Blast

User Tutorial for the Blast Tool and Test Bench

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1.0 Purpose

The Blast Analysis tool evaluates the design assembly against a variety of blast threats. The user can create custom blast threats by describing the location, charge size (in kg of TNT equivalent), and burial depth of the charge. Five tiers of analysis are supported to give the user flexibility in the trade-offs between computation time and analysis fidelity.

Tier 1 treats the entire vehicle as a rigid, non-deformable body and calculates the vertical and horizontal velocities and maximum jump height due to the blast. This calculation can be accomplished in a few minutes and is intended for experimenting with the overall shape of the undercarriage of the hull, e.g. V-hull, double-V-hull, etc.

Tier 2 takes into account the deformable nature of vehicle panels and structural members but saves significant processing time by not accounting for the case when one deforming material contacts another and continues to deform. The duration of this calculation can be as short as a few minutes and as long as many hours.

Tier 3 and up use LS-DYNA, a commercial finite element analysis code that accounts for contact between parts. The duration of these computations is measured in many hours to days, even when deployed on a computer cluster. Tier 3 employs a 30 mm resolution on the mesh generated from the STEP geometry. Tier 4 uses a 15 mm resolution mesh. Tier 5 uses a 15 mm resolution mesh and includes anthropomorphic test dummies (ATDs) to simulate the blast response on the human occupants of the vehicle.

1.1 Requirements Tested

Crew survivability in the context of buried mine type blasts.

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 blast 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\blast.exe C:\SwRI-AVM-Tools\Examples\double_v_aluminum\BlastConfigT1.json
```

This will run a Tier 1 blast 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 command finishes and you see something similar to the following:

```
INFO: ==== Collecting Results from Rigid Summary ====
INFO: C:\SwRI-AVM-Tools\Examples\double_v_aluminum\AP203_E2_SINGLE_FILE\rigidsummary.dat
INFO: Max Jump Height: 1.816127 m
INFO: Max Vertical Velocity: 4.594857 m/s
INFO: Max Horizontal Velocity: 2.029084 m/s
INFO: Crew Survivability - Dynamic Response Index Z: 30.623384
INFO: Crew Survivability Score: 0.000000
INFO: ==== Writing Results to C:\SwRI-AVM-Tools\Examples\double_v_aluminum\BlastConfigT1-res.json
WARNING: Could not locate testbench_manifest.json.
INFO: ==== Timing Statistics ====
INFO: Startup time: XX.XXXXXX Seconds
INFO: Convert to mesh time: XX.XXXXXX Seconds
INFO: Shader time: XX.XXXXXX Seconds
INFO: Blast Calculation time: XX.XXXXXX Seconds
INFO: Movie creation time: XX.XXXXXX Seconds
INFO: ELAPSED TIME: XX.XXXXXX Seconds
```

You can then open LS-PrePost through the start menu. To make LS-PrePost easier to use, enable the "Text and Icon" toolbars by checking the following menu items:

- View->Toolbar->Text and Icon (Right)
- View->Toolbar->Text and Icon (Bottom)

When the program opens, select:

- File->Open->LS-DYNA Keyword File Ctrl-K

Then navigate to:

