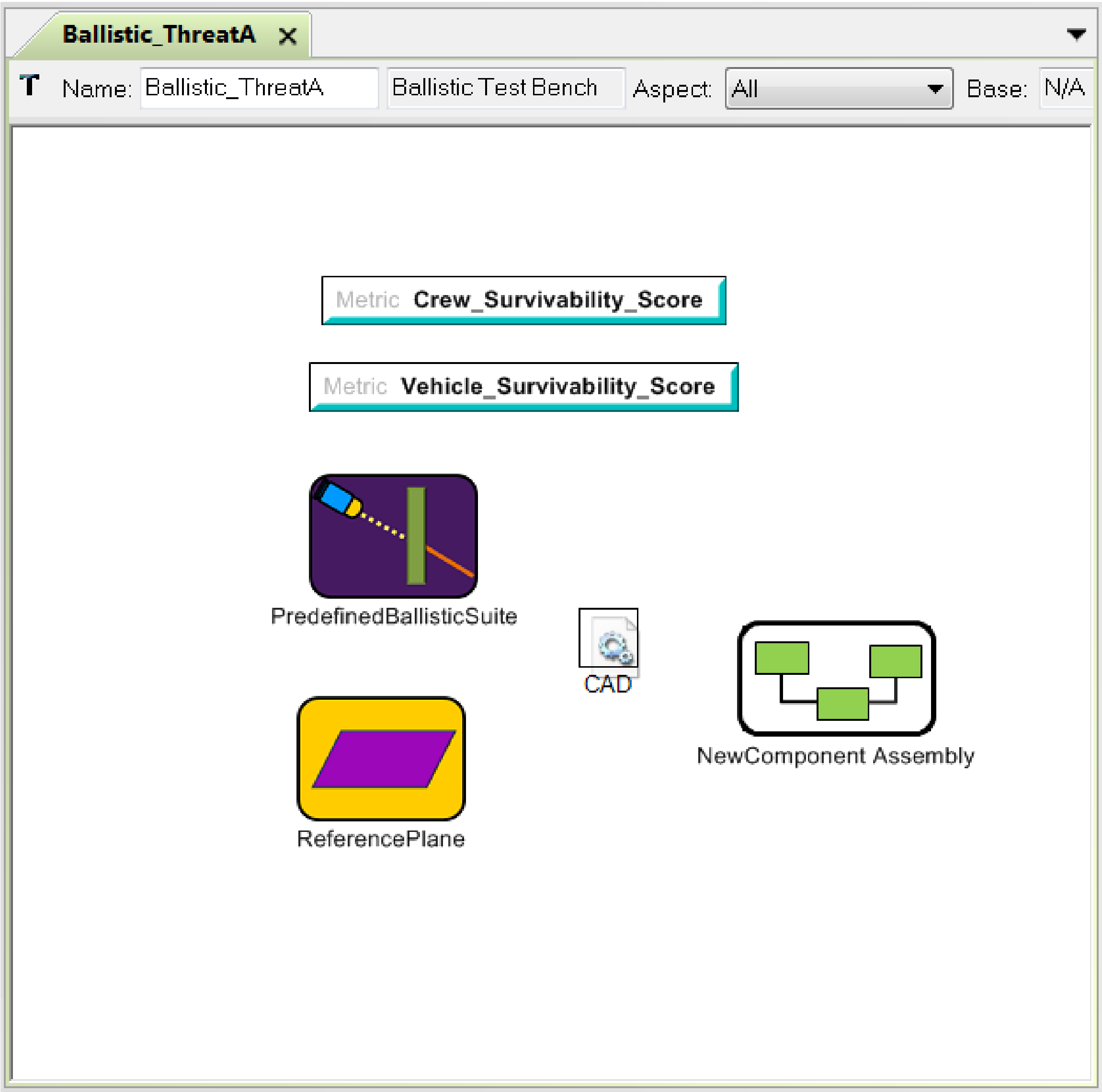

Figure 8: Ballistic_Test test bench window

2.2.10 Step 5: Run DESERT

Run DESERT as usual, applying all constraints and exporting all configurations. You should end up with 3 configurations.

2.2.11 Step 6: Running the interpreter

From the META tool bar, select the Master Interpreter (icon shown in Figure 9).

Figure 9: Master Interpreter

Select the design configurations on which you would like to run test and then run the master interpreter. If you want to run the analysis locally, deselect the Remote Execution option. Tiers 1 and 2 can be run locally or remotely. Tier 3 can be run locally only if you have access to an installation of CTH, otherwise it should be run remotely.
Select the options as shown in Figure 10.

- Make sure that "Use Project Manifest" is checked
- Make sure that "AP203_E2_Single_File" is checked. It is fine for "AP203_E2_Separate_Part_Files" to be checked as well but it is not required.

