Beta 2 Resources ▾ Ballistics I Spiral II B

Ballistics Tool Installer & Documentation

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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 or 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.

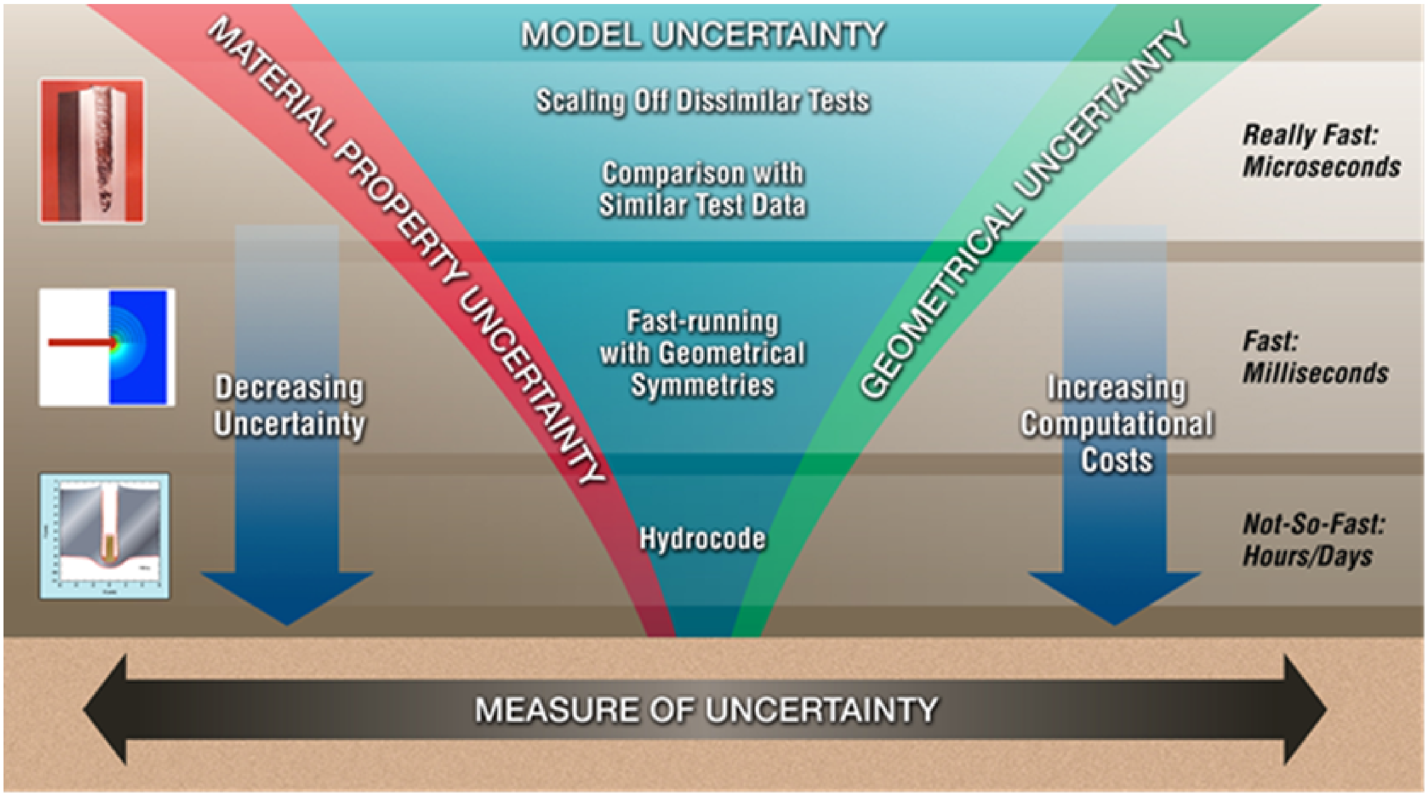


Figure 3: Ballistic Tiers

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.

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\Armor Plated Chassis\BallisticConfigPD-A-Front.json"
```

This will run a Tier 2 ballistics computation on a Meta-generated vehicle 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\Armor Plated Chassis\BallisticConfigPD-A-Front_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 =================
SLViewer.exe -i "C:\SwRI-AVM-Tools\Examples\Armor Plated Chassis\BallisticConfig
PD-A-Front_sl_geo_res.json" -o "None" -v
```

The final command listed above launches the Shotline Viewer program to view the results.

Please note that the command SLViewer.exe is for release 11 and prior versions of the SwRI AVM Tools. Starting in Release 12 a new 64-bit version of the software was introduced and has the name of shotline-viewer.exe.

A window similar to the following should appear on your screen:

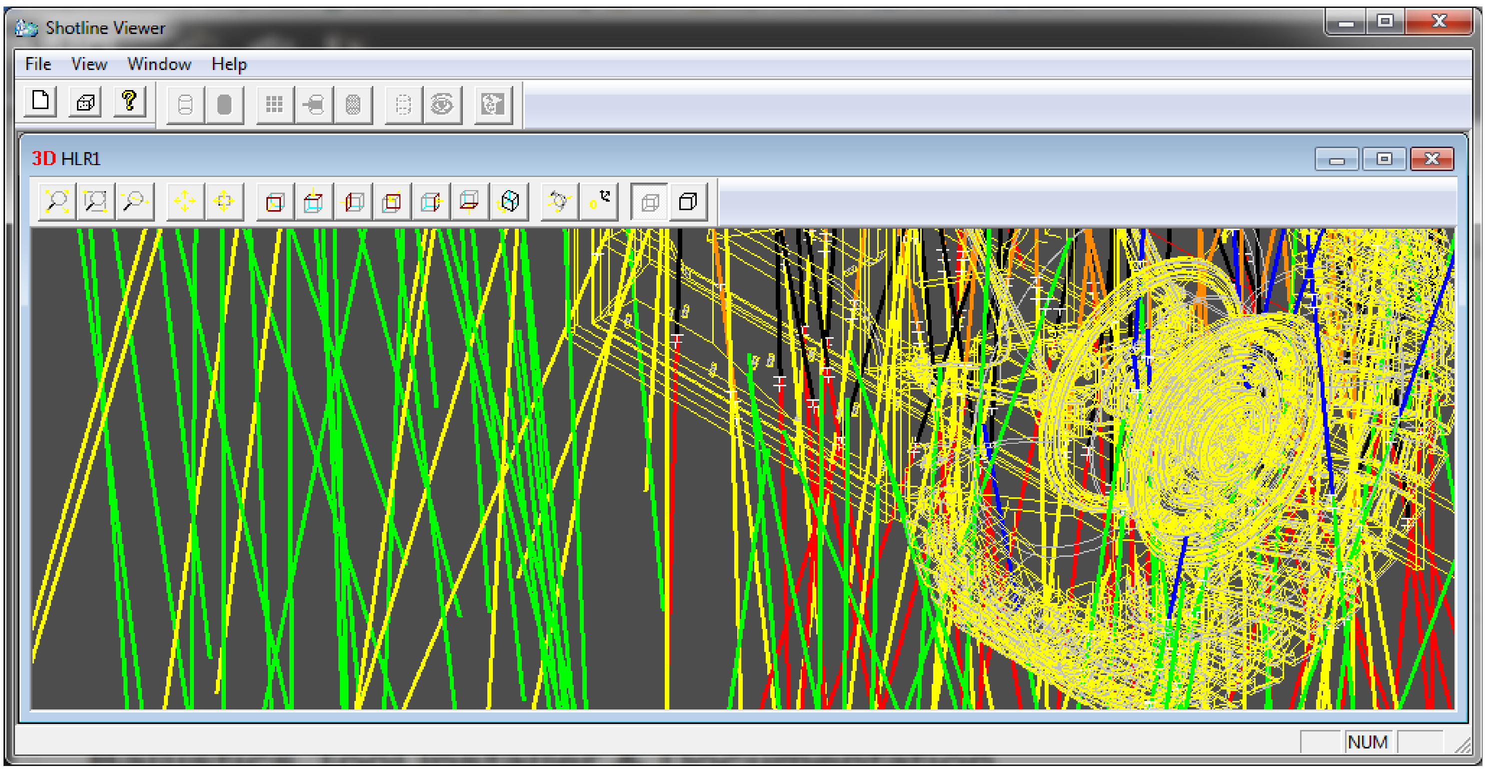


Figure 1: Shotline Viewer

Maximize the internal window and click the "Fit All" button in the toolbar. The "Fit All" button is the left-most button on the lower toolbar. After doing this, the display should look something like the following:

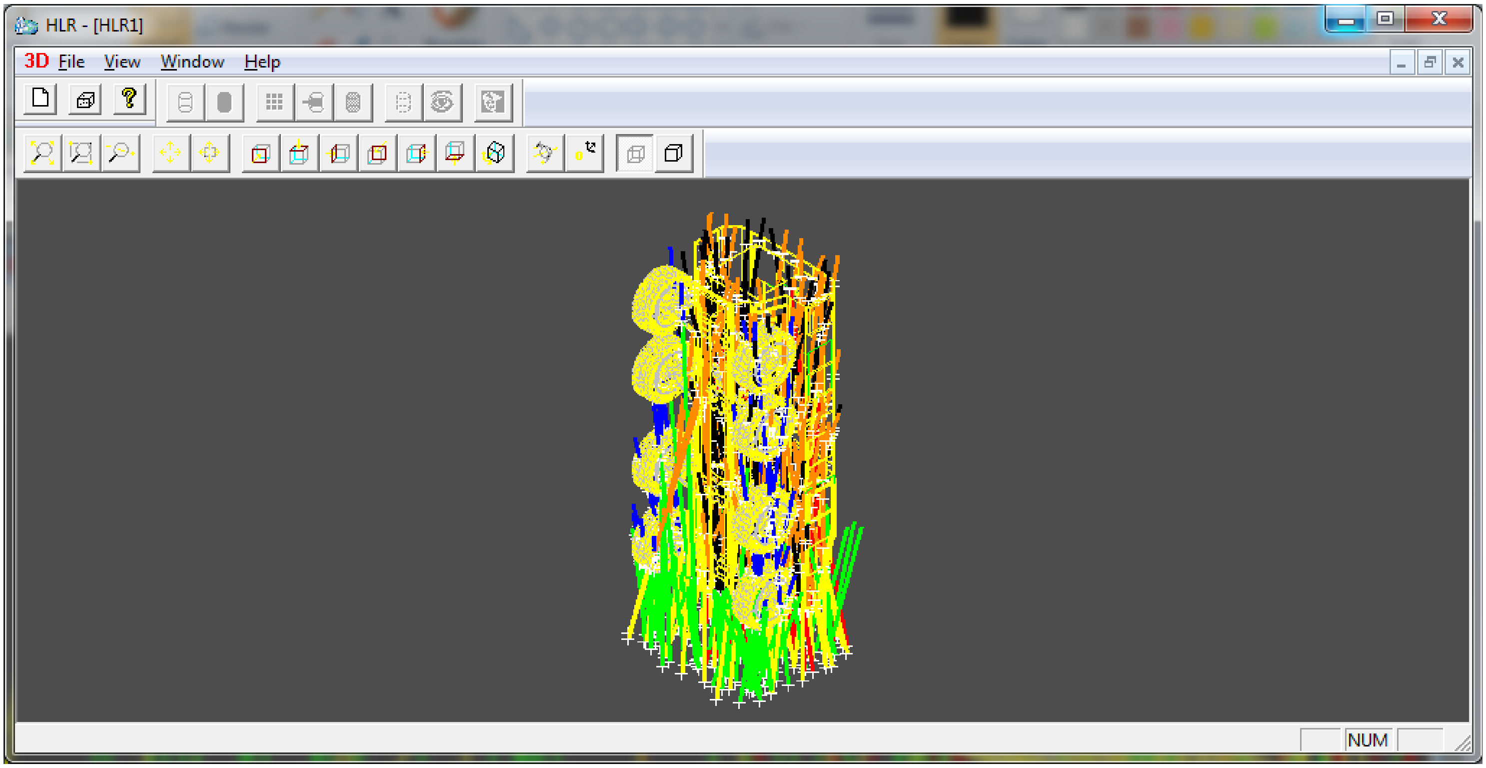


Figure 2: Fit All

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 Browswer.

