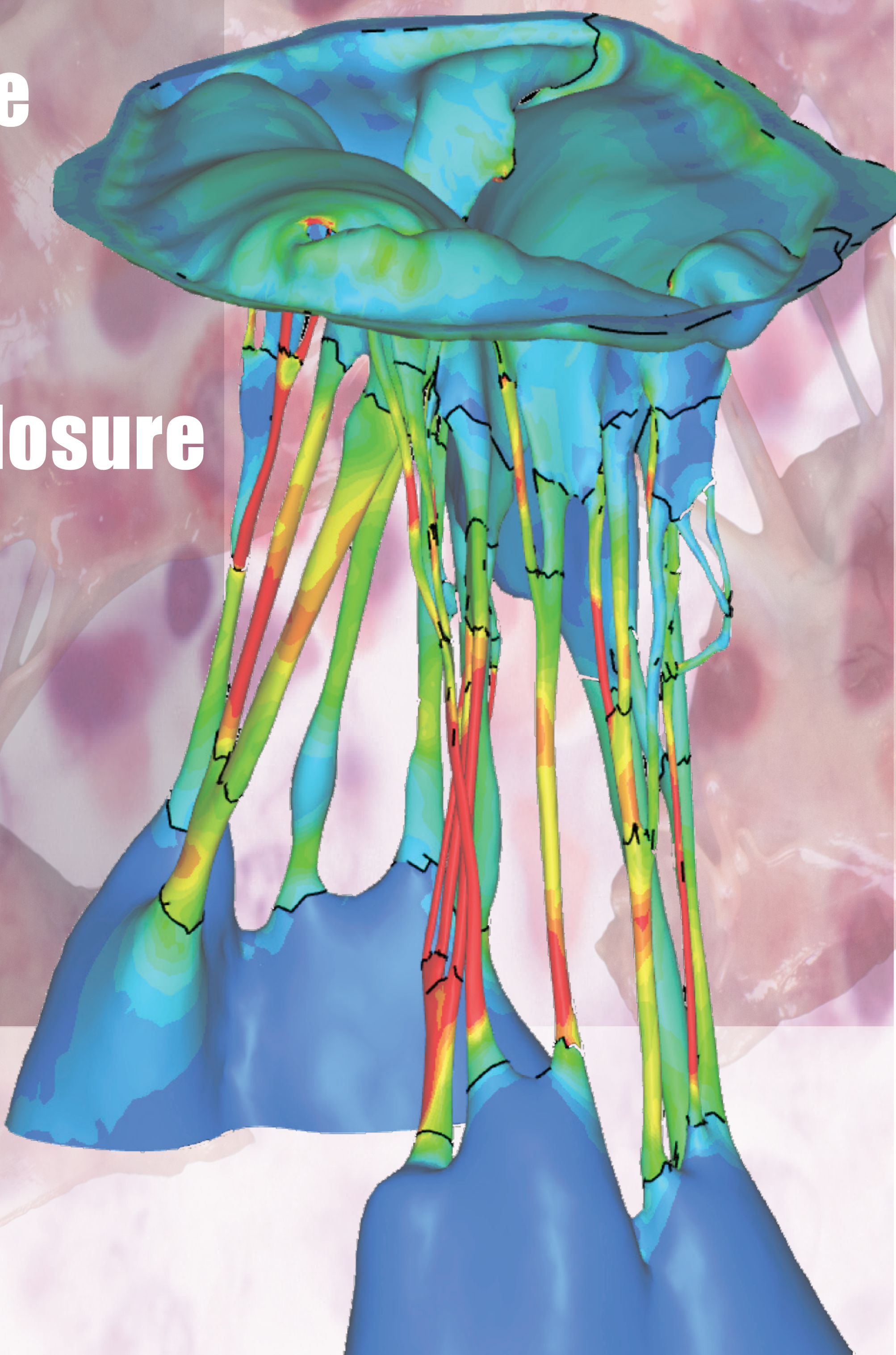
the CertaSim SOLUTION™

Featuring: Fluid-Structure Interaction Simulation of Mitral Valve Closure



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CertaSIM, LLC is the official distributor of the IMPETUS Afea Solver® in North, Central and South America and provides technical support and training for the IMPETUS suite of software.