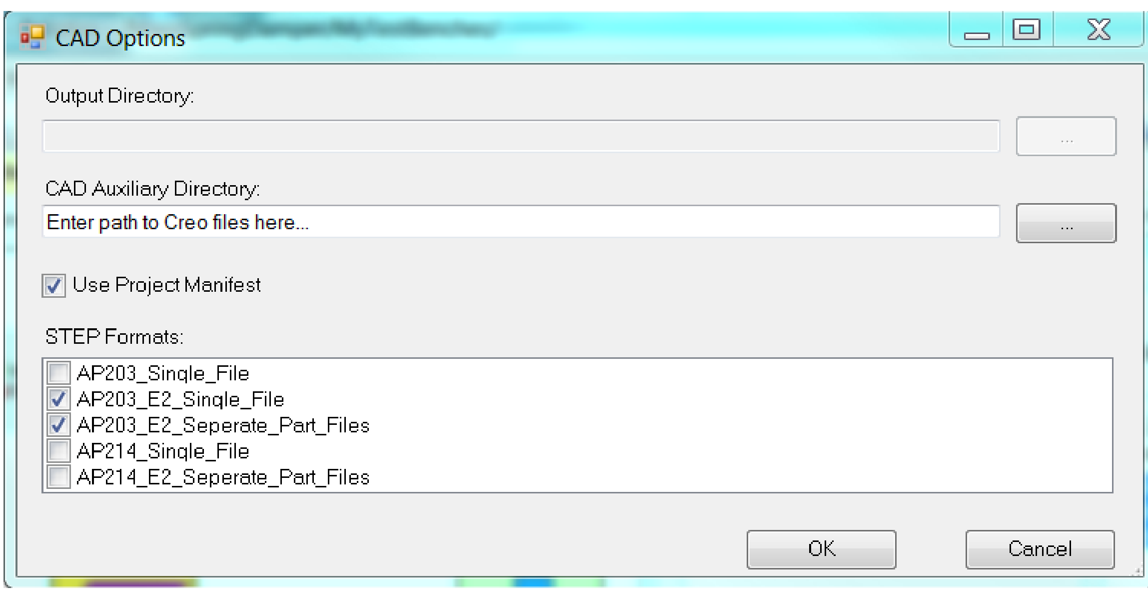

Figure 10: CAD Options dialog box

Select OK.
If the test bench was correctly set up, after the analysis is completed open the results folder run the runShotlineViewer.bat to run the "Shotline Viewer" and see results displayed for the collection of shotlines in the predefined shotline suite. See section 2.4 for more information on viewing results in the ShotlineViewer.

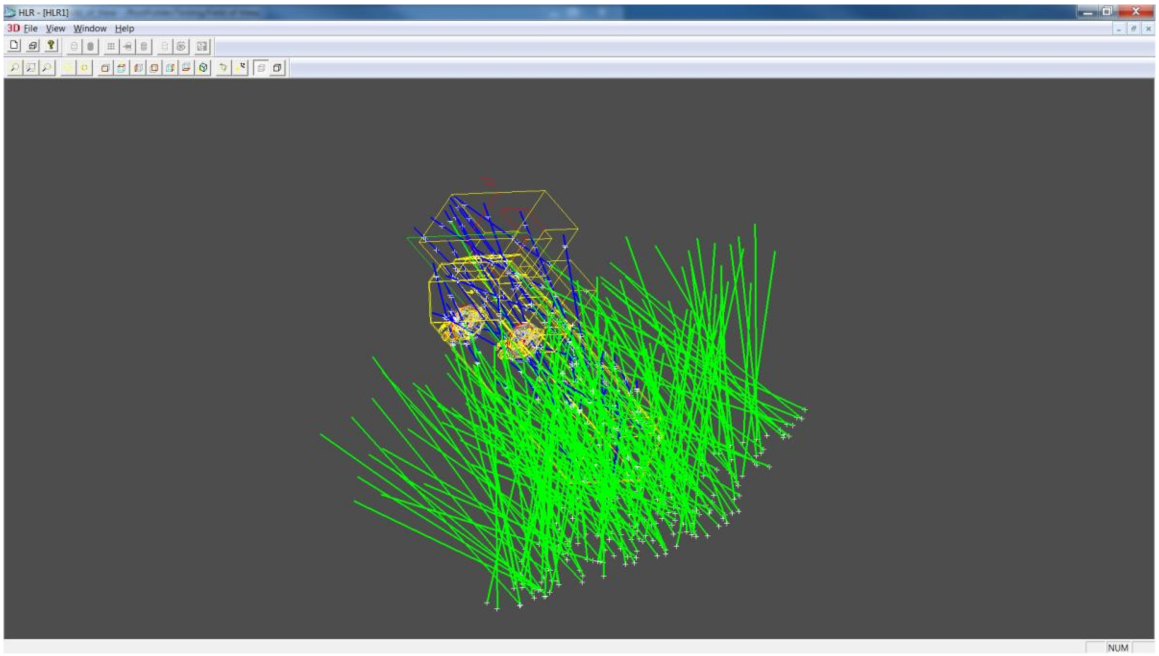

Figure 11: Output of Ballistics Analysis tool in Shotline Viewer program

2.3 Running "Custom Shotline" Ballistics Analysis on the MSD

This tutorial will demonstrate the steps required to run a ballistics simulation of a single "custom shotline" on the MSD.

2.3.1 Step 1: Set Up Test Folder

In the GME Browser, insert a new Testing subfolder within the existing Testing folder and name it "Ballistics Test."
Within this subfolder, insert a new BallisticTestBench model and name it "Ballistics TestBench."

2.3.2 Step 2: Insert Design Space Reference

Copy/Paste As Reference... the MyMassSpringDamper design container into the Ballistics Test window.
When prompted, select TopLevelSystemUnderTest.

2.3.3 Step 3: Ballistic Test Bench Requirements

The ballistic test bench has four components:

- Ballistic target - Projectile that is being shot

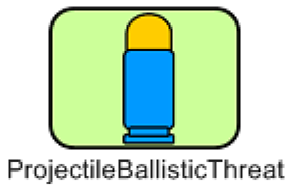

Figure 12: ProjectileBallisticThreat Element

- Shot line model

Figure 13: ShotlineModel Element

- Reference plane

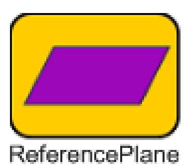

Figure 14: ReferencePlane Element

2.3.4 Step 3a: Setting up the Ballistic Target

Within a component assembly, there will be at least one component that you wish to fire upon. This component is called the Ballistic Target. In this assembly, the "Mass" is the desired target.

If, in another analysis, you wanted to fire two shots in two locations on the spring component and one location on the mass, you would need to copy in both the mass and spring design containers. The spring must have at least two point ports representing the two locations on the spring you want targeted.

Within the "Ballistics TestBench" BallisticsTestBench model, expand the "MyMassSpringDamper" design container so that it displays all components making up the assembly.

Within the "MyMassSpringDamper" design container, locate the "Mass" design container and right-click > Copy.

Go back within the "Ballistics TestBench" BallisticsTestBench model and Paste... As Reference the "Mass" design container into the test bench.

When prompted, select BallisticTarget.

The part in the test bench window should display the component's ports.