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 three components:

- Ballistic target you are shooting at (e.g. MSD)
- Predefined Ballistic Suite (Figure 4)

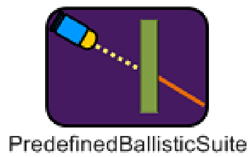


Figure 4: PredefinedBallisticSuite Part

- Reference plane (Figure 5)

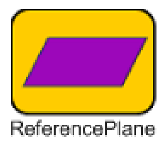


Figure 5: ReferencePlane Part

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.

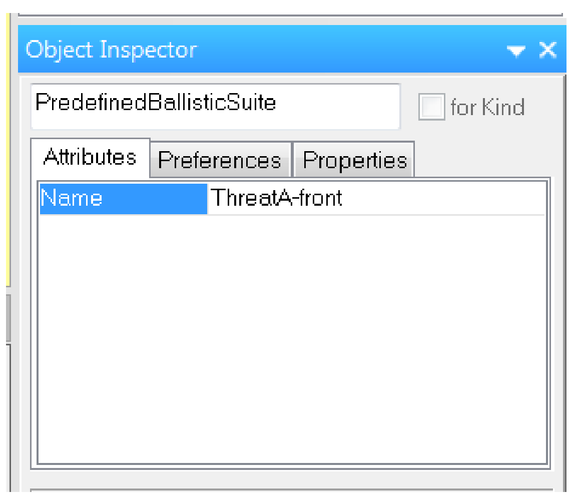


Figure 6: Object Inspector for PredefinedBallisticSuite

This is the necessary information required for the simulation to run.

There are currently 15 predefined shotline suites for 3 threats with 5 directions:

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
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".

Your screen should now resemble the following figure:

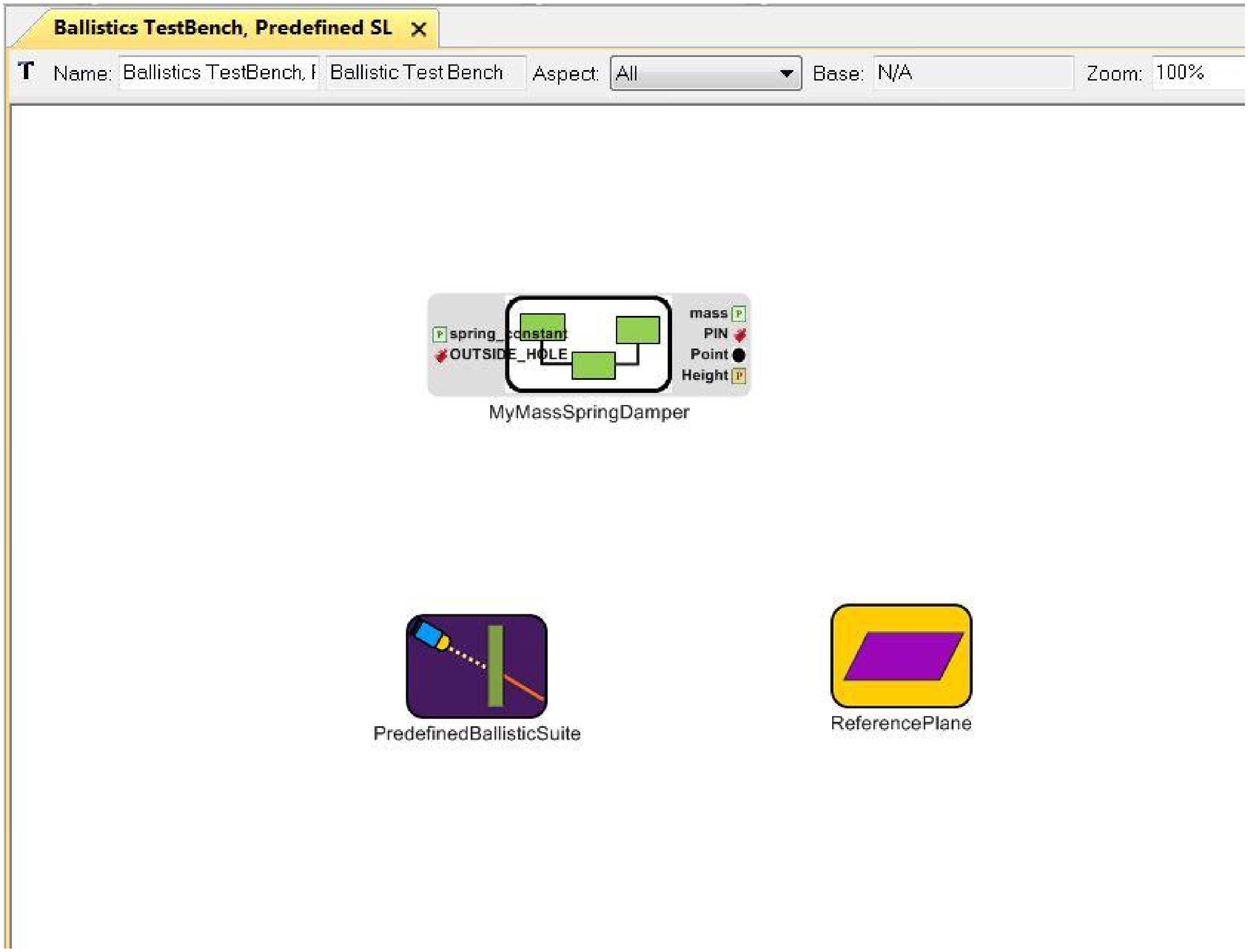


Figure 7: Ballistic_Test test bench window after completing step 8

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.