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EVENTS

GPU Techonology Conference (GTC) 2015

The IMPETUS Afea Solver® utilizes GPU Technology for parallelization of the solver. Each year NVIDIA holds their GTC Conference and CertaSIM was there along with the lead CUDA developer from IMPETUS Sweden, Mr. Henrik Lam. The conference was held in San Jose, California March 17-20, 2015. There were over 4000 attendees and 500 presentations. Dr. Wayne Mindle from CertaSIM, presented a paper titled, "GPU Parallelization is the Perfect Match with the Discrete Particle Method for Blast Analysis". The paper focused on the benefits of GPU Technology for modeling mine blast.

The presentation can be found in PDF format at:
http://files.certasim.com/download/file/tech-info/publications/S5449-Wayne-Mindle.pdf

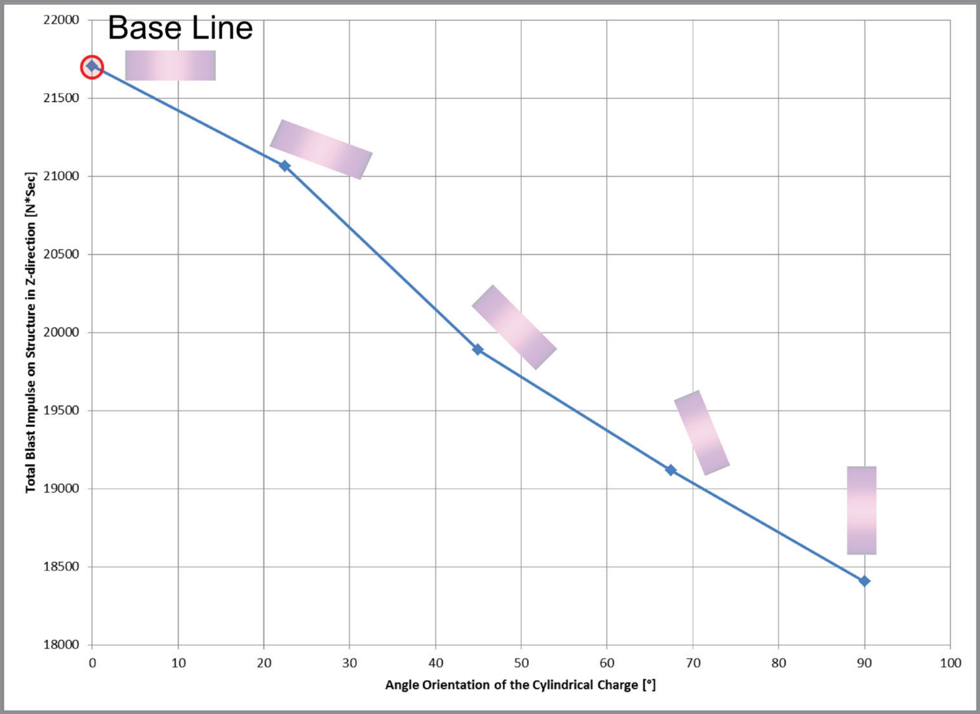
An audio of the presentation can be found at:
http://files.certasim.com/download/file/tech-info/videos/S5449_VPCF-v86f40-1300.mp4

2015 NDIA Ground Vechicle Systems Engineering and Technology Symposium (GVSETS), August 4-6, 2015 – Novi, Michigan.

CertaSIM attended the GVSETS 2015 conference which had over 900 attendees. The conference included a session that showcased "the state of the art" for buried mine blast where current research in this application was presented. The session was called "Modeling & Simulation, Testing and Validation (MSTV) Technical Session." Dr. Morten Rikard Jensen presented the results of a sensitivity study of the process and approach parameters in a buried mine blast load using the IMPETUS Afea model of the TARDEC Generic Vehicle Hull. The study covers 14 Design Variables and the experimental matrix contains around 80 simulations leading to over 1000+ computational hours. It showcases the effects of charge size, DOB, soil parameters, etc. The Response Parameter was chosen to be the Total Blast Impulse on the structure in the Z-direction and the results are compared with a Base Model. The results confirmed all expectations and verifies that the IMPETUS Afea Solver® is a predictive tool for modeling buried mines. As an example of a Design Variable consider the orientation of a cylindrical charge where the horizontal orientation results in the largest Blast Impulse and the vertical position leads to the smallest Blast Impulse.
The paper is titled, "Discrete Particle Method is a Predictive Tool for Simulation of Mine Blast – A Parameter Study of the Process and Approach."
In the next edition of the Journal the work will be described in more detail as the paper is published.