NOTE 1:

The target MUST be referenced from the component assembly that is the TopLevelSystemUnderTest in the test bench. You cannot just Copy/Paste... As Reference the component from the list of components in the GME browser window.

The reason for this is that when the BallisticsTestBench is run, the TopLevelSystemUnderTest is the design container of the assembly that allows for the full assembly to be created within the test bench. Since the shotline is told to fire at the "Mass" (in this example), the "Mass" must be referenced as part of the TopLevelSystemUnderTest. If, instead, the "Mass" from the list of components in the GME Browser was Copy/Pasted... As Reference, this "Mass" would not be a reference of the overall assembly (i.e. TopLevelSystemUnderTest).

NOTE 2:
In order to be a ballistic target, the component must have a "point" feature in the Creo part file at the location you wish to fire on. This point must then also be a part of the CyPhy component model.
In another analysis, if one wanted to fire two shots at two locations of the "Spring" component and one shot at a location of the "Mass," one would need to Copy/Paste...As Reference both the "Mass" and "Spring" design containers. The "Spring" would have to have at least two point ports representing the two locations on the spring one wanted targeted.

2.3.5 Step 3b: Projectile Ballistic Threat

Within the Element Browser, find the "ProjectileBallisticThreat" element and Drag/Drop it into the test bench window.
In order for the simulation to run, the threat must have the following information supplied:

- Speed (m/s)
- Material
- Length (m)
- Diameter (m)
- Mass (kg)

Highlight the ProjectileBallisticThreat and fill out the information so that the fields under the Object Inspector match that of Figure 15.

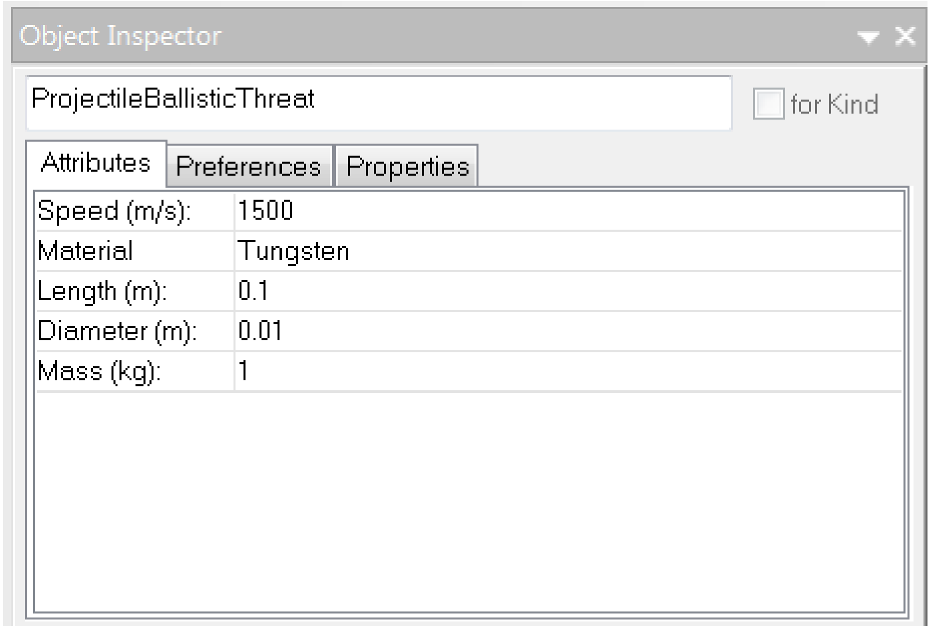

Figure 15: Object Inspector for ProjectileBallisticThreat

This is the necessary information required for the simulation to run. While "Steel-Generic" and "Tungsten" are likely the most common materials for projectiles, other materials may be chosen from the "Material Label" column of the "metals" sheet of the SwRI-Open-Materials-Database-YYYYMMDD.xlsx spreadsheet included under C:\SwRI-AVM-Tools.

2.3.6 Step 3c: Shot line Model

Now that the target and projectile have been defined, the path the threat will take to the target needs to be defined.
Locate the ShotlineModel part in the Element Browser and Drag/Drop it into the test bench window.
Double click the ShotlineModel element to open it.
Two angles need to be specified to define its path: its elevation angle and azimuth angle. The angles are given in degrees and are based from the assembly coordinate system that is in front of the hull, with the azimuth angle being defined in a clockwise direction (90 degrees equates to east if the front of the vehicle is facing north).
The only two elements in the Element Browser will be AzimuthAngle and ElevationAngle. Drag/Drop one of each into the ShotlineModel element.
Select the AzimuthAngle element and enter a value of 45 in the Attributes tab of the Object Inspector.

Repeat the above step for the ElevationAngle element, also entering a value of 45. Returning to the "Ballistics TestBench," the ShotlineModel part should now look like Figure 16. Note the two small attribute icons on the right side of the ShotlineModel icon.

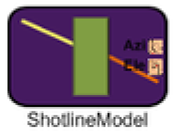

Figure 16: ShotlineModel element after specifying angles.

2.3.7 Step 3d: Reference Plane

Locate the ReferencePlane element in the Element Browser and Drag/Drop it into the Ballistics TestBench window.
Select the element and ensure that under the Attributes tab in the Object Inspector that its Type is specified as "Ground".

2.3.8 Step 3e: Tier

Select the BallisticTestBench under the Testing folder in the GME Browser
Select the Tier in the Object Inspector Window. Tier 1, 2 and 3 are supported.