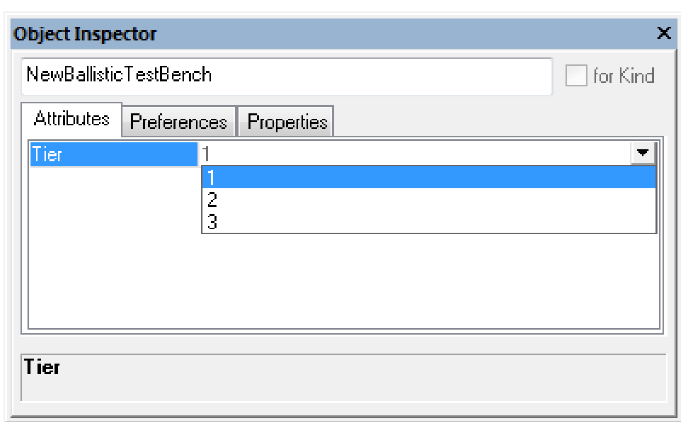


Figure 8: Tier selection in Object Inspector Window

2.2.7 Step 3d: Critical Components

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

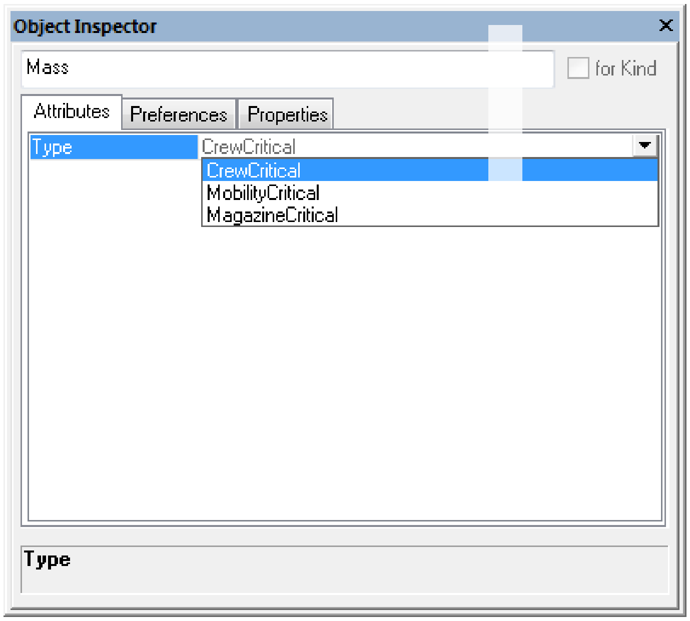


Figure 9: Critical component type selection in Object Inspector

Your ballistics test bench is now set up.

2.2.8 Step 4: Run DESERT

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

2.2.9 Step 5: Running the interpreter

- From the META tool bar, select the Master Interpreter (icon shown in Figure 10).

Figure 10: Master Interpreter

Select the design configurations you would like to run the test on and run the master interpreter.

When you run this interpreter, you must:

- Choose the location of the Creo part files that make up the assembly
- Make sure that both "AP203_E2_Single_File" and "AP203_E2_Separate_Part_Files" are checked.

Reference Figure 11 for the CAD Options dialog box.

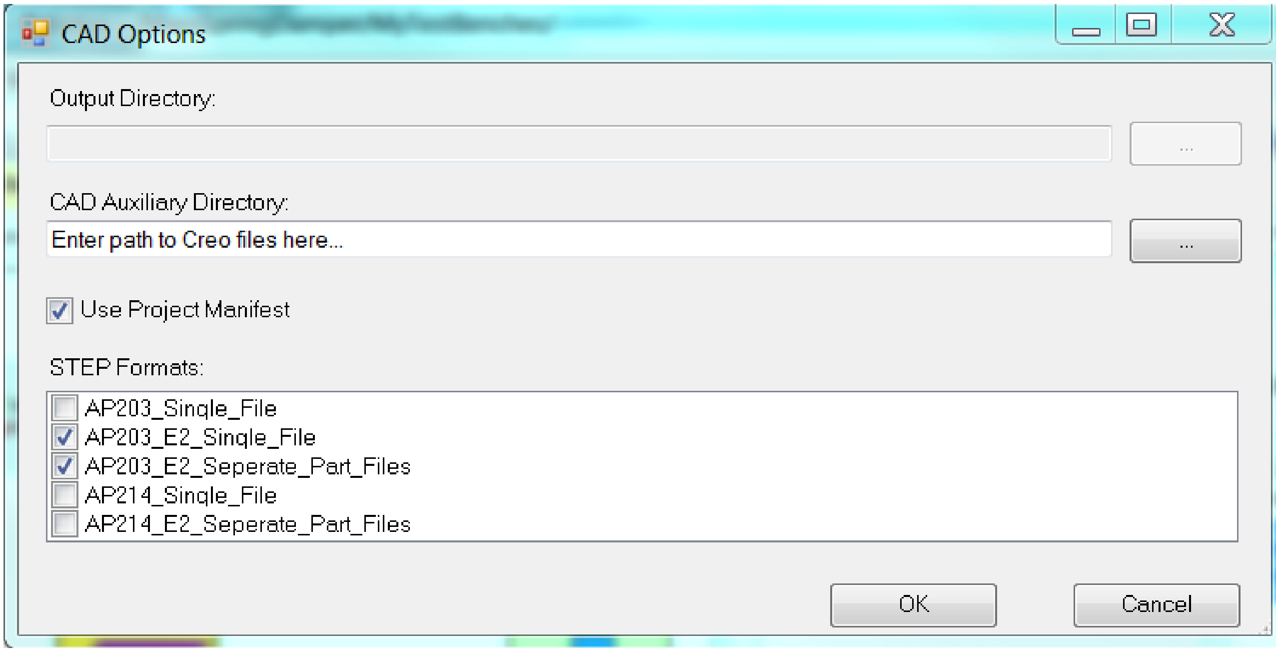


Figure 11: CAD Options dialog box

- 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.