An abstract for the paper can be found at:

http://files.certasim.com/download/file/tech-info/publications/Abstract_Jensen_Smith_GVSETS_2015.pdf



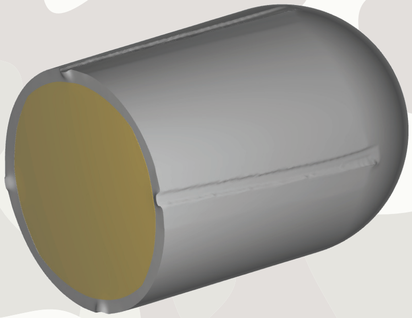
BALLISTIC IMPACT: Scoring of a Copper Bullet and Penetration of a Brittle Aluminum Target

CertaSIM just completed a project aimed at demonstrating to the US Army research establishment how the IMPETUS Afea Solver® can accurately model ballistic impact scenarios. The project involved impact of a copper bullet on a brittle aluminum plate which included both bullet engraving and target impact.

The process has two parts, (1) engraving of the bullet by the "lands" as it travels down the gun barrel and (2) target impact. From an analysis perspective this is typically performed in 2 steps as the requirements to accurately model the bullet is quite different for the 2 scenarios. For the engraving, mesh refinement is important where the "lands" contact the side of the bullet and for the target impact the front of the bullet is the critical area for mesh refinement. Because we chose to do both within one simulation it was necessary to refine in both critical areas. The target that was chosen is a brittle aluminum and the unique node splitting algorithm in IMPETUS was used to accurately capture the fragmentation and fracture that occurs as the standard method of element erosion is not accurate and leads to the bullet pushing a plug through the target which is not at all physical in this case.

The bullet has a diameter of 0.25 inches and the motion is defined by an applied pressure history curve at the backend of the bullet. The bullet travels inside the barrel and makes contact with the lands that have a width of 0.0106 inches. The bullet is modeled with two layers of cubic ASET™ Elements along the surface to capture the deformation and the core is represented by linear elements. The scoring of the bullet is clearly observed and the resulting engraving is very smooth which would not be possible if linear elements had been used for the bullet surface.