```
C:\SwRI-AVM-Tools\Examples\double_v_aluminum\BlastConfigT1-res-mesh-Rigid.k
```

LS-PrePost should then look something like Figure 1:

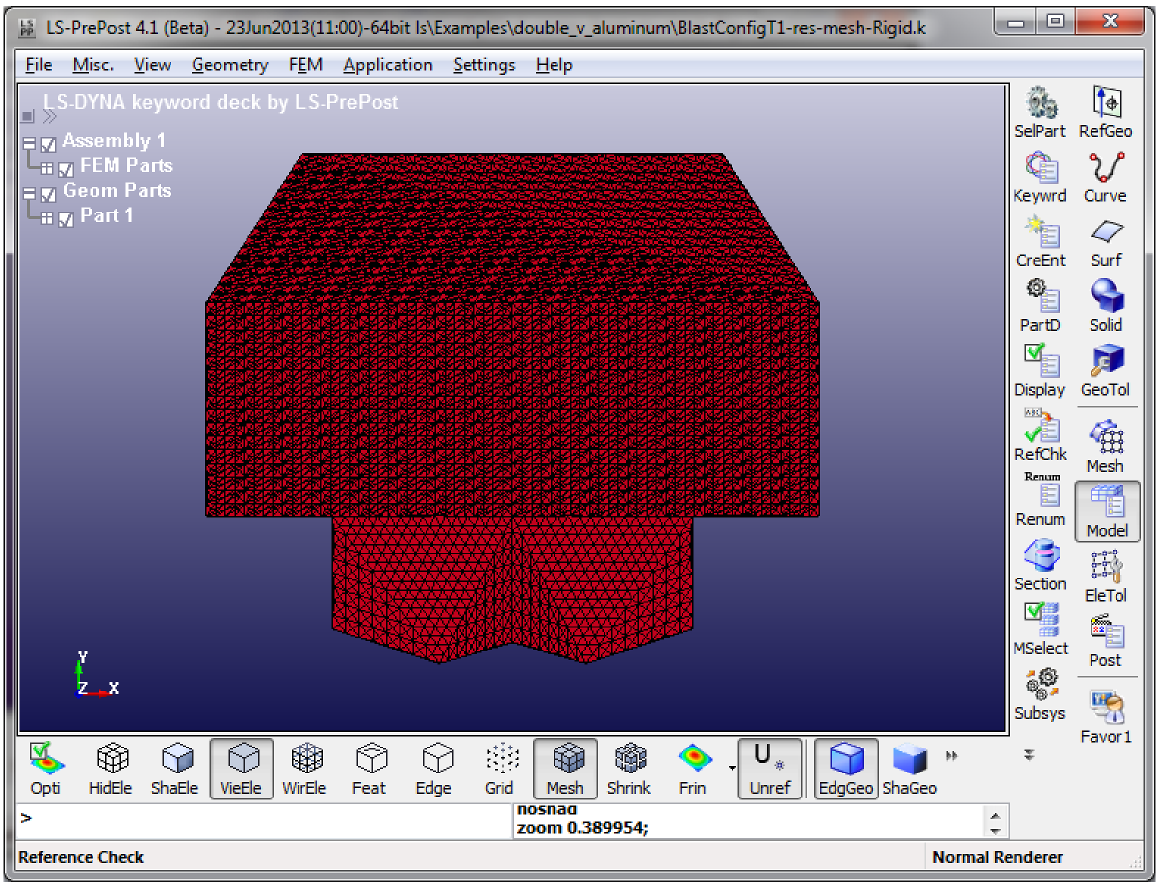

Figure 1: Viewing results of tier 1 blast in LS PrePost

For 3D rotation of the view, hold down the Ctrl key and click-and-drag the left mouse button.

For zooming the view, hold down the Ctrl key and click-and-drag the right mouse button.
To view the animation of the blast, click the "Animation Toolbar" icon in the bottom menu. Depending on your screen resolution, you may need to click on the "double right arrow" on the right edge of the bottom toolbar as seen in Figure 2:

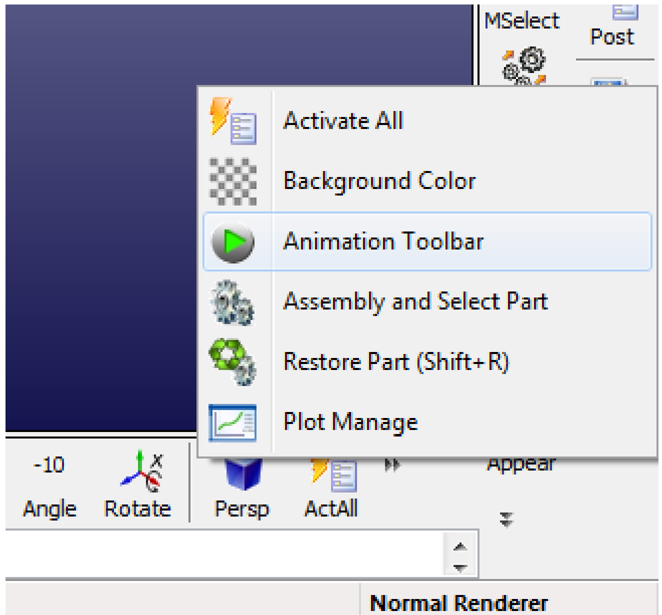

Figure 2: Animation Toolbar in LS PrePost

The animation controls shown in the following screenshot allow the user to start, stop, and adjust the frame rate of the animation.

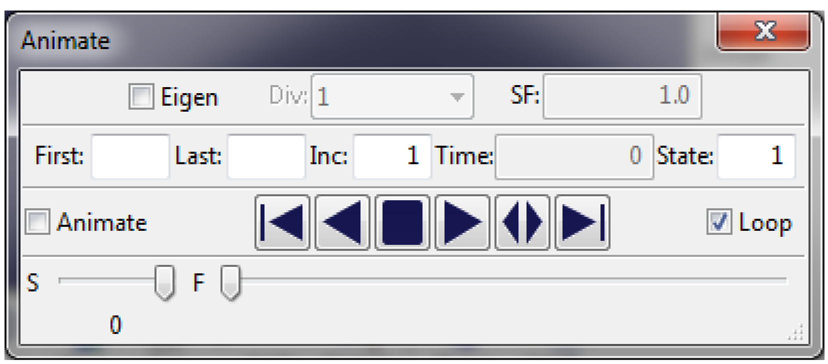

Figure 3: LS PrePost animation control window

2.2 Use

2.2.1 Predefined Blast Suite

This tutorial will demonstrate the steps required to run a predefined blast suite on an existing design. The details of building the design are not included in this tutorial. One of the concept hulls would be a good place to start. Some tutorials have applied blasts to the MSD example, however the results are not terribly interesting.
The tools include 50 predefined blast suites for use in test benches. There are 49 suites that test a single charge/location combination and a 50th suite, called "Blast-All" that sequentially and independently performs all 49 tier 1 blast suites on the same design. It is also possible to configure a custom blast suite with variable size charge at a user-defined blast location. The predefined blast suites include 7 sizes of blast, corresponding to and equivalent blast of 1, 4, 7, 10, 13, 16, and 20 pounds of TNT. Note that internal to the tools, the charge is described in kilograms of TNT. The suites cover 7 unique locations around the vehicle. The exact x, y, z coordinates of the blast location is determined by the configured burial depth, the location of the ground plane, and the bounding box of the vehicle. For example, the -Left-Front blast suites will place the blast at a point that is 10% of the vehicle width in from the left and 10% of the vehicle length in from the front and at burialdepth below the ground plane. The -CG suites place the charge at burial depth below the ground plane and directly beneath the center of mass of the vehicle. The other blast suites around the perimeter of the vehicle place the charge at the 10% offset point as described for the Left-Front suites.
Table 1 contains a list of all available predefined blast suites and their associated charge weights. The name of a predefined blast suite can be configured in META when performing the blast analysis.

2.2.2 Step 1: Set Up Test Folder

If you have *not* already created a Testing folder, in the GME Browser, insert a new Testing subfolder within the existing Testing folder and name it "Blast Test".
Within the Testing subfolder, insert a new **BlastTestBench model** and name it "BlastD_Center_Front". Note that in order for scoring to work with the VehicleForge system, the name of the test bench model must match the name of the blast suites listed in Table 1.

2.2.3 Step 2: Insert Design Space Reference

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

2.2.4 Step 3: Predefined Blast Suite Test Bench Requirements

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

- Target you are subjecting to a blast
- Predefined Blast Suite

Figure 4: Icon for predefined blast suite

- Reference plane

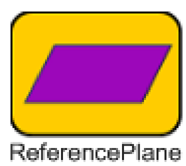

Figure 5: Reference plane icon

- CAD Workflow

Figure 6: CAD Workflow in GME Browser

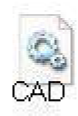

Figure 7: CAD Workflow icon

- Scoring Metrics. The scoring metric that is currently supported for blast are "Crew_Survivability", "Corrosion_Thickness_Loss_Metric", and "Corrosion_Score". It is suggested that all three metrics be included in the testbench such that when support is added for these metrics, the testbenches do not require any modifications. If you are attempting to run the tier 1 Blast-All suite, see section 2.5 for the complete list of metrics that should be included.

2.2.5 Step 3a: Select the Predefined Blast Suite

Within the Element Browser, find the "PredefinedBlastSuite" element and Drag/Drop it into the test bench window.
In order for the simulation to run, the Name of the predefined blast suite must be supplied.
Highlight the PredefinedBlastSuite and fill out the information in the Object Inspector so that the Name field matches one of the options in the table below.
The tools include 50 predefined blast suites for use in test benches. There are 49 suites that test a single charge/location combination and a 50th suite, called "Blast-All" that sequentially and independently performs all 49 tier 1 blast suites on the same design. It is also possible to configure a custom blast suite with variable size charge at a user-defined blast location. The predefined blast suites include 7 sizes of blast, corresponding to and equivalent blast of 5, 10, 20, 30, 40, 50, and 60 pounds of TNT. Note that internal to the tools, the charge is described in kilograms of TNT. The suites cover 7 unique locations around the vehicle. The exact x, y, z coordinates of the blast location is determined by the configured burial depth, the location of the ground plane, and the bounding box of the vehicle. For example, the -Left-Front blast suites will place the blast at a point that is 10% of the vehicle width in from the left and 10% of the vehicle length in from the front and at burialdepth below the ground plane. The -CG suites place the charge at burial depth below the ground plane and directly beneath the center of mass of the vehicle. The other blast suites around the perimeter of the vehicle place the charge at the 10% offset point as described for the Left-Front suites.

The following table lists the predefined blast suites included with the tools and their associated charge weights.

5 lb. Charge	10 lb. Charge	20 lb. Charge	30 lb. Charge	40 lb. Charge	50 lb. Charge	60 lb. Charge
BlastA-Center-Front	BlastB-Center-Front	BlastC-Center-Front	BlastD-Center-Front	BlastE-Center-Front	BlastF-Center-Front	BlastG-Center-Front
BlastA-Center-Rear	BlastB-Center-Rear	BlastC-Center-Rear	BlastD-Center-Rear	BlastE-Center-Rear	BlastF-Center-Rear	BlastG-Center-Rear
BlastA-CG	BlastB-CG	BlastC-CG	BlastD-CG	BlastE-CG	BlastF-CG	BlastG-CG
BlastA-Left-Front	BlastB-Left-Front	BlastC-Left-Front	BlastD-Left-Front	BlastE-Left-Front	BlastF-Left-Front	BlastG-Left-Front
BlastA-Left-Rear	BlastB-Left-Rear	BlastC-Left-Rear	BlastD-Left-Rear	BlastE-Left-Rear	BlastF-Left-Rear	BlastG-Left-Rear
BlastA-Right-Front	BlastB-Right-Front	BlastC-Right-Front	BlastD-Right-Front	BlastE-Right-Front	BlastF-Right-Front	BlastG-Right-Front
BlastA-Right-Rear	BlastB-Right-Rear	BlastC-Right-Rear	BlastD-Right-Rear	BlastE-Right-Rear	BlastF-Right-Rear	BlastG-Right-Rear

Table 1: Table of blast charge size for each predefined blast suite

In addition, a blast suite is provided that sequentially and independently computes all 49 blast suites against the same design. The blast suite is called:

```
Blast-All
```

More information on configuring the Blast-All suite is provided in section 2.5.
The name of a predefined blast suite can be configured in META for performing the blast analysis.

2.2.6 Step 3b: Reference Plane

Locate the ReferencePlane element in the Element Browser and Drag/Drop it into the Blast TestBench window.
Select the element and ensure that under the Attributes tab in the Object Inspector that its Type is specified as "Ground".
See section 2.7 for more on how the ground plane is calculated.

2.2.7 Step 3c: CAD Workflow

In the GME Browser, add a workflow definition folder in your testing folder.
Add a workflow to this folder, and call it CAD.

Open the workflow, and drag in a task from the part browser.
Select CyPhy2CAD_CSharp from the list.
Copy/Paste as Reference the CAD workflow into the Blast TestBench window.
Your screen should now resemble Figure 8:

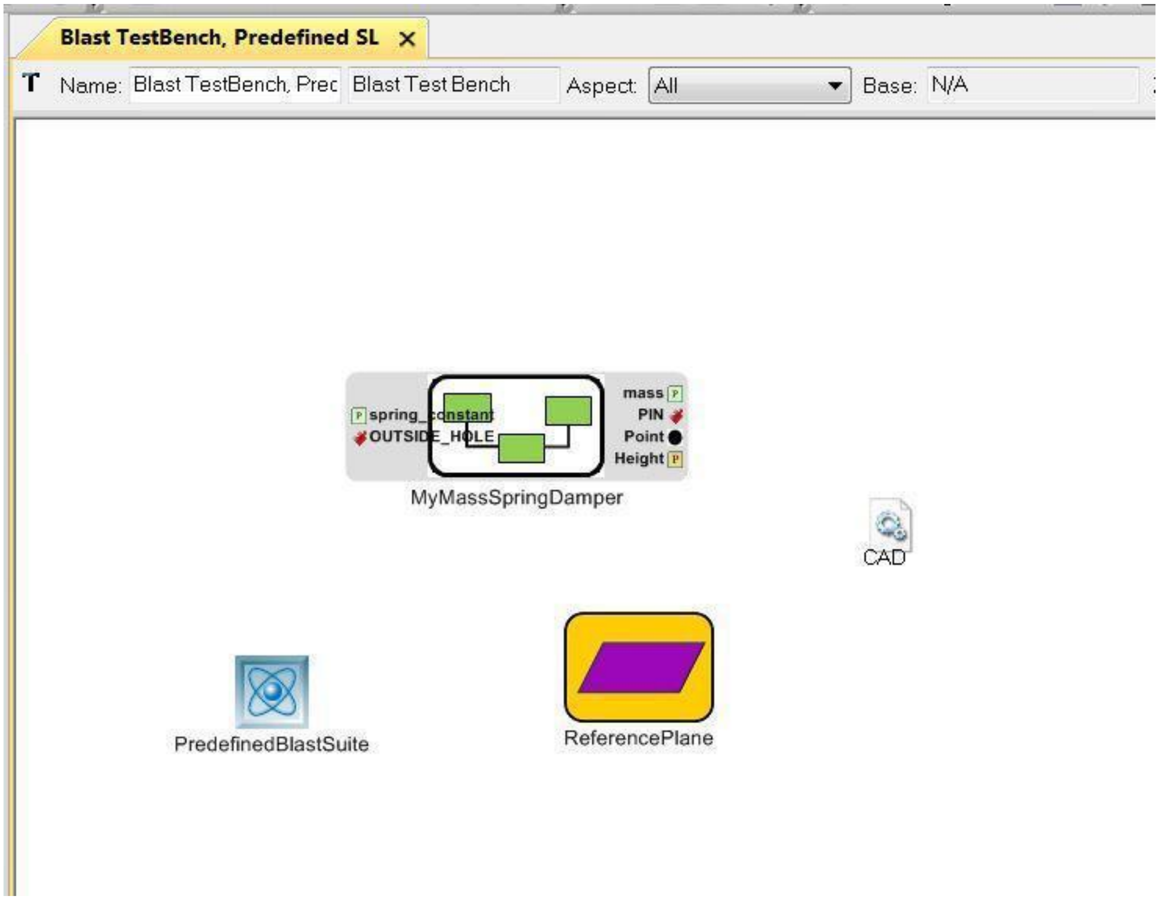

Figure 8: Predefined Blast Testbench

2.2.8 Step 3d: Tier

Select the testbench under the Testing folder in the GME Browser. In this case, the testbench is called "BlastD_Center_Front".
Select the Tier in the Object Inspector Window. Tiers 1-4 are supported at this time.
For Tier 1 analysis, a duration of at least 1 second is desirable so that the vehicle has time to reach its maximum jump height and fall back down.
For Tiers 2-4, a duration of 30 milliseconds (0.030) is more typical. After 30 milliseconds, the loading from the blast has finished and the major deformations have occurred. The higher tiers are computationally expensive so it makes the most sense to only simulate as long as required to see the effects of the blast loading.

However, the blast scoring algorithm (DRIz) analyzes the vertical motion and maximum jump height of the vehicle in determining a score. For these reasons, a longer duration is required if the goal is to obtain a blast score.

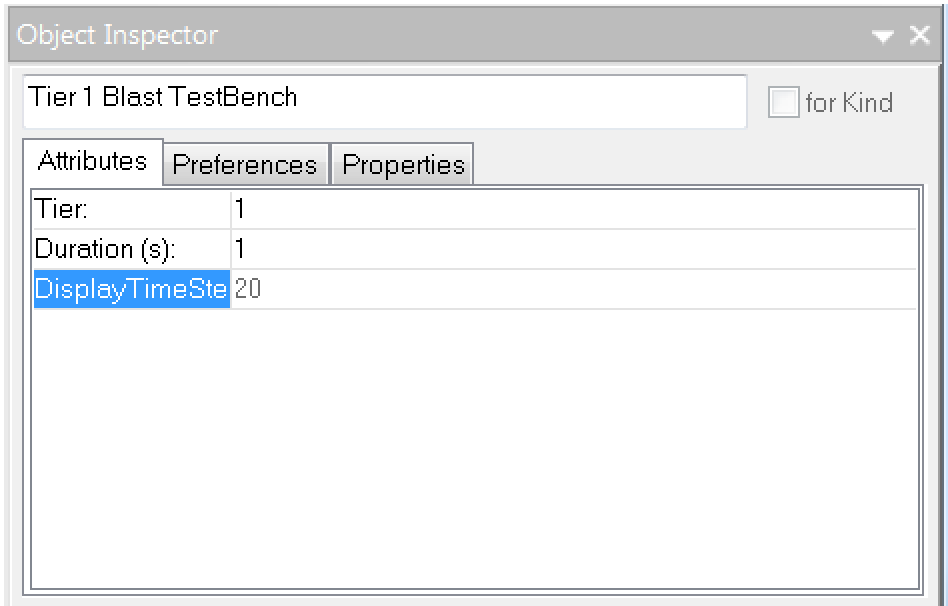

Figure 9: Setting the blast tier, simulation duration, and number of timestep frames to compute

Your blast test bench is now set up.

2.2.9 Step 4: Run DESERT

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

2.2.10 Step 5: Running the interpreter

From the META tool bar, select the Master Interpreter.

Figure 10: The Master Interpreter Icon

Select the design configurations you would like to run the test on, and click OK. When you run this interpreter, you must:

- Make sure that "Use Project Manifest" is checked.

- Make sure that both "AP203_E2_Single_File" and "AP203_E2_Separate_Part_Files" are checked.

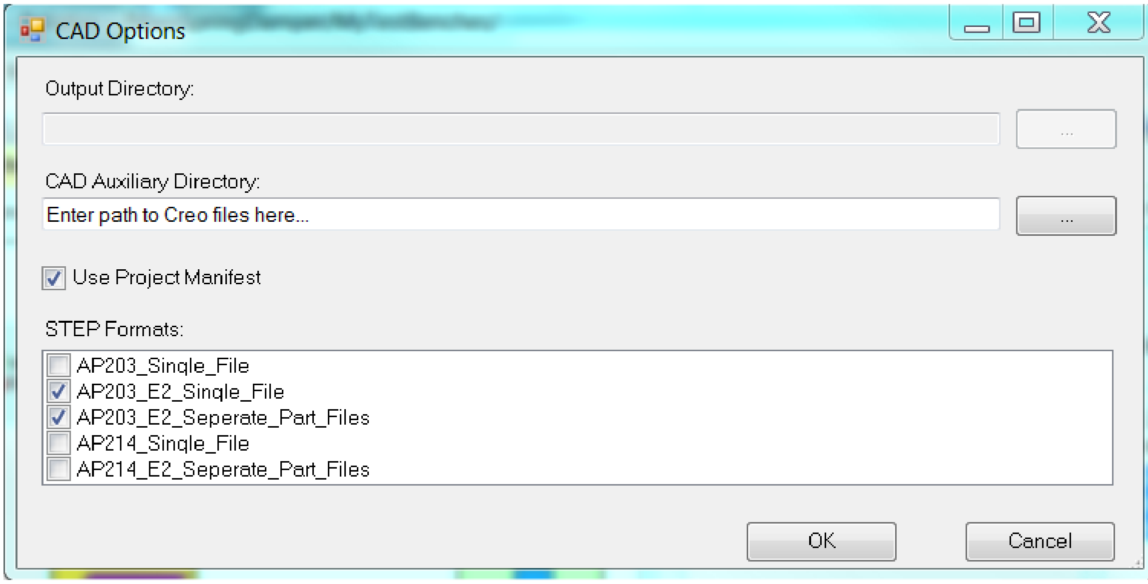

Figure 11: CAD Options dialog box

Select OK.
Make sure to run the job locally by deselecting the remote execution box in the job manager configuration box.

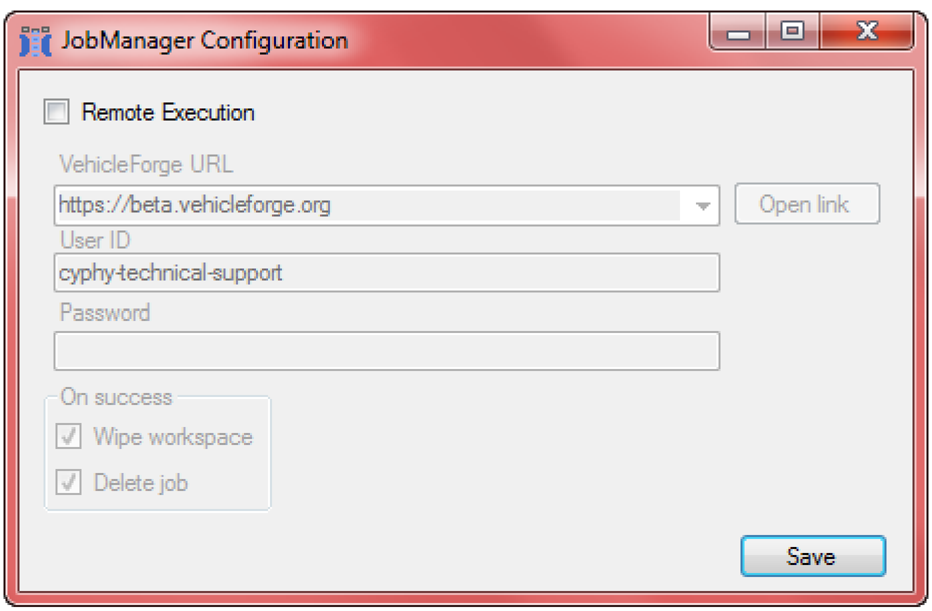

Figure 12: Job Manager configuration dialog

If the test bench was correctly set up after the analysis is completed, a file called BlastConfig-res-mesh-Rigid.k" should be in the same directory where the files were exported. Startup LS-PrePost and load in the "k-file".

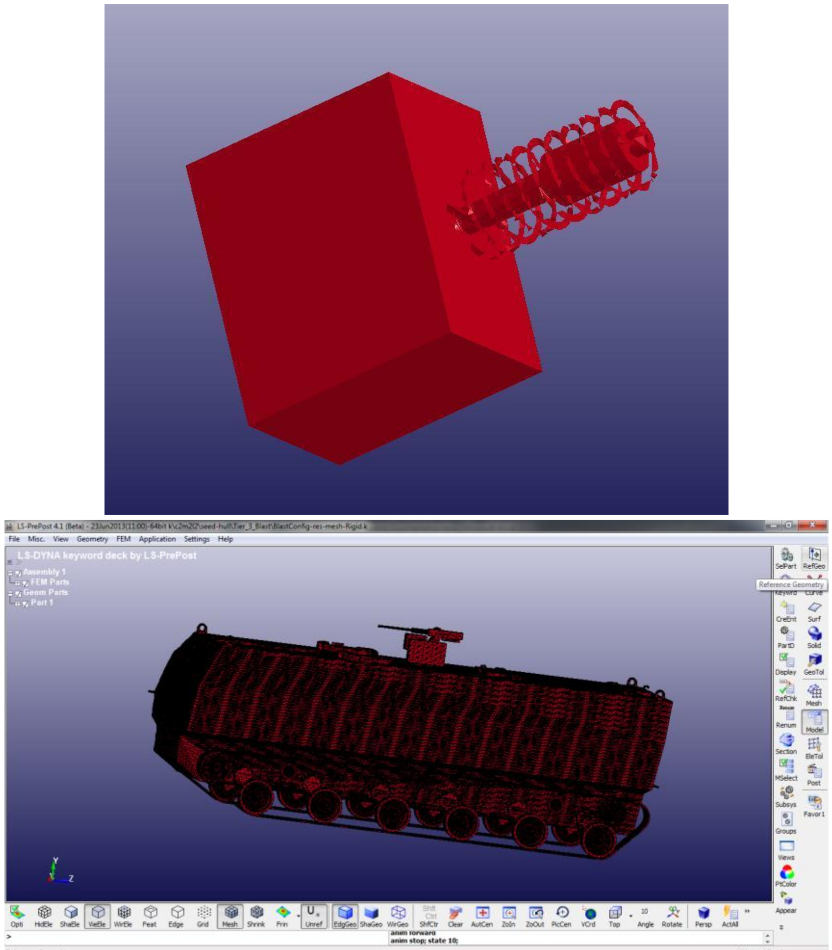

Figure 13: Viewing tier 1 blast results in LS PrePost

Attribute	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Test Bench Name	At least 24 (8 directions, 3+ threats)	At least 24 (8 directions, 3+ threats)	At least 24 (8 directions, 3+ threats)	At least 24 (8 directions, 3+ threats)	At least 24 (8 directions, 3+ threats)
Description	Computes the rigid body motion of the vehicle under a blast loading.	Computes a deformable blast analysis using a SwRI-custom solver that ignores contact between parts and is	Performs an LS-Dyna blast analysis including part contact. Mesh is generated with	Same as Tier 3 but with 15 mm mesh element resolution.	Same as Tier 4 but includes the full test dummies for human response.

Attribute	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
		therefore relatively fast running.	30 mm element resolution.		
Estimate Run Time	Measured in minutes (5 to 50)	On the order of hours (1 to 4 for examples run to date)	Hours to days	Hours to days	One example run took 9 hours (wall clock) on 24 cores.
Error Margin	Provides an accurate rigid body response of the vehicle. Does not account for part deformations.	Very accurate for cases where no part-to-part contact is encountered.	Very accurate including cases of part-to-part contact.	Highly accurate due to increased mesh resolution.	Highly accurate full-body response on the test dummies in the seats.
Results Provided	Injury Metric (DRI) Score	Injury Metric (DRI) Score	Injury Metric (DRI) Score	Injury Metric (DRI) Score	Injury Metric (DRI) Score
	View rigid motion	Blast simulation movie including "fringe" overlay data for stresses and strains of parts.	Blast simulation movie including "fringe" overlay data for stresses and strains of parts.	Blast simulation movie including "fringe" overlay data for stresses and strains of parts.	Blast simulation movie including "fringe" overlay data for stresses and strains of parts.
Local/Remote	Both	Both	Mainly Remote. Users may run locally if they have access to LS Dyna.	Mainly Remote. Users may run locally if they have access to LS Dyna.	Mainly Remote. Users may run locally if they have access to LS Dyna.
Tool Used	SwRI-provided solver	SwRI-provided solver	LS Dyna	LS Dyna	LS Dyna

Attribute	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
How to Interpret Results	Injury metric score & motion video. Minimize injury metric and jump height	Minimize injury metric. Evaluate material failures, stresses and strains. If parts pass through one another, may need to move up to tier 3 or higher	Minimize injury metric. Evaluate material failures, stresses and strains.	Minimize injury metric. Evaluate material failures, stresses and strains.	Minimize injury metric. Evaluate material failures, stresses and strains
					Evaluate full dummy response to blast.
Model Requirements	Single STEP file of assembly. Vehicle mass and inertia tensor from CAD metrics file.	Separate STEP files (one per part) of assembly. Full part details in CAD metrics file. Will use weld data in ADM and HuDAT Welds.xml if available.	Same as tier 2.	Same as tiers 2-3.	Same as tiers 2-4.

Table 2: Description of blast tiers

2.3 Viewing Results from Tiers 2-5

Blast tiers 2 through 5 perform a deformable blast analysis of the assembly. Depending on the amount of simulation time selected and the complexity of the assembly, the calculation can take anywhere between a few hours to many days to complete. However, when the user has access to the machine on which the solver is running, he/she can view the results of calculations completed to that point. Simply open LS PrePost and select "File->Open->LS-Dyna Binary Plot" and select *C:\SwRI-AVM-Tools\blast-tools\d3plot*. To view results from a simulation that has already completed, select the BlastConfig.d3plot file in the results directory.

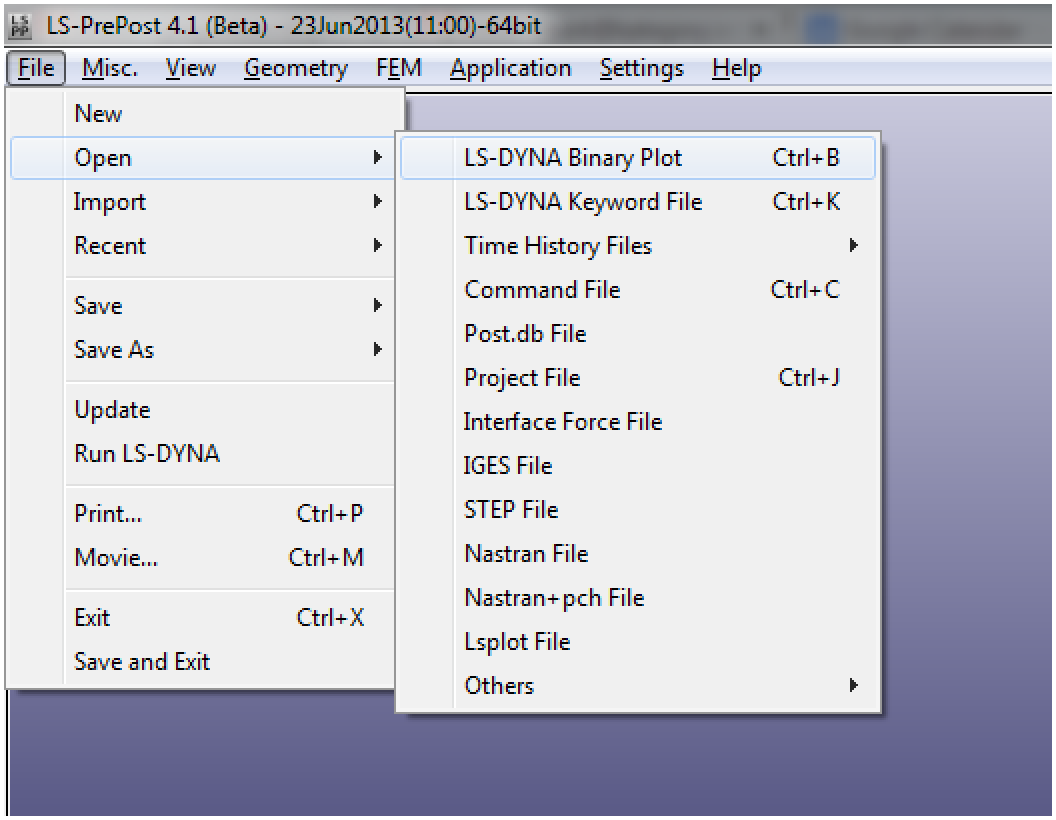