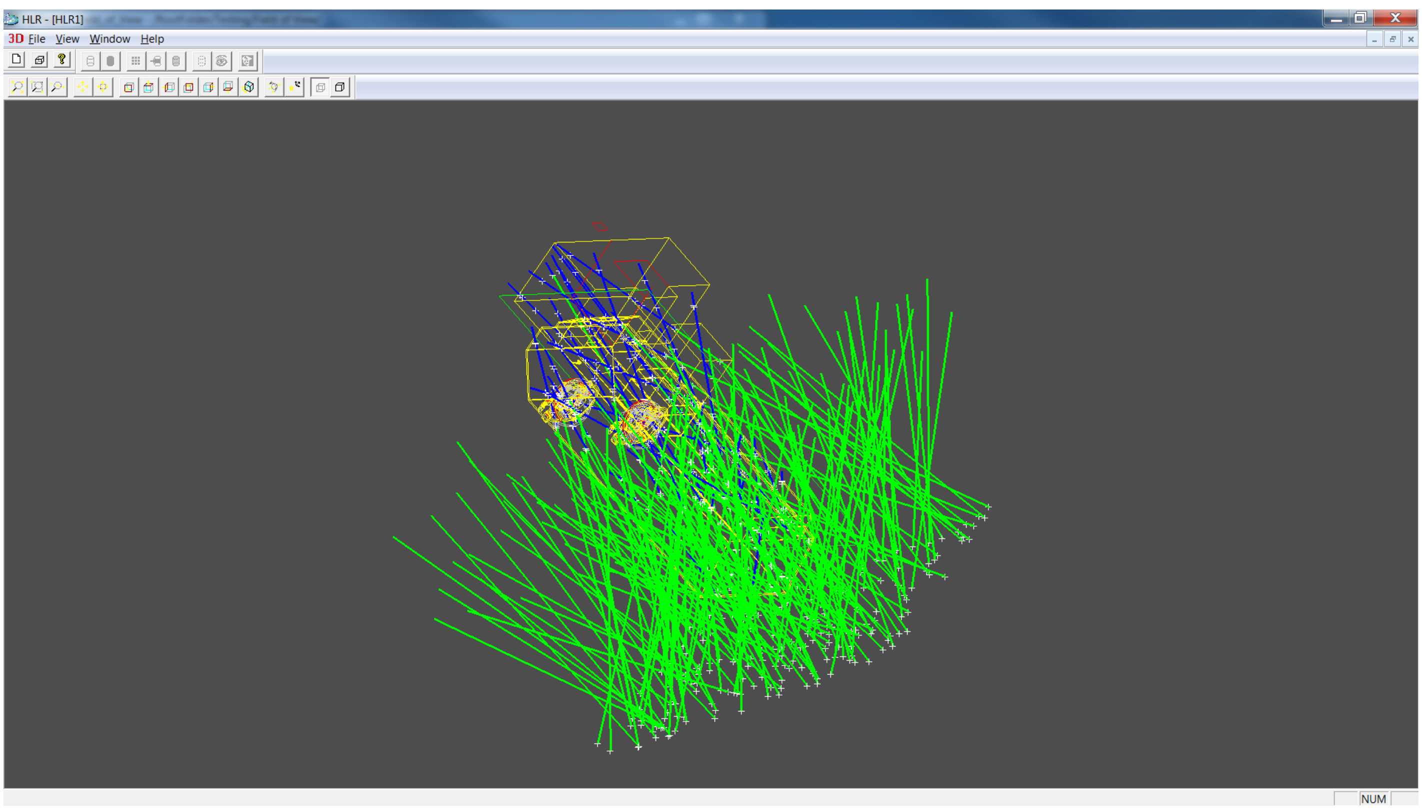


Figure 12: Output of Ballistics Analysis tool in Shotline Viewer program

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

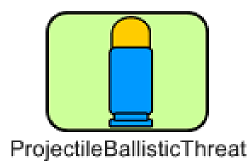


Figure 1: ProjectileBallisticThreat Element

- Shot line model

Figure 2: ShotlineModel Element

- Reference plane

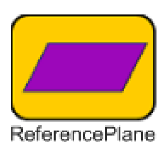


Figure 3: ReferencePlane Element

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 testbench. 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 Prowser 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.
enter>

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 4.

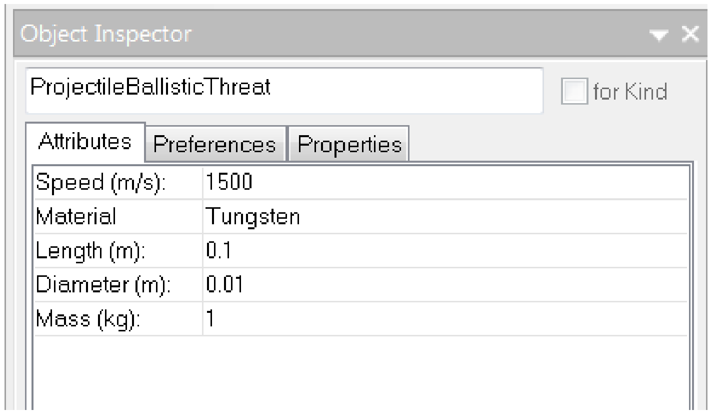


Figure 4: Object Inspector for ProjectileBallisticThreat

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 5.

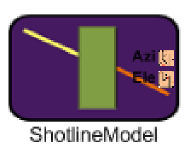


Figure 5: ShotlineModel element after specifying angles.

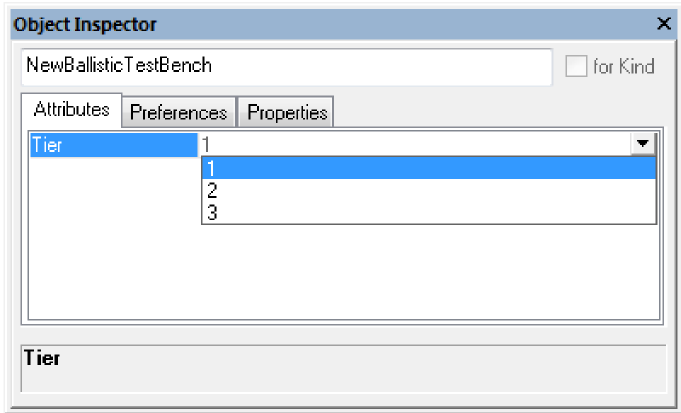
2.3.7 Step 3d: Reference Plane

- 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.



*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 6.