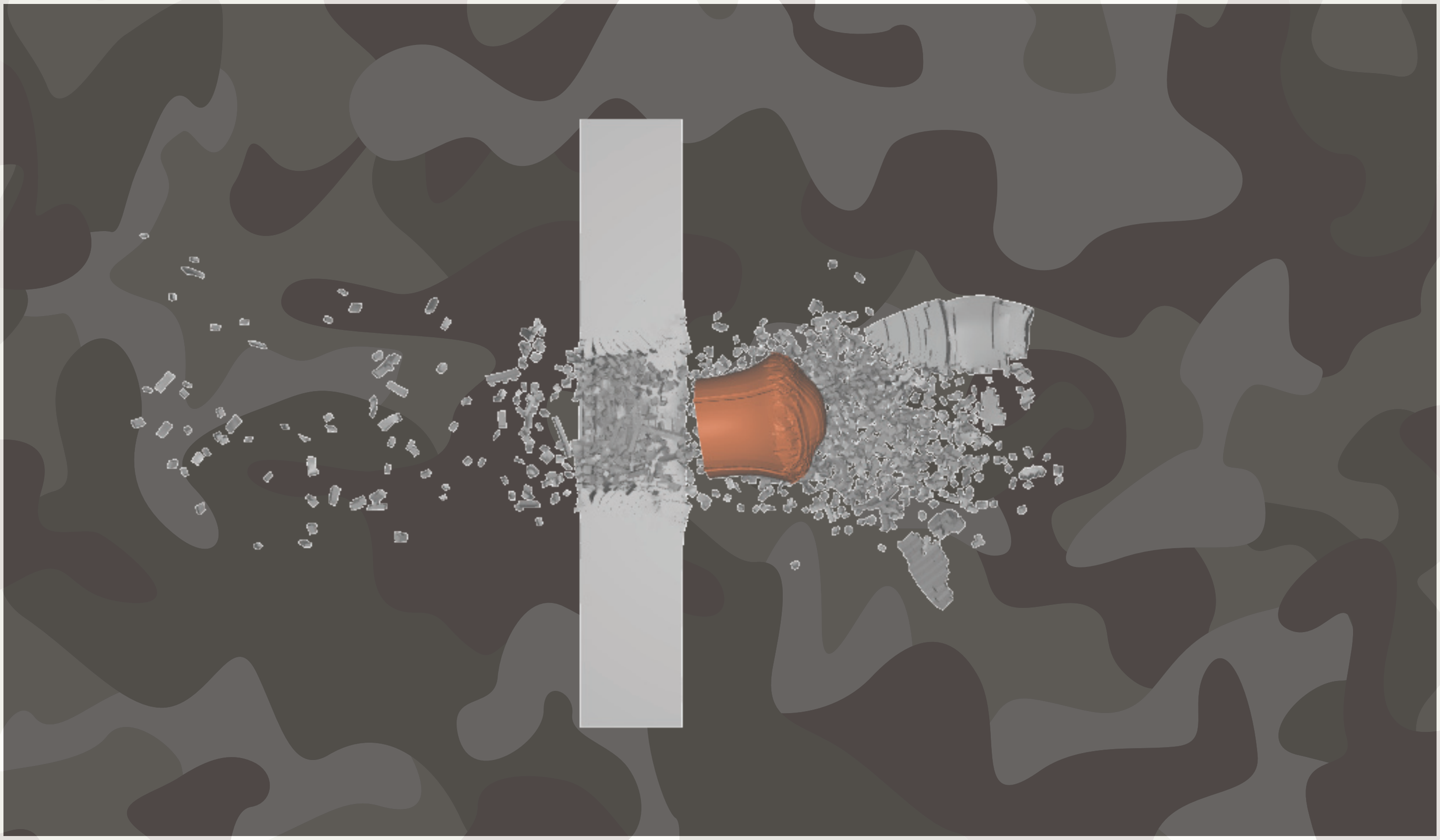
The impact with the aluminum target involves highly non-linear behavior both geometrically, materially and contact is also non-linear. The fragmentation of the plate is captured due to the node splitting. In IMPETUS the damage criteria is lifted out of the material model which makes modeling of damage very flexible since a damage model can be specified for any relevant material model. It is also very simple to apply node splitting, this is done in the damage command, *PROP_DAMAGE_*option*, in this case the Johnson-Cook damage criteria is used for the target.



***PROP_DAMAGE_JC**
did, erode, noic
d1, d2, d3, d4, d5, ε0, T0, Tm

The *did* in the damage property command is a unique ID, which is referenced in the *MAT_*option* command. The *erode* parameter is set to 1 for element erosion, 2 or 3 for node splitting, depending on if the crack plane is orthogonal to the maximum principal strain or stress. The *noic* parameter determines if a crack is allowed in interfaces between different materials. The rest of the parameters are parameters in the classic Johnson-Cook damage criteria. A more detailed description can be found in the IMPETUS User's Manual.

In this model, *noic* is set to 3 which is often used for applications where spalling occurs. Fragmentation of the aluminum plate is seen with fragment sizes on the order of 0.0125 inches, so element refinement is used in the impact area. This is easily done with the "Shadow Refinement" technique where the user defines a geometry to specify the area to be refined by the Solver at runtime. The elements surrounding the impact area are modeled with linear elements.