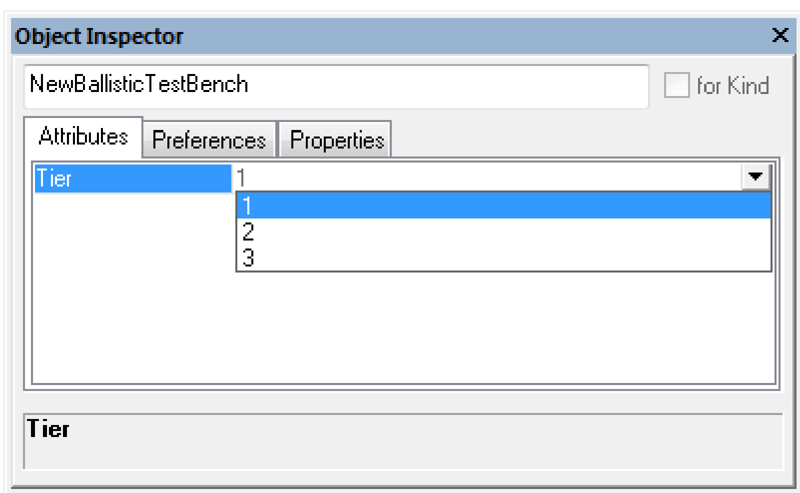

Figure 17: Tier selection in Object Inspector Window

2.3.9 Step 4: Connect Parts

Enter **Connect Mode** (CTRL-2) and connect from the ProjectileBallisticThreat to the ShotlineModel.
Then connect from the ShotlineModel to the point port on the "Mass".
Your screen should now resemble Figure 18.

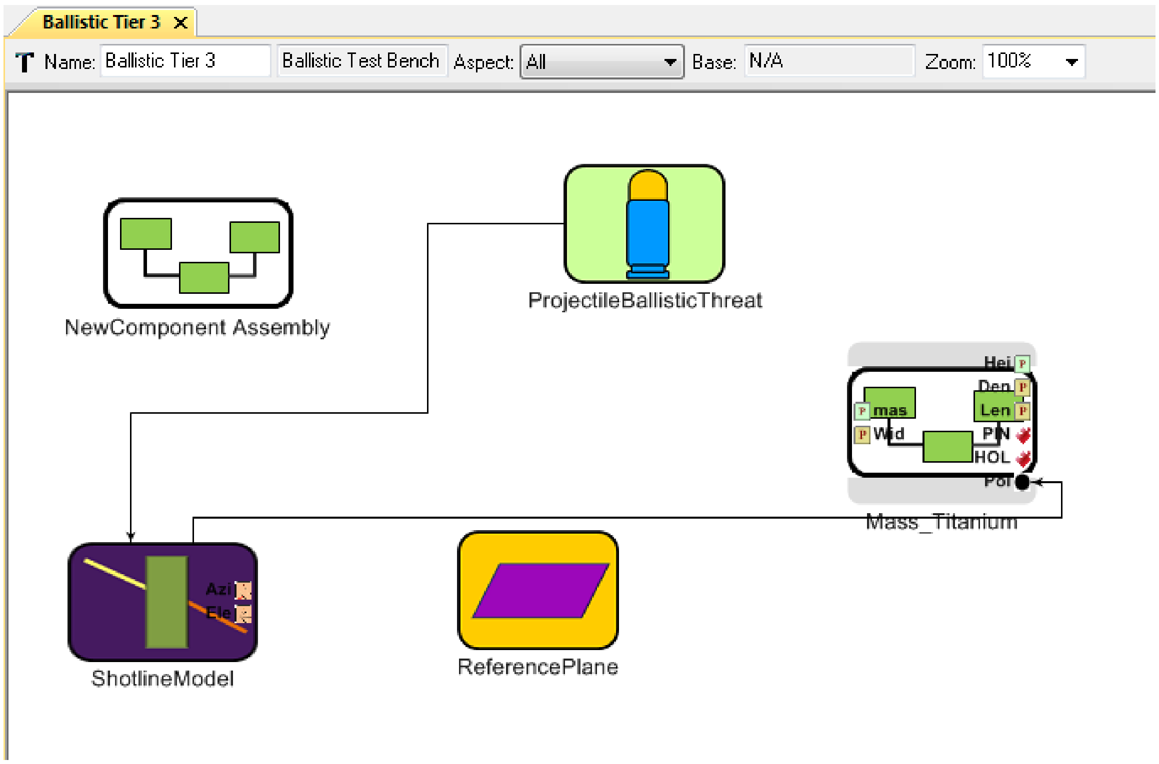

Figure 18: Ballistic_Test test bench window after completing step 4

> **NOTE:**
> For the projectile to hit a target, the component in question must have the point of impact defined as a feature in both its Creo part file and CyPhy component.

Your ballistics test bench is now set up.

2.3.10 Step 5: Run DESERT

Run DESERT as usual, applying all constraints and exporting all configurations. You should end up with 3 configurations.

2.3.11 Step 6: Running the interpreter

From the META tool bar, select the Master Interpreter (icon shown in Figure 19).

Figure 19: Master Interpreter

Select the design configurations on which you would like to run test and then run the master interpreter. If you want to run the analysis locally, deselect the Remote Execution option. Tiers 1 and 2 can be run locally or remotely. Tier 3 can be run locally only if you have access to an installation of CTH, otherwise it should be run remotely.

When you run this interpreter, you must:

- Choose the location of the Creo part files that make up the assembly
- Make sure that "AP203_E2_Single_File" is checked. It is fine for "AP203_E2_Separate_Part_Files" to be checked as well but it is not required.

Reference Figure 20 for the CAD Options dialog box.