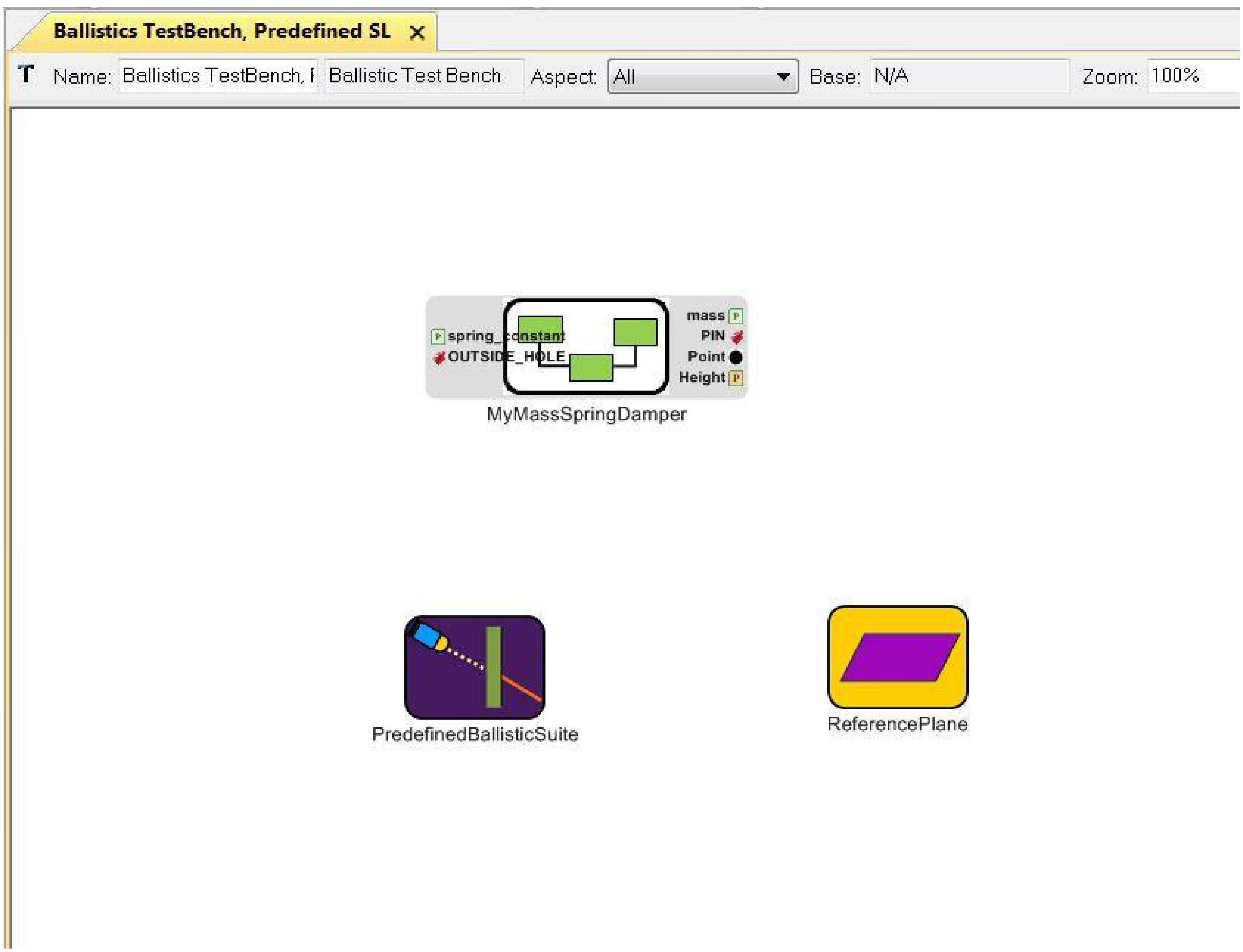


Figure 6: Ballistic_Test test bench window after completing step 8

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 7).

Figure 7: Master Interpreter

Select the design configurations you would like to run the test on and run *locally* (i.e., deselect *Post to META JobManager*).

When you run this interpreter, you must:

- Choose the location of the Creo part files that make up the assembly
- Make sure that both "AP203_E2_Single_File" and "AP203_E#_Separate_Part_Files" are checked.

Reference Figure 8 for the CAD Options dialog box.

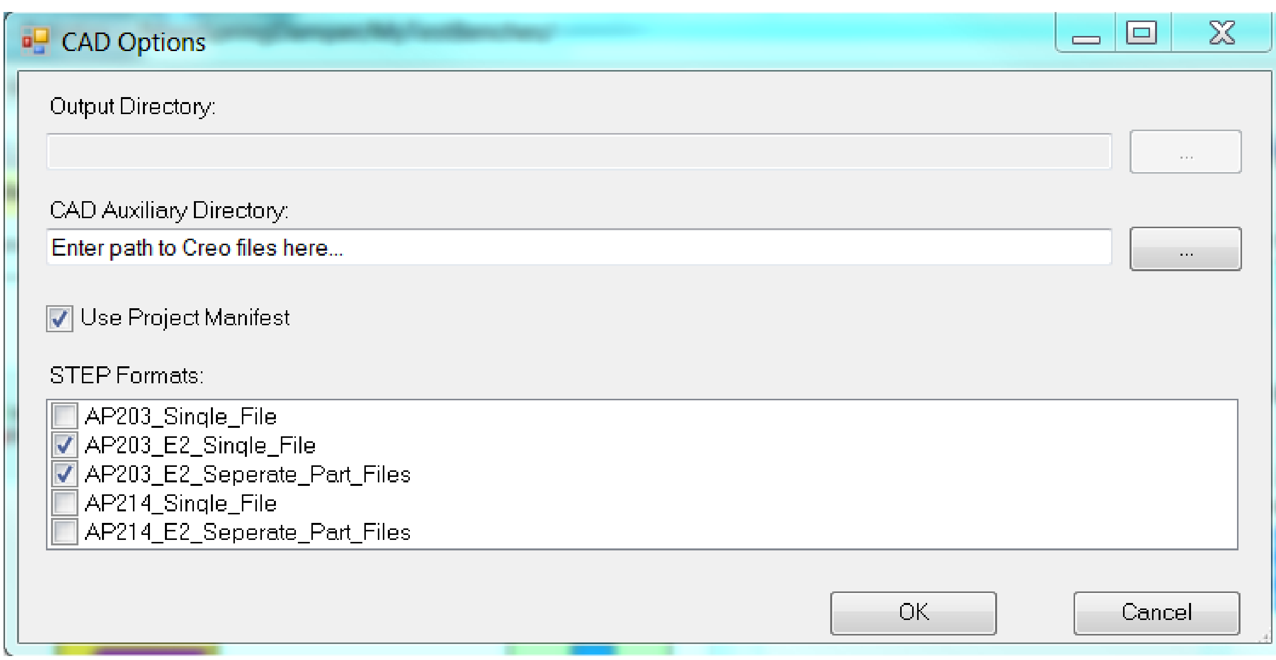


Figure 8: CAD Options dialog box

- 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 9.