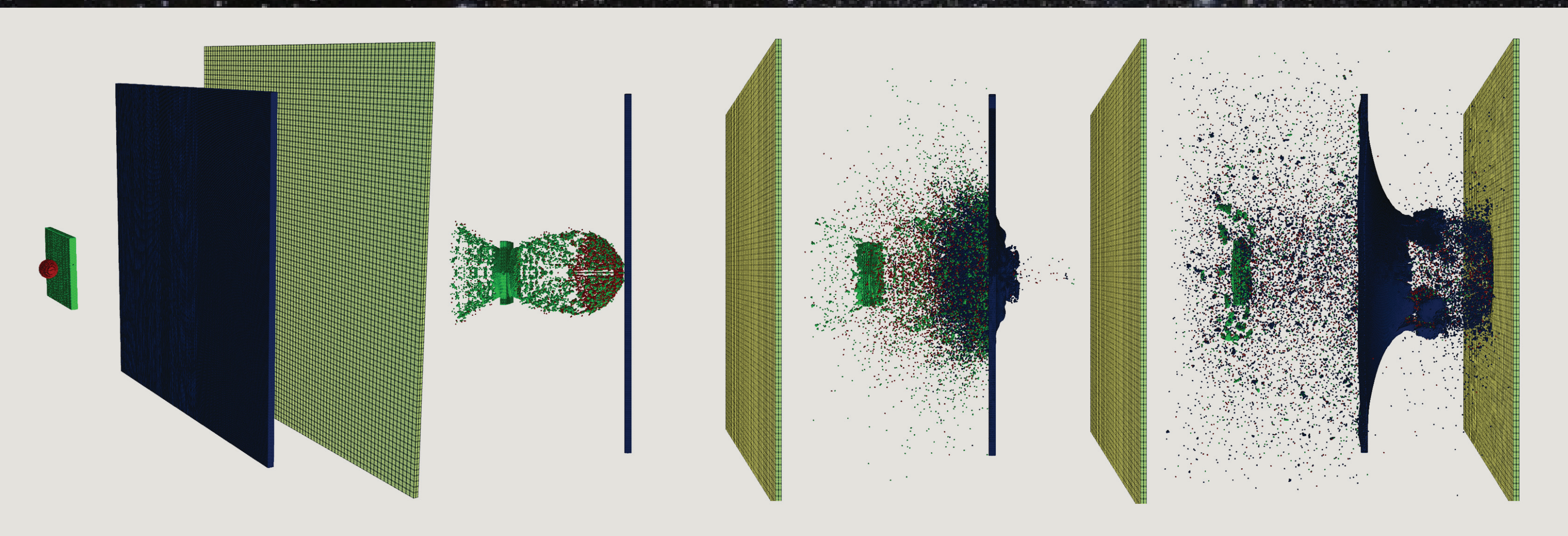
A video showing one model capturing both the scoring and the ballistic impact can be found at:

http://files.certasim.com/download/file/tech-info/videos/Ballistic-Impact_Small-Caliber-Munitions.mp4

To get more information about ballistic modeling in IMPETUS and this particular model, contact support@certasim.com.

HYPERVELOCITY

A 3 plate aluminum Whipple Shield Experiment was recently simulated for the case of a spherical impactor traveling at 6 km/sec. Just over 4.2 million SPH elements were used to represent the structure. The simulation time was 80 microseconds and ran in only 27 hours on a standard workstation with GPU Technology. The third and final plate could also have been modeled with SPH elements, however what makes the IMPETUS Model unique is that the final plate was modeled with Finite Elements. The ASET™ Element Technology at the heart of the IMPETUS Finite Element Solver has 3rd order Hexahedron elements that can handle very large deformation even at the fast but reduced velocity of the debris coming from the 2nd plate. To determine fracture of the final plate the IMPETUS Node Splitting Algorithm for modeling fracture was used. The figure shows the progression of the impact on each plate. Note that (b) shows the classic image of a single plate impact.



(a) t=0 (b) t=5.2 microsec (c) t= 12.4 microsec (d) t=80 microsec

Simulation of the Whipple Shield Experiment involving 3 plates.