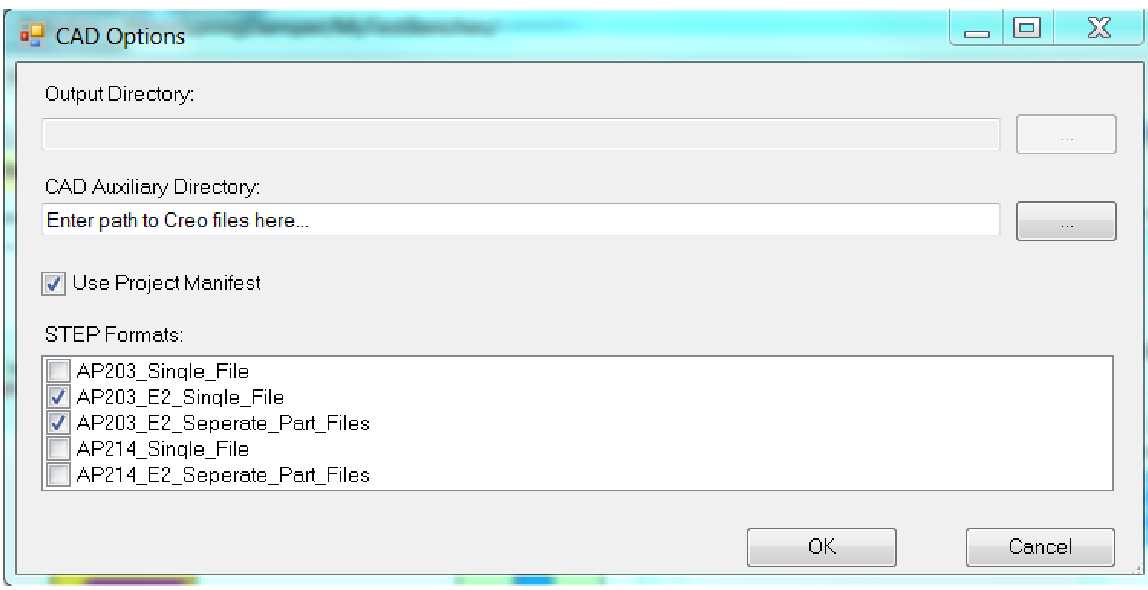

Figure 20: CAD Options dialog box

Select OK.
If the test bench was correctly set up, after the analysis is completed a "Shotline Viewer" program window will automatically open with the results displayed for each configuration that was selected and succeeded.
The viewer will display the assembly and the shot line that was fired at the mass. An expected output is shown in Figure 21.

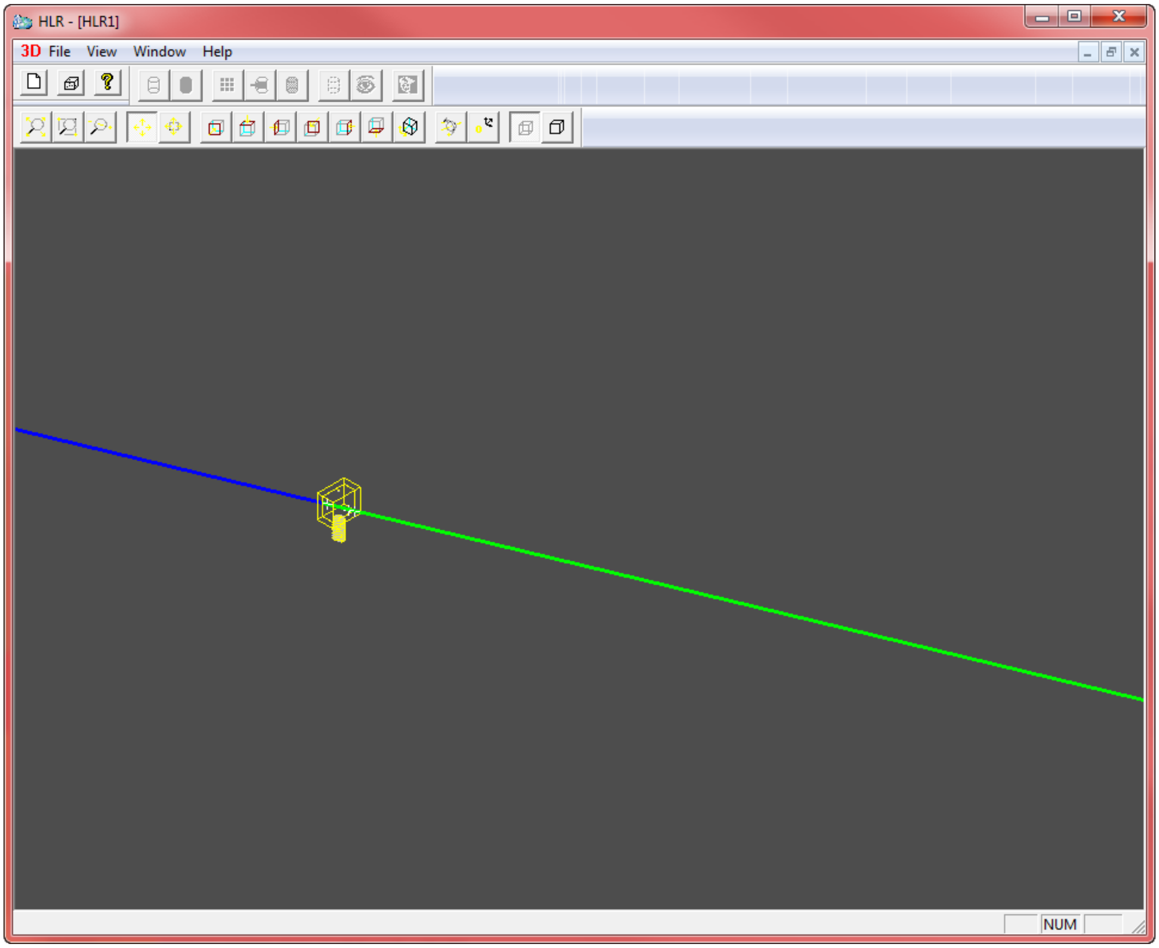

Figure 21: Output of Ballistics Analysis tool in Shotline Viewer program

2.4 Examining Shotlines

The Shotline Viewer is a tool intended to help the user visualize the results of ballistic analyses. When viewing results from a ballistic analysis, the computed shotlines will appear as colored lines intersecting the geometry of the design.

To 3D rotate the view, hold down the Ctrl key and click-and-drag the right mouse button.
To zoom the view, hold down the Ctrl key and click-and-drag the left mouse button.
The shotlines are color coded according to the following scheme:

- A Green shotline does not intersect a part marked as "Critical"
- A Green shotline turns to Blue at the point where the projectile stopped.
- A Yellow shotline intersects a "critical" part but the projectile stopped before perforating the critical part.
- A Yellow shotline turns to Orange at the point where it was stopped.
- A Red shotline perforates a "critical" part, representing a Kill, and turns to Black at the point of the kill.