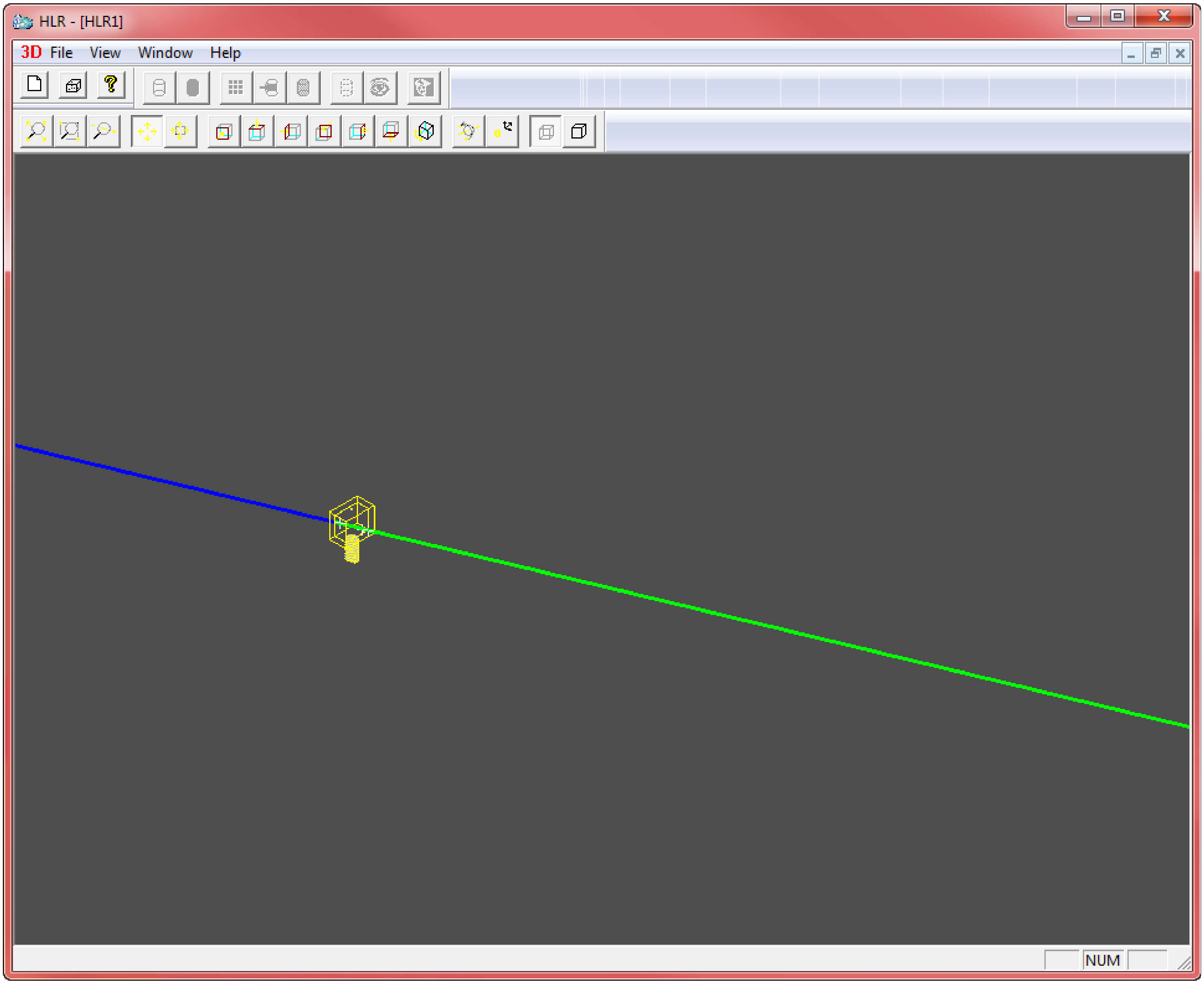


Figure 9: Output of Ballistics Analysis tool in Shotline Viewer program

2.4 A Note on Metrics

The following is a description of the metrics collected for tier 1 and tier 2 ballistics. They are printed to the screen and can also be found in the results JSON file.

- Total Shots: The total number of shots taken

- Total Intersections: The total number of times any component was intersected by a shotline. One intersection consists of an entry point and an exit point. This count is based solely on the geometry of the shotlines and the components and has nothing to do with the ballistic simulation.

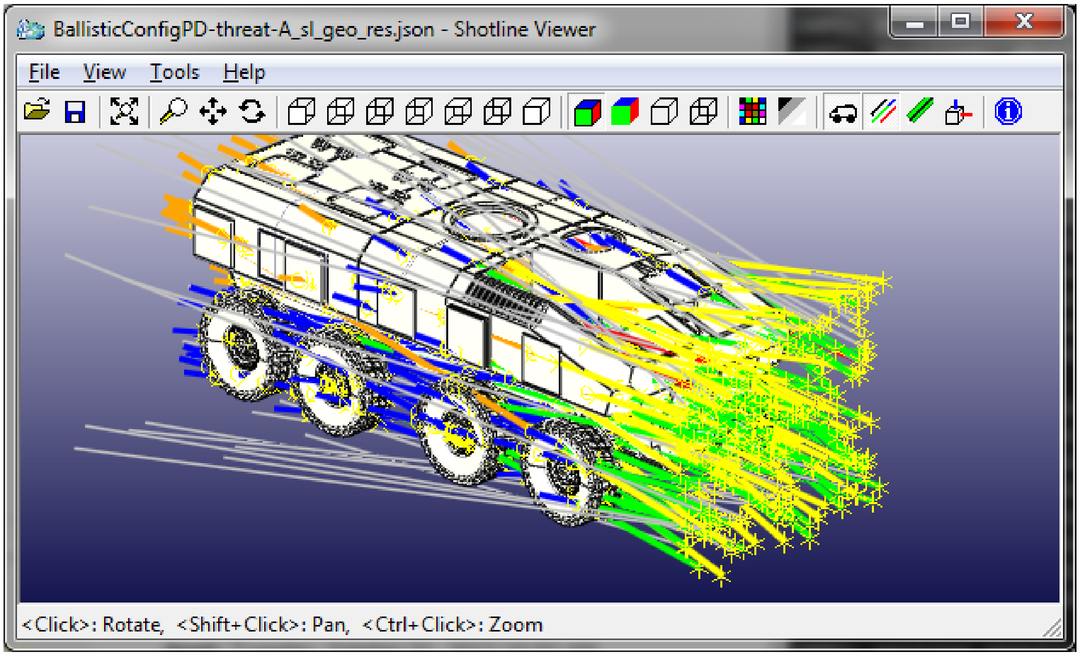
- Perforations: The total number of components that were completely perforated by a shot (in one side and out the other)