A video of the model can be found at:

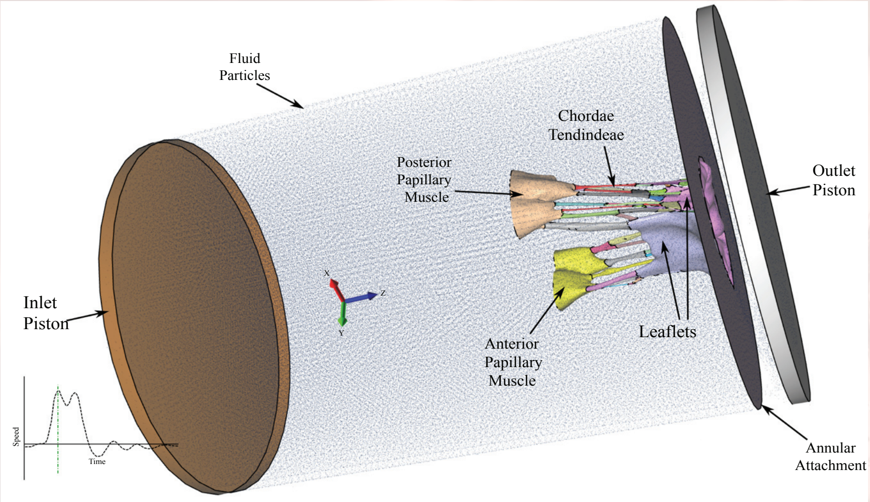
http://files.certasim.com/download/file/tech-info/videos/HypervelocityImpact-3Plates.mp4

Fluid-Structure Interaction Simulation of Mitral Valve Closure

We asked Dr. Milan Toma of the Georgia Institute of Technology, Department of Biomedical Engineering, to discuss their recently published paper titled "Fluid-structure Interaction Analysis of Papillary Muscle Forces Using a Comprehensive Mitral Valve Model with 3D Chordal Structure." Key to this simulation is the scanning technology developed at Georgia Tech which allowed them to develop the 3D geometry that could be easily converted to a tetrahedral mesh. The benefit of the IMPETUS Afea Solver® ASET™ Element Technology, in particular accurate and robust high order tetrahedron elements, is evident for this type of structure which is geometrically complicated and extremely delicate in nature. If one considers that the diameter of the Chordal structure is on the order of 0.33 mm one can see that classic solid or shell elements are not adequate to capture the deformation. Finally, as Dr. Toma points out, "We have also confirmed that when investigating the role of chordae tendineae, the use of FSI is important since structural analysis proved to be insufficient in capturing realistic behavior of the chordal structure." The IMPETUS Afea SPH Solver provided the last piece of the puzzle to model the blood flow. Because SPH is a meshless continuum based method it is a perfect match for this application as it can easily follow the intricate movement of the mitral valve structure as the contact is purely node to surface and so redirection of the flow does not require remeshing.

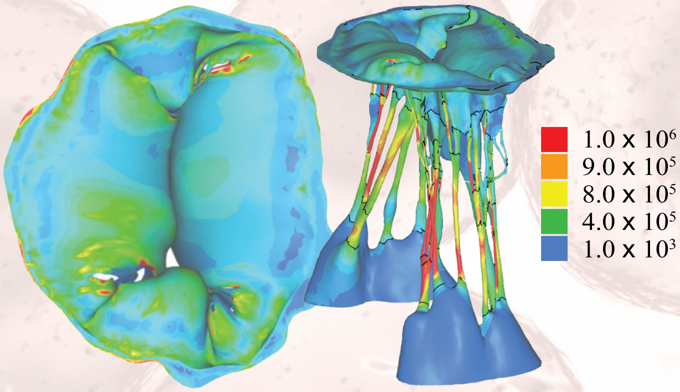
Mitral valve (MV) is the valve regulating blood inflow for the left side of the heart. Blood flows from the lungs, where it picks up oxygen, into the left atrium of the heart. When open, it lets blood flow from the left atrium to the left ventricle. When closed, it keeps blood from leaking back into the lungs when the ventricle contracts to push blood out to the body to deliver the oxygen. The MV is the most complex of the heart's four valves and is the one most commonly associated with disease, such as mitral stenosis (obstruction), mitral regurgitation (leakage) and MV prolapse (bulging backward during valve closure). Thus, a complete understanding of the complex mechanical function of the normal mitral valve remains elusive.