The Shotline Viewer includes support for examining details of individual shotlines. Figure 22 shows the Shotline Viewer with the results of the "ThreatD-All" shotline suite. The toolbar along the top of the display allows the user to view standard view angles on the design, and to toggle viewing options such as CAD opacity among other options.

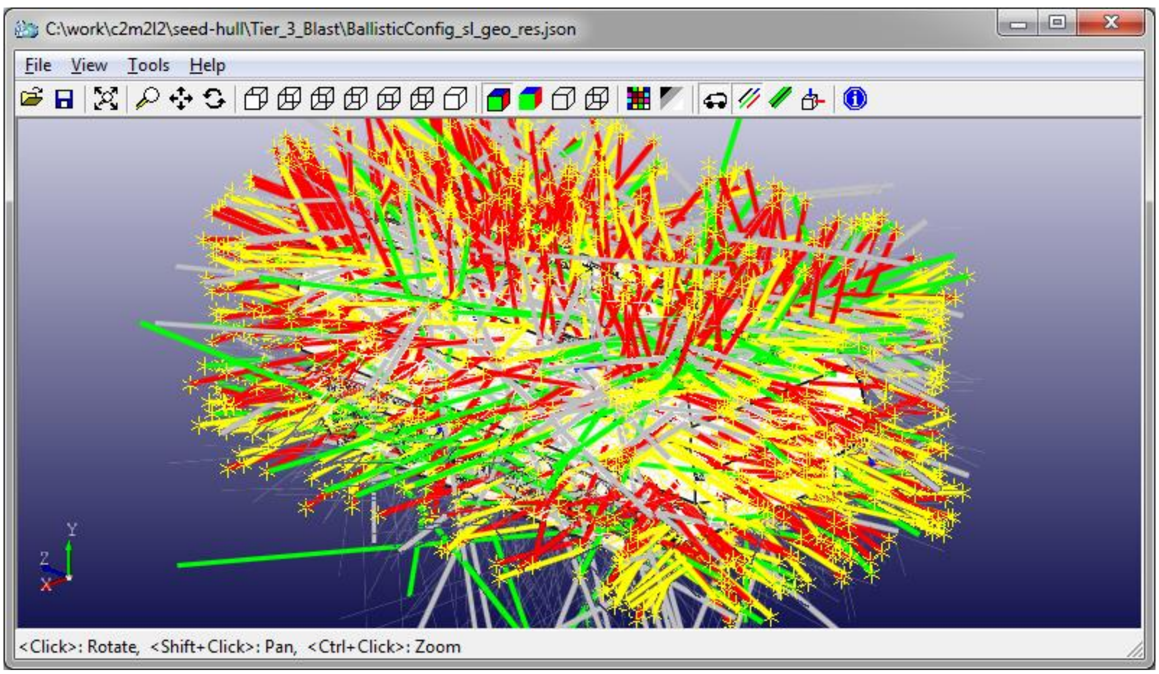

Figure 22. Results of "ThreatD-All" predefined ballistics suite on the seed design

When the user hovers over the top of a shotline, the line is highlighted in cyan as in Figure 23. If the user clicks on a single shotline, all but that one shotline temporarily disappears to allow the user to zoom in and examine the geometry of the shotline in more detail (See Figure 24). Simply click outside the vehicle to bring back all of the original shotlines.