- Total Kills: The number of times a "critical" component was perforated by a shot

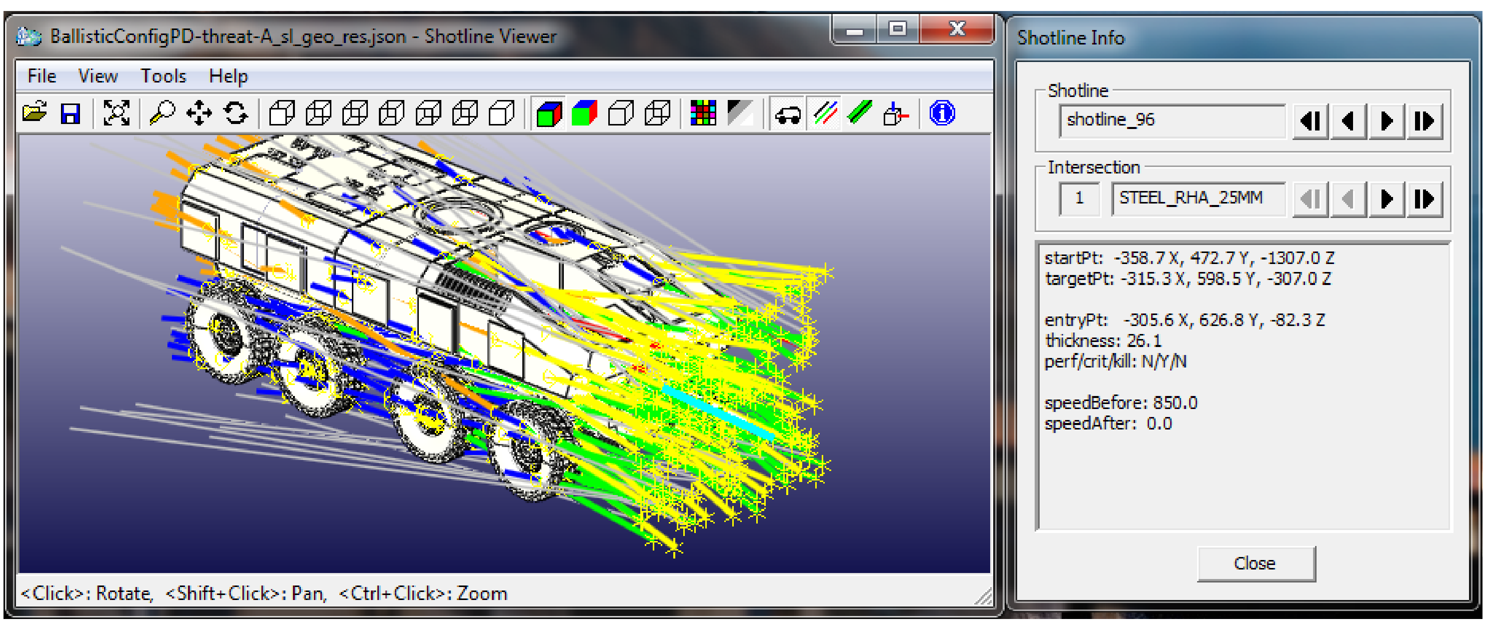
The approach to Total Kills was taken in this way, at least in part, because of the phenomenon known as spalling. Spall are fragments that are cast off the back of a plate (for example) when the front of the plate is impacted by a projectile. This can occur even when the plate is not completely perforated. Thus, if a perforation occurs into a crew compartment, it is very likely that spall will be cast into the crew compartment in unpredictable directions resulting in injury or death. For this reason Spall Liners, which are armor fabrics, are placed around the inner walls of crew compartments to stop spall from killing the occupants. In such a scenario, the spall liner could be marked as crew critical. If anything got past the spall liner it would represent a kill. I hope this helps to explain the choice of terms.

2.5 Examining Shotlines

Starting with Release 15 of the SwRI AVM Tools, the Shotline Viewer now includes basic support for examining details of individual shotlines. The following screenshot is of the release 15 Shotline Viewer. Clicking the blue "I" icon on the right edge of the toolbar will open a side window where details of a selected shotline will be shown.



In the following screenshot, 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_96" and it impacts the component called "STEEL_RHA_25MM". The armor panel completely defeats the threat since the speed after impact/penetration is 0.0 meters per second.



2.6 Tool Details

2.6.1 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
```

2.6.2 Pipeline Stages

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

1. Load shotline JSON file.
2. Load Materials Database file which contains material properties specific to ballistic analysis.
3. 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.
4. Evaluate the geometry of the shotlines and where they intersect with the parts in the assembly under test.
5. For tiers 1 & 2: Invoke the ballistic solvers to compute shotline results. Results are then displayed in the shotline viewer.
6. For tier 3: Generate CTH input deck as a zipfile ready to be copied to a computer running CTH, unzipped, and run in CTH.

2.7 Named Projectiles

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

2.8 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 vecinity of the shotline.

2.9 Release Notes and Future Capabilities

TBD