Figure 14: LS PrePost menu to open binary plot file (*d3plot*) with results from tiers 2 and higher

With the d3plot file loaded into LS PrePost, the user can view the animation of the blast event as with the tier 1 analysis. Additionally, for tiers 2-5, the user may select to view stresses or strain data overlaid on top of the mesh. In LS PrePost these are referred to as "Fringe". To view fringe data, open the Fringe Component window by clicking on the "FriComp" button in the upper-right corner of the display. This will bring up the Fringe Component window and allow the user to select the fringe data to be viewed on the mesh. The following image shows the plastic strain data from a tier 2 analysis on a flat-bottomed hull. The user is able to view the animation and step forward and backward to view the fringe data or to generate an AVI movie file of the data by selecting *File->Movie*. The colors are an indication of the amount of plastic strain for that element.

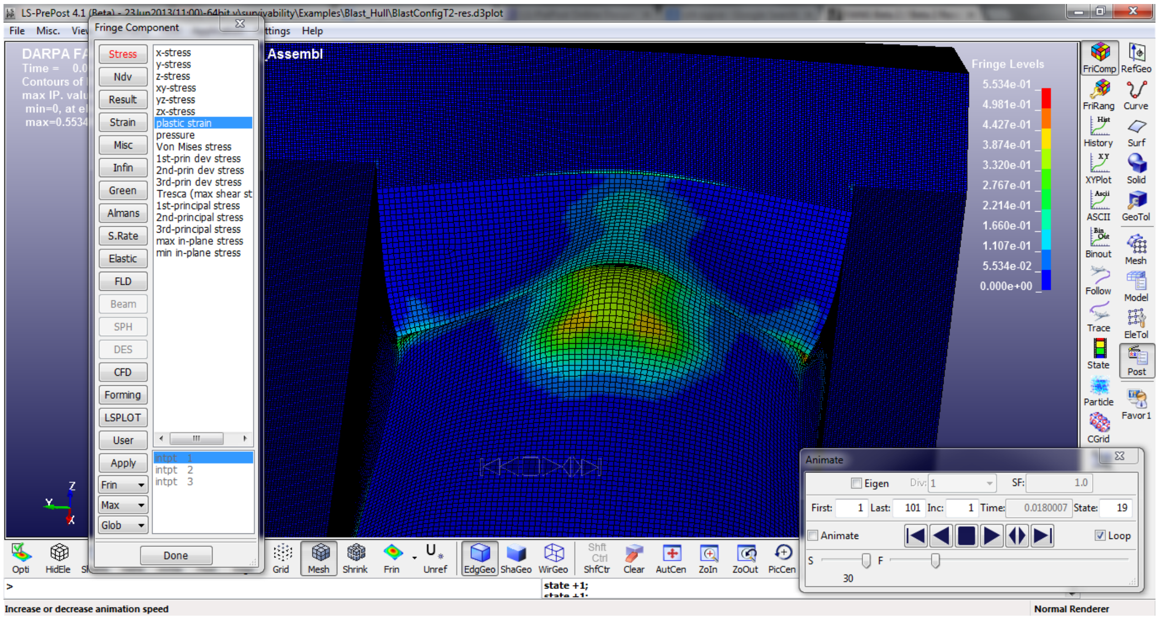

Figure 15: Viewing plastic strain "fringe" data during animation of vehicle response to blast

2.4 Jump Height versus Mass Surrogate -- Notes on Multi-Fidelity Modeling

One of the goals of the AVM tools is to enable the exploration of design spaces in a more automated fashion than previously possible. An example of this type of activity might be examining the intersection of the competing constraints of jump height caused by an underbelly blast and the time for the drive train to accelerate the vehicle to top driving speed in the horizontal direction.

If, for example, you increase the mass of the vehicle, it experience less vertical jump under blast scenarios, which is desirable; however, the increased mass results in a longer time required to accelerated to top driving speed, all other things being equal.

The SwRI Blast tools assist in evaluating these competing constraints by producing a PNG image containing a plot of expected vehicle jump height versus mass each and every time a Tier 1 blast scenario is computed. Generally the file is called "BlastConfig-jump-vs-mass.png" and is located in the results directory where the blast scenario was computed. The following is an example of this auto-generated plot.

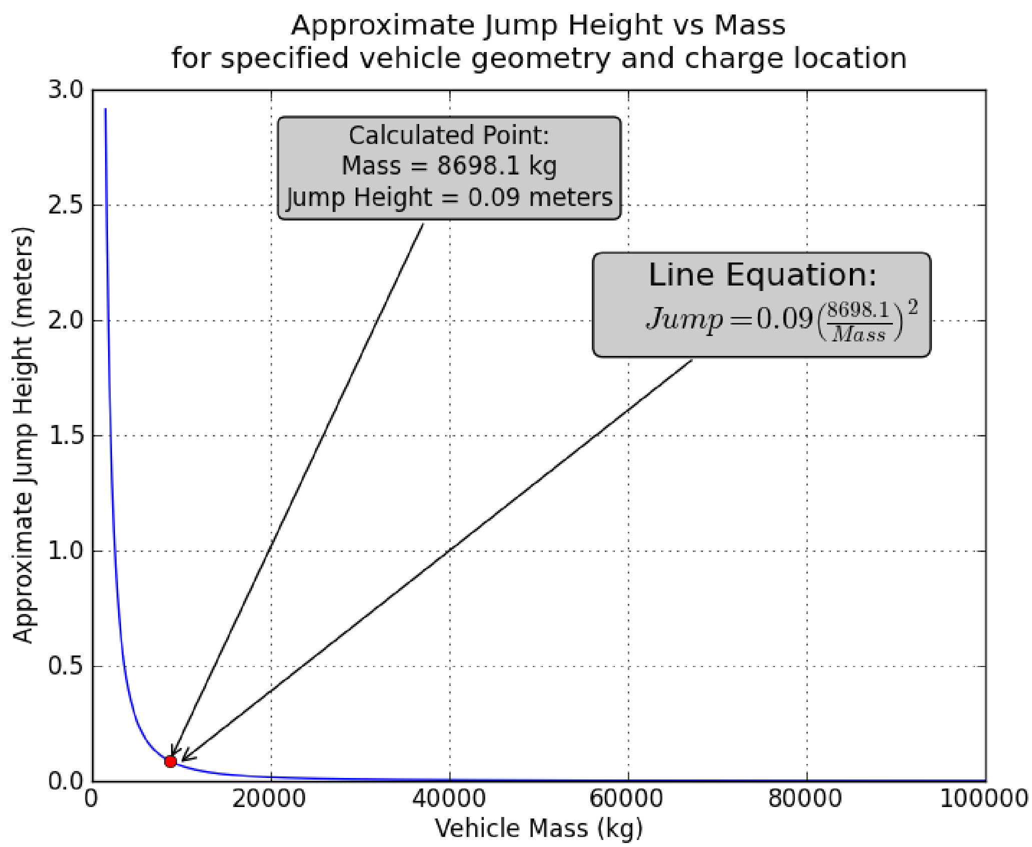

Figure 16

In addition to the plot, the "mass vs. jump height" equation is printed for the specific hull shape and charge size and location. This equation can be used in conjunction with other mass-based performance equations for quickly exploring the design space.

The mass vs. jump height is sensitive to:

1. Blast charge size
2. Blast charge location relative to the vehicle (which depends, in part, on the placement of the ground plane)
3. The outer hull geometry of the vehicle.

For these reasons, care must be taken if the goal is to compare the results for different hull geometries. For example, the Double V parametric hull and the Single V parametric hull, produce very similar standoff distances to the ground plane and therefore the results are directly comparable. Likewise the Flat Bottom and Wing Bottom hulls have similar flat bottom shapes and the same height above the ground plane, thus the blast loading on these hulls is nearly identical. However the results from these latter calculations cannot be directly compared with the Single V hull because the standoff distances are different (the ground plane location is not the same). The following plot is a comparison of results for individual blast analyses (the points) with their respective blast surrogate (jump-height-versus-vehicle-mass) curves. The ground plane location used was the one provided by CyPHY to the blast tools at the time of the analysis. Additional ground plane calculation tools have been added that place the ground plane at the lowest point in the mesh geometry.

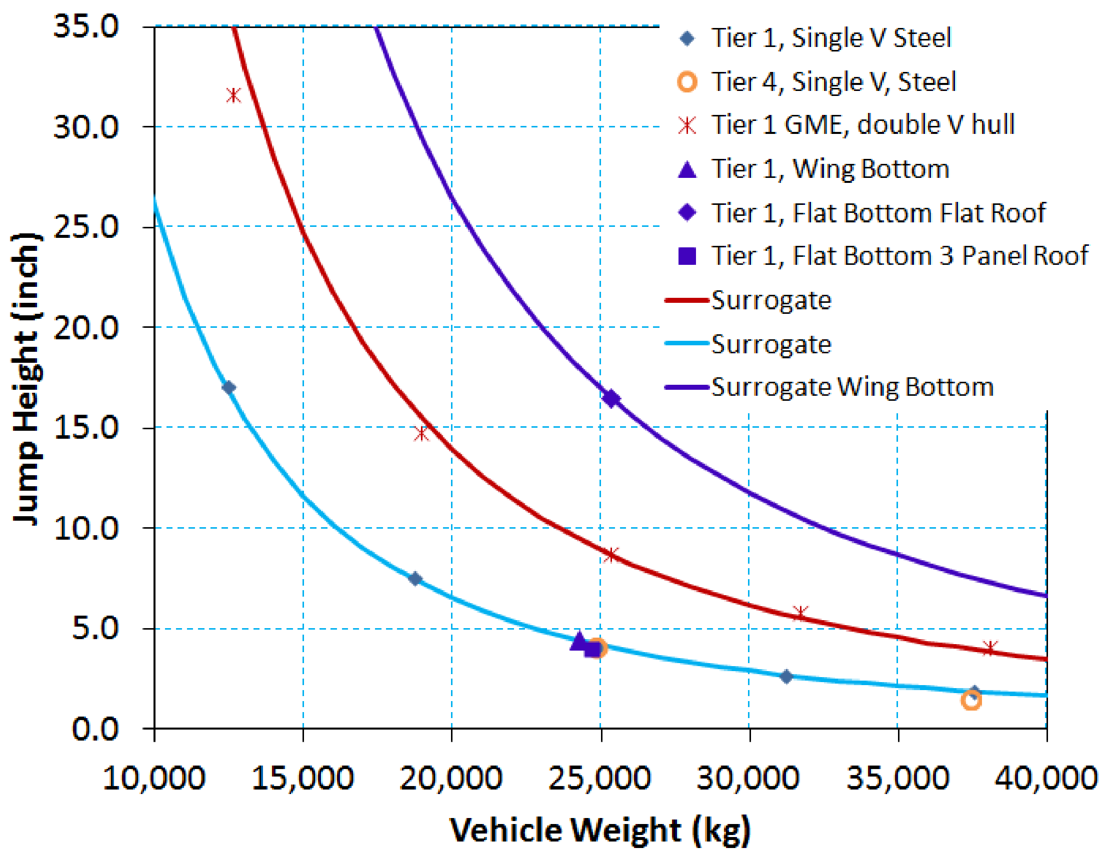

Figure 17: Comparison of blast jump height for various design configurations

2.5 The Blast-All Suite

Please note that as of R30, the Design Space Analyzer can view the metrics from the Blast-All suite, but VehicleForge scoring does not work properly. A resolution to this issue has been discussed between the VehicleForge, Meta, and SwRI teams and will be implemented in the Mid-Gamma releases.
Release 29 of SwRI AVM Tools supports a "Blast-All" suite the sequentially and independently runs each of the 49 tier 1 blast suites against the same vehicle

geometry. **Blast-All is only supported for tier 1 analysis.** This represents a tremendous time savings to the user since exporting the STEP geometry files for a single blast suite on a recent seed design can take on the order of 20-30 minutes. To build a Blast-All testbench, follow these steps:

1. Create a new blast testbench model and call it "Blast-All", and set it as described earlier in this tutorial.
2. Add Metrics elements to the testbench, one Metric for each of the 49 blast suites. The list of Metric names is given in the following table.
3. Run the testbench

Tables of Test Bench Metrics Required for Blast-All Suite

Center_Front_Crew	Center_Rear_Crew	CG_Crew	Left_Front_Crew
BlastA_Center_Front_Crew	BlastA_Center_Rear_Crew	BlastA_CG_Crew	BlastA_Left_Front_Crew
BlastB_Center_Front_Crew	BlastB_Center_Rear_Crew	BlastB_CG_Crew	BlastB_Left_Front_Crew
BlastC_Center_Front_Crew	BlastC_Center_Rear_Crew	BlastC_CG_Crew	BlastC_Left_Front_Crew
BlastD_Center_Front_Crew	BlastD_Center_Rear_Crew	BlastD_CG_Crew	BlastD_Left_Front_Crew
BlastE_Center_Front_Crew	BlastE_Center_Rear_Crew	BlastE_CG_Crew	BlastE_Left_Front_Crew
BlastF_Center_Front_Crew	BlastF_Center_Rear_Crew	BlastF_CG_Crew	BlastF_Left_Front_Crew
BlastG_Center_Front_Crew	BlastG_Center_Rear_Crew	BlastG_CG_Crew	BlastG_Left_Front_Crew

Left_Rear_Crew	Right_Front_Crew	Right_Rear_Crew
BlastA_Left_Rear_Crew	BlastA_Right_Front_Crew	BlastA_Right_Rear_Crew
BlastB_Left_Rear_Crew	BlastB_Right_Front_Crew	BlastB_Right_Rear_Crew
BlastC_Left_Rear_Crew	BlastC_Right_Front_Crew	BlastC_Right_Rear_Crew
BlastD_Left_Rear_Crew	BlastD_Right_Front_Crew	BlastD_Right_Rear_Crew
BlastE_Left_Rear_Crew	BlastE_Right_Front_Crew	BlastE_Right_Rear_Crew
BlastF_Left_Rear_Crew	BlastF_Right_Front_Crew	BlastF_Right_Rear_Crew
BlastG_Left_Rear_Crew	BlastG_Right_Front_Crew	BlastG_Right_Rear_Crew

2.6 The AutoMesher for Tiers 2+

The AutoMesher used for tiers 2 and higher of blast is implemented as a wrapper around LS PrePost's meshing tools. The AutoMesher repeatedly launches LS PrePost and directs it to mesh each part in the design. If the meshing fails, the AutoMesher tries again with different settings. There are some combinations of files and settings that can cause LS PrePost to crash and display the crash dialog. These dialogs can simply be dismissed. They are a nuisance but they do not necessarily represent a failure of the blast pipeline.

If the user wishes to disable the pop-up crash dialogs for LS PrePost **and all other applications**, a 3rd party utility is provided in:

```
C:\SwRI-AVM-Tools\3rdParty\UnhandledExceptionsToggler.exe
```

Running this application will toggle the Windows setting for generating the crash dialogs. The utility reports the current state of the setting.

2.7 Ground Plane Determination

The ground plane is determined by analyzing the exported STEP geometry files and finding the lowest points in the "up" direction. In the context of AVM, the global geometry is placed in a Right-Up-Back (+x, +y, +z) orientation, so "up" in the STEP files will always be in the positive Y direction. Things like datum planes and hidden geometry are not exported to the STEP files and therefore have no effect on the ground plane determination.

2.8 Notes on Scoring

The Dynamic Response Index in the Z direction (DRIz) is a spinal injury metric developed for evaluating ejection seat design and injury due to mine blasts. In the context of AVM, the tools compute the DRIz for one or more locations around the vehicle and then take the highest value as the overall score.
The center of gravity (CG) of any seats that are included in the design are the first choice for scoring locations. If there are no seats in the design, a location is chosen on the top of the vehicle directly above the blast. The choice of this last point is because many vehicles have a space between the exterior hull and the floor of the vehicle so choosing a point on the bottom exterior of the hull would provide an overly pessimistic score.
The locations and scores for each location are listed in the log file, search for DRIz. Additional details on the DRIz scoring that were provided in SwRI monthly status reports are provided in this PDF.

2.9 Guidance for Running with Local LS Dyna

LS Dyna is used as the blast solver for tiers 3, 4, and 5. The user may, if he or she chooses, run the blast pipeline locally on his/her own computers if LS Dyna is available. When a tier 3 or higher execution of the blast pipeline is run locally, a zipfile of the full LS Dyna input deck is generated. This zipfile is placed in the results

directory (meaning the folder with the random name under "results"). The zipfile is normally called BlastConfig-DYNA-deck.zip.
The user is free to copy this file to a local LS Dyna cluster, unzip it and run the analysis with a standard LS Dyna start command such as:

```
/rusr/lstc/ls-dyna_s_r7_etc NCPU=8 i=run.k
```

The "run.k" file in the generated Dyna deck is the main start file. The path to to the local LS Dyna executable, as well as the name of the executable itself, may vary from the above. This is just an example.
There are a variety of ways to instruct LS Dyna to allocate memory for the analysis.

1. The user may set an environment variable "LSTC_MEMORY" to "auto", which will instruct Dyna to dynamically allocate memory as needed. According to LSTC, this option is not as robust as whould be hoped.
2. The user may set a command-line option "memory=XM", where X is the number of mega-words of memory to allocate. On a 64-bit machine, one word is 8 bytes. On a 32-bit machine, one word is 4 bytes. A command such as memory=500M would instruct Dyna to allocate 500e6 * 8 bytes = 4 GB of RAM.

NOTE:
We have found some sensitivity to version number of LS Dyna on whether the auto mode will work. For example, some tier 5 blast decks were run on R6 of LS Dyna using the auto memory option, while running the same deck in R7 of LS Dyna required us to specify "memory=500M" to allocate 4GB of RAM for the analysis.

Once the simulation is complete, the user can run LS PrePost with the postprocess.cfile that is included in the zipfile to automatically generate some movies from the blast analysis. Those experienced with LS Dyna and PrePost, may not need to perform this step since they will likely want to do more in-depth analysis of the results directly in LS PrePost.
To generate the score, copy the LS Dyna nodout file back to the AP203_E2_SEPARATE_PART_FILES folder under the results directory and run:

```
C:\SwRI-AVM-Tools\blast.exe path\to\BlastConfig.json --post-process
```

This will analyze the nodout data, produce a DRIz score, and update the testbench_manifest.json file which gets uploaded to VF when you export and commit your results.
Non-SMP (Symetric Multi-Processing) multi-processor LS Dyna installations (such as MPP) may not produce the ASCII-formatted nodout file, but rather produce a binary-formatted binout file. Oasys Software, an LS Dyna distributor in the UK offers a free download of a utility called l2a which can convert binout files to the ASCII nodout format.

2.10 Examining the Blast Deck Prior to Simulation

Given the amount of time required for some blast simulations, it may be desirable to examine the input deck produced by the blast pipeline prior to running the solver. One way to do this is to **locally** run a tier 3 or higher testbench. When the tier 3 or higher testbench is run locally, the blast pipeline will generate a complete input deck in LS Dyna format and then terminate, no solvers are run. The final input deck, including only the files required to run, is saved in a zipfile in the results directory and is typically named "BlastConfig-DYNA-deck.zip". In addition, the final files, as well as all of the intermediate files that were produced during the blast pipeline, are stored in the "AP203_E2_SEPARATE_PART_FILES" folder. Once the user is happy with the generated Dyna deck, the user can submit a remote job to complete the blast analysis.

2.11 Tier 5

A tier 5 blast analysis includes the full pre-meshed seats along with Anthropomorphic Test Devices (ATDs or dummies) positioned correctly in the seats and secured by seat belts. The components are meshed at a 15mm mesh resolution, the same as a tier 4 analysis. Tier 5 analyses can take significantly longer to run than tier 3 due to the reduced mesh element size and the additional complexity of of the ATDs.
In order to get the pre-meshed seats to operate correctly, the lower rails portion of the seats are included directly in the mesh.k file that gets passed to the BoltWelder. This ensures that the lower portion of the seat gets welded to the floor, or bulkhead to which it is connected. The upper seat and the ATD are contained in separate k-format files that are included in the run.k file. If the user locally produces a tier 5 mesh and opens the run.k in LS PrePost, the user may see warning messages such as the following:

```
Warning -Duplicate keyword: NODE input with ID=70000354
  Warning occurs in file C:\work\c2m2l2\seed-
hull\Official_Seed_RC6_Feb24\results\kz3ilxyg-T5\AP203_E2_SEPARATE_PART_FILES\run.k
line # 133
Data input seq. 535788 from file mesh.k
Data input seq. 1113838 from file seat_upper_00.k
Last one will be used
```

There may be similiar duplicate keyword warnings for NODE, MAT, or SECTION. These warnings can be ignored. They are due to the way the upper and lower portions of the seats are connected with each other, by sharing nodes that get connected to the active damper elements in the seats.

2.12 Release Notes

R40 contains the following change from R39:

- Minor bug-fix to the "--post-process" option to blast.exe. This option is used when a user locally runs a tier 3 or higher analysis and then manually runs the LS Dyna solver. Upon completion of LS Dyna, the user can run blast.exe with the "--post-process" option to compute the DRIz score from the outputs of LS Dyna.

R39 contains the following change from R38:

- Minor change to the code that calculates the ground plane of the LS Dyna mesh. It now also takes into account the beam elements generated by the BoltWelder code. Having beam elements initially penetrating the ground plane was causing crashes of the solvers.

R38 contains the following change from R36:

- Added delete_files_to_minimize_server_downloads option to setup.cfg file. Setting this to "true" will cause the blast 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. This setting only deletes files when performing tier 3 and higher analyses. The setup.cfg file is found in the installation directory. This option is set to "false" by default.
- Disabled the file2shape.json workaround for the AutoMesher. This workaround is no longer needed after the bug-fixes in R34.

R36 contains the following change from R35:

- Calculates blast uncertainty quantification 95% upper bound on the DRIz score. This is reported in the BlastConfig.log file but not anywhere else.

R35 contains the following changes from R34:

- Tier 5 support. Tier 5 is now fully supported with Anthropomorphic Test Devices (ATDs or dummies) and pre-meshed seats.
- Simple Seats for tiers 2 through 4. Full pre-meshed seat support in tier 5.
- Minor adjustments to handling of some material properties such as the failure strain.

R34 contains the following changes from R33:

- Fixed a bug in the AutoMesher that would, under certain conditions, successively reduce the mesh element size so that parts meshed at the end of the process would have elements that were orders of magnitude smaller than they should be.
- Added a 64-bit build of the STL to K-mesh converter to support larger designs in the tier 1 pipeline.
- Added a 64-bit build of the BoltWelder code
- Fixed errors in material properties for beams/welds that were causing instabilities in the solvers.

R33 contains the following changes from R32:

- Made a one-liner change to the AutoMesher so that, on timeout, it kills the prior worker thread and waits for it to fully terminate before proceeding.
- 64-bit recompile of the STL to K-mesh converter (stl2tri64.exe) to handle large meshes
- 64-bit recompile of BoltWelder code to handle larger meshes

R32 contains the following changes from R31:

- Fixed an "oops" type bug (Beta Ticket #795) related to improper handling of metric values in the testbench_manifest.json
- Updated DRIz algorithm to include extrapolating the total jump height from short duration, higher tier analyses. (Gamma ticket #180)

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

- Changed charge sizes for predefined blast suites (A through G) to 5, 10, 20, 30, 40, 50, 60 lbs to allow for tier 1 differentiation of designs that are as heavy as the seed design.
- Fixed "tool checkout" documentation to point to a more recent example
- Fixed charge location/standoff distance to take into account the size of the charge
- Added "rid" to testbench_manifest.json for scoring of Blast-All suite
- Gamma Ticket #180:
    - Fixed error in "--post-process" option
    - Added documentation on how to run on local LS Dyna installations