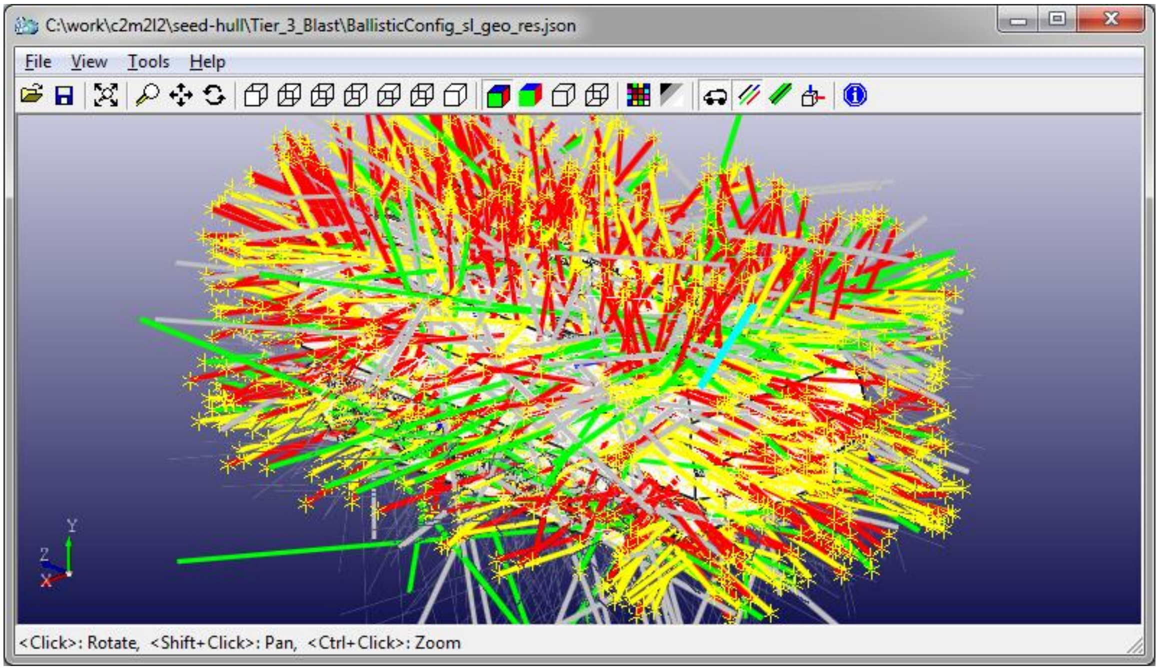

Figure 23. Hovering over a shotline highlights it in cyan

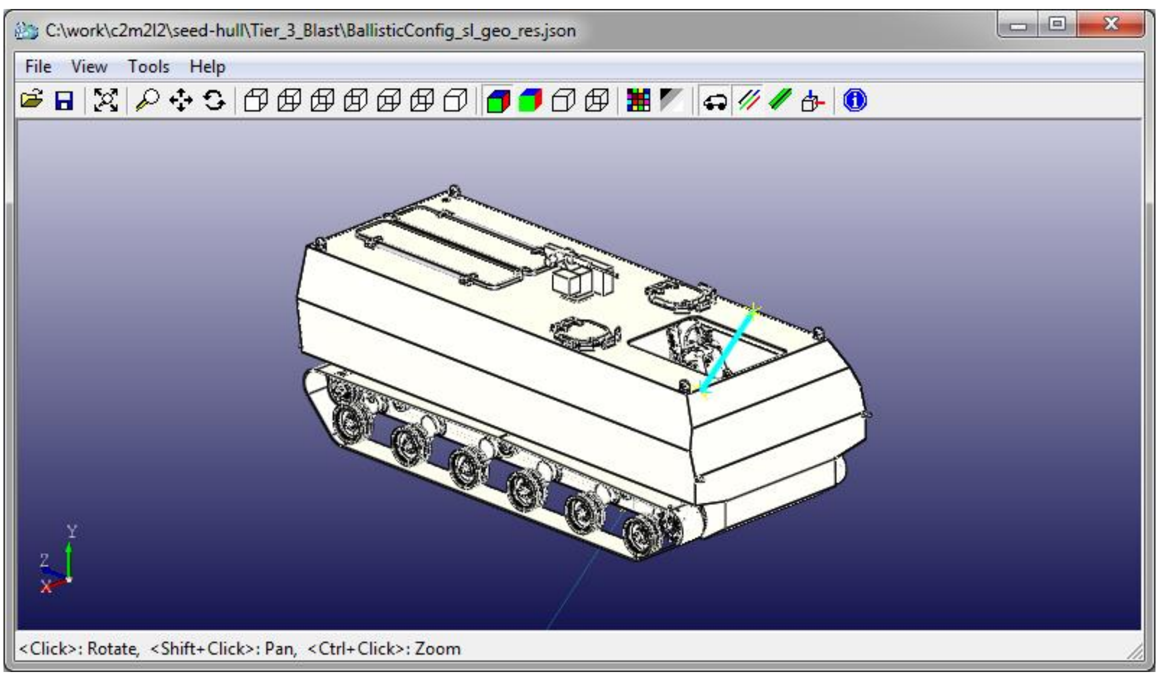

Figure 24. Clicking on a shotline temporarily hides all other shotlines. Click outside the vehicle to restore all shotlines.

In Figure 25, the blue highlighted shotline was selected by the user and the side window shows details about the line. The name of the shotline is "shotline_684" and it impacts the "E137_F1_PANEL_H5_..." component. The projectile completely perforated the part since there is a non-zero "speedAfter" value. The "perf/crit/kill: Y/Y/Y" indicates that the threat perforated the part, that the part was a critical component, and that it resulted in a kill. The user can click the arrows in the interface to cycle between shotlines as well as the various intersections of the shotline with system components.

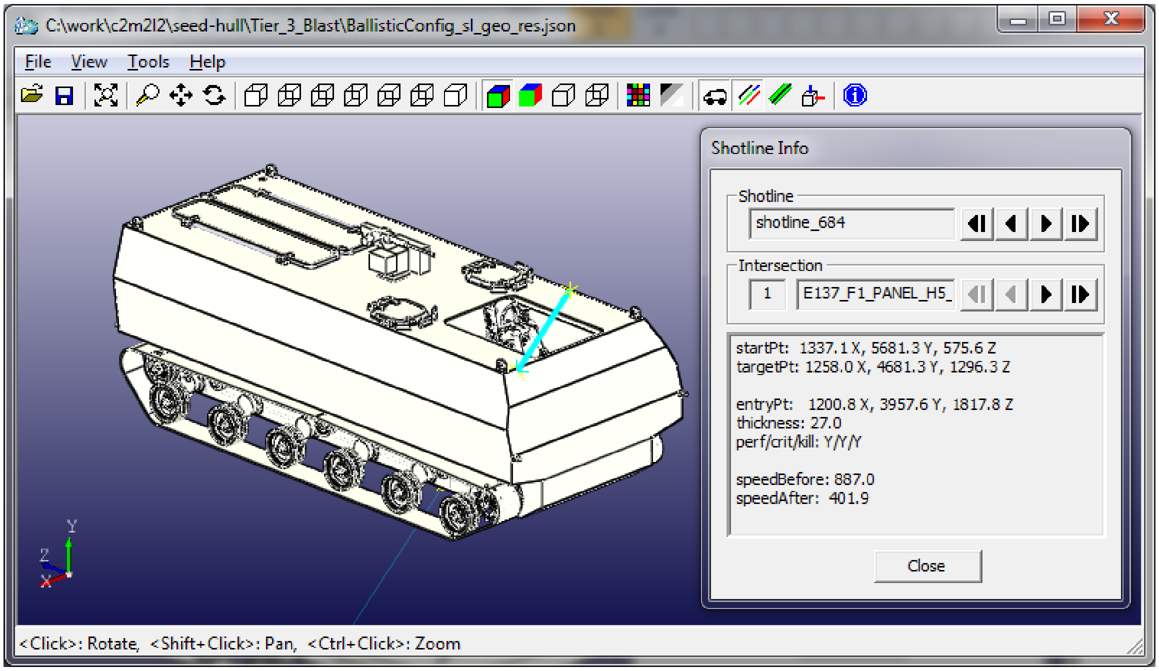

Figure 25. Examining the details of a shotline.

2.5 Tool Details

2.5.1 Tool Options

By default, the tools are installed under

```
C:\SwRI-AVM-Tools
```

The ballistic tools are bundled into a single executable called ballistics.exe. Running ballistics.exe with a '-h' provides additional options that are available to a power user of the software.

```
C:\SwRI-AVM-Tools>ballistics.exe -h
Usage: ballistics.exe [options] SHOTLINES
```

This program performs a ballistics analysis on the shot lines described in the SHOTLINES file, which conforms to the shotlines-schema.json schema.

Options	
-h, --help	show this help message and exit
-n, --no-validate	don't validate input files against JSON schemas
--only-validate	only validate input files against JSON schemas, then exit
-m MATDBFILENAME, --matdb=MATDBFILENAME	specify a non-default materials spreadsheet file (xlsx)
--no-display	don't display the results in 3D viewer
--force	force the pipeline to re-run all steps
-v, --verbose	print status messages to stdout

The main key is that the ballistics.exe is passed on the command-line a JSON-formatted file containing details about the shotline analysis being performed. Details about the format of the shotline JSON file can be found in the ballistics tool ICD that is included with the installer under the directory:

```
C:\SwRI-AVM-Tools\BallisticAnalysisICD.docx
```

2.5.2 Pipeline Stages

Ballistics.exe performs the following steps in order to analyze the system under test:

- Load shotline JSON file.
- Load Materials Database file which contains material properties specific to ballistic analysis.
- Load CADAssembly_metrics.xml file which is produced by META/CyPhy and contains details of the assembly under test. Ballistics.exe obtains a listing of part names and their associated material name from the CAD metrics file.
- Evaluate the geometry of the shotlines and where they intersect with the parts in the assembly under test.
- For tiers 1 & 2: Invoke the ballistic solvers to compute shotline results. Results are then displayed in the shotline viewer.
- For tier 3: Generate CTH input deck as a zipfile ready to be copied to a computer running CTH, unzipped, and run in CTH.

2.6 Named Projectiles

TBD need to add details about the list of specific projectiles that can be called out.

2.7 Output

The output of tier 1 and 2 analyses is most easily understood by examining the results in the Shotline Viewer. It provides a 3D representation of the assembly-under-test with graphical representations of the shotlines intersecting the assembly. The full details of the analysis are available to the user in the results JSON file. This file is typically named BallisticConfig_sl_geo_res.json and is found in the same directory as the shotline JSON file that is the input to ballistics.exe.
The output of tier 3 CTH simulations takes the form of a movie file which displays the interaction of the projectile with the geometry of the assembly-under-test in the immediate vicinity of the shotline.

2.7.1 Test Bench Tiers

Attribute	Tier 1	Tier 2	Tier 3
Test Bench Name	55 test benches (11 threats, 5 directions)	55 test benches (11 threats, 5 directions)	user defined
Description	Performs scaling off of historical penetration data sets.	Applies physics-based models of the penetration of one material into another.	Hydrocode computation using full 3D part geometry.
Estimated Run Time	Heavily dependent on the amount of time required to parse the STEP geometry. Between 2 minutes to 1 hour.	Heavily dependent on the amount of time required to parse the STEP geometry. Between 2 minutes to 1 hour.	Measured in hours to days.
Error Margin	Dependent on how closely the test scenario matches test cases that make up the data sets. Close matches will be extremely accurate. Physics models are written with assumptions of a semi-infinite plane of material into which the projectile penetrates. Test scenarios in regions near an edge or a join lose accuracy.	Full 3D material simulations are very accurate.	Hydrocode simulations are particularly useful for scenarios where the simplifying assumptions of tiers 1 & 2 do not apply, such as near edges and corners of plates.
Results Provided	Score plus results from each part intersection with each shotline in JSON file that is visualized by the Shotline Viewer	Score plus results from each part intersection with each shotline in JSON file that is visualized by the Shotline Viewer	Movies of the ballistic penetration simulation.
Local/Remote	Both	Both	Mainly remote. Users may run locally if they have access to CTH.
Tool Used	Custom solvers	Custom solvers	CTH
How to Interpret Results	View Score, Visually inspect shotlines using the provided Shotline Viewer	View Score, Visually inspect shotlines using the provided Shotline Viewer	View movies generated by CTH and post-processing scripts.
Model Requirements	None	None	Tier 3 support for cermaic materials is not yet complete. Tier 3 requires a custom shotline. Predefined

Attribute	Tier 1	Tier 2	Tier 3
			shotline suites are not allowed.

2.8 Black Box Armors

Starting in R31 of the SwRI AVM Tools, support has been added for "black box" armors. These are armors for which no internal details are given, the only information about the armor is the NIJ and/or STANAG level of threat which it defeats. When the pipeline encounters a black box armor, if the projectile carries a threat level less than or equal to the level of the armor, the projectile is completely defeated. If the projectile carries a threat level that is greater than the level of the armor, the projectile passes through the armor completely unchanged, without degradation to the speed or size of the projectile. Absent the internal details of the armor, this pass/fail approach is the only sensible option available to the pipeline.

2.9 Release Notes

R38 contains the following changes from R35

- Added delete_files_to_minimize_server_downloads option to setup.cfg file. Setting this to "true" will cause the ballistics pipeline to delete from the working directory many Meta-generated files that are not needed for the analysis. This was added to help with The server uploads and downloads. The setup.cfg file is found in the installation directory. This option is set to "false" by default.
- Additional shotline results information is shown in the "info" box in the ShotlineViewer
- Added checks to tier 3 pipeline to disallow the use of a predefined shotline suite with tier 3. The prior behavior simply selected the first shotline from the predefined suite but it doesn't make sense to run a computationally expensive tier 3 calculation on what is essentially a random shotline. The user must define a custom shotline that targets the region of interest on the design for tier 3 analyses.
- Added checks to ensure that at least one material intersected by the tier 3 shotline carries appropriate material properties.

R35 contains the following change from R34

- Updated materials database

R34 contains the following change from R33

- Fixed generation of tier 3 CTH projectile snippets for some threats (Beta ticket #846)

R33 contains the following the following change from R32/31

- One liner fix to post-impact projectile diameter

R31 is mainly a bug-fix release in response to Gamma and Beta tickets. Some items of note:

- Fixed "tool checkout" documentation to point to a more recent example
- Gamma Tickets #100, #101:
  - Support for blackbox armors (NIJ & STANAG levels)
  - Fixed units conversion errors that were affecting the computed strength of some materials