The anatomy of the MV is of high complexity; it includes two asymmetric leaflets attached to the left ventricle at the annulus, and numerous chordae tendineae that serve to attach the leaflets to the left ventricle via the papillary muscles. The chordae connect to both the free edge of the leaflet but also to the ventricular surface. Some smaller chords do not connect to the leaflet at all but rather provide connections between adjacent chords. The function of the valve throughout the cardiac cycle is complex, and involves interaction between all of the aforementioned structures.



The model development included μCT in-vitro scanning, image processing, mesh generation and the use of fluid-structure interaction (FSI) approach to simulate and evaluate the opening and closing of the valve. The image acquisition, image processing, mesh generation and segmentation, fiber directions and constitutive model with the material parameters used are explained and stated in detail elsewhere. [1]

The leaflet and chordal stress computed by the FSI simulations showed a distinct increase in stress magnitude at full closure, as compared to the open state. The stress was not symmetrically distributed, a result of the valve specific geometry, which is itself not symmetric. The local maxima of the principal stress values (1 MPa) were found primarily on the chordae tendineae and their connections to the leaflets.



The model has been validated against experimental data[1] as well as against medical images of the actual MV in closed state in an in-vitro setup. We have also confirmed that when investigating the role of chordae tendineae, the use of FSI is important since structural analysis proved to be insufficient in capturing realistic behavior of the chordal structure. Moreover, these are simulations that lead to very high deformations of very complex models. Therefore, the choice of proper numerical techniques is of high importance.

[1] M. Toma, M.O. Jensen, D.R. Einstein, A.P. Yoganathan, R.P. Cochran, and K.S. Kunzelman, “Fluid-structure interaction analysis of papillary muscle forces using a comprehensive mitral valve model with 3D chordal structure,” Annals of Biomedical Engineering, 2015 [Epub ahead of print], DOI: 10.1007/s10439-015-1385-5.

Dr. Jean-Luc Lacome is the CEO of IMPETUS Afea SAS, which is located in Grenade, France. The French team develops the IMPETUS Afea SPH Solver. Dr. Lacome is an expert on the SPH method, having first studied it extensively as a graduate student followed by 9 years as the sole developer of the SPH solver for LS-DYNA. With the chance to begin fresh he joined the IMPETUS Afea Group in 2007 and assembled a team of SPH experts, which includes Dr. Jerome Limido as the CTO, to create from the ground up a truly "Next Generation SPH Solver". We asked Jean-Luc to discuss the key features and technological improvements that they have made over the last 8 years.

"As one would expect when the opportunity to "re-invent the wheel" is presented, in this case to develop a new SPH Solver, the goal must be to make it better than what was done before. We sat down as a team and asked ourselves, how can we improve the classic SPH Solver? On our list were these key points: improve accuracy, ease of use, better parallelization and better coupling with the Finite Element Solver.

Parallelization and Accuracy

The solver parallelization had a simple answer, GPU Technology. The IMPETUS Finite Element and Discrete Particle Solvers were already focused on using GPUs for parallelization, so it was a natural choice to go in that direction to be compatible. But the result was incredible speed compared to standard cluster solutions and the limit on the number of SPH elements per simulation was 20 million for the original NVIDIA Tesla C2070 GPU and for the current GPU model, the K40, greater than 40 million. This also solved part of the "how to improve accuracy" question, because more elements lead to better accuracy. The Classic SPH Solver suffers from the requirement to include "artificial viscosity" to stabilize the solution. This introduces a non-physical variable that is hard to quantify for the various scenarios. What our team developed was a modification to the Classic SPH Kernel which minimizes the influence of artificial viscosity, makes the solver parameters more physical and at the same time improves accuracy. The result was a method that is less dispersive and so capturing shock wave propagation is more accurate in both time and position.

Coupling with FE Solver

To perform FSI (Fluid Structure Interaction) requires a FE Solver to model the structure and the IMPETUS Afea Solver® was a perfect match as it was also newly developed as opposed to "Legacy Solvers" with 30 year old data structures. Consequently, it was straight forward to couple the two solvers to effectively work in concert, the result being a very robust connection.

Ease of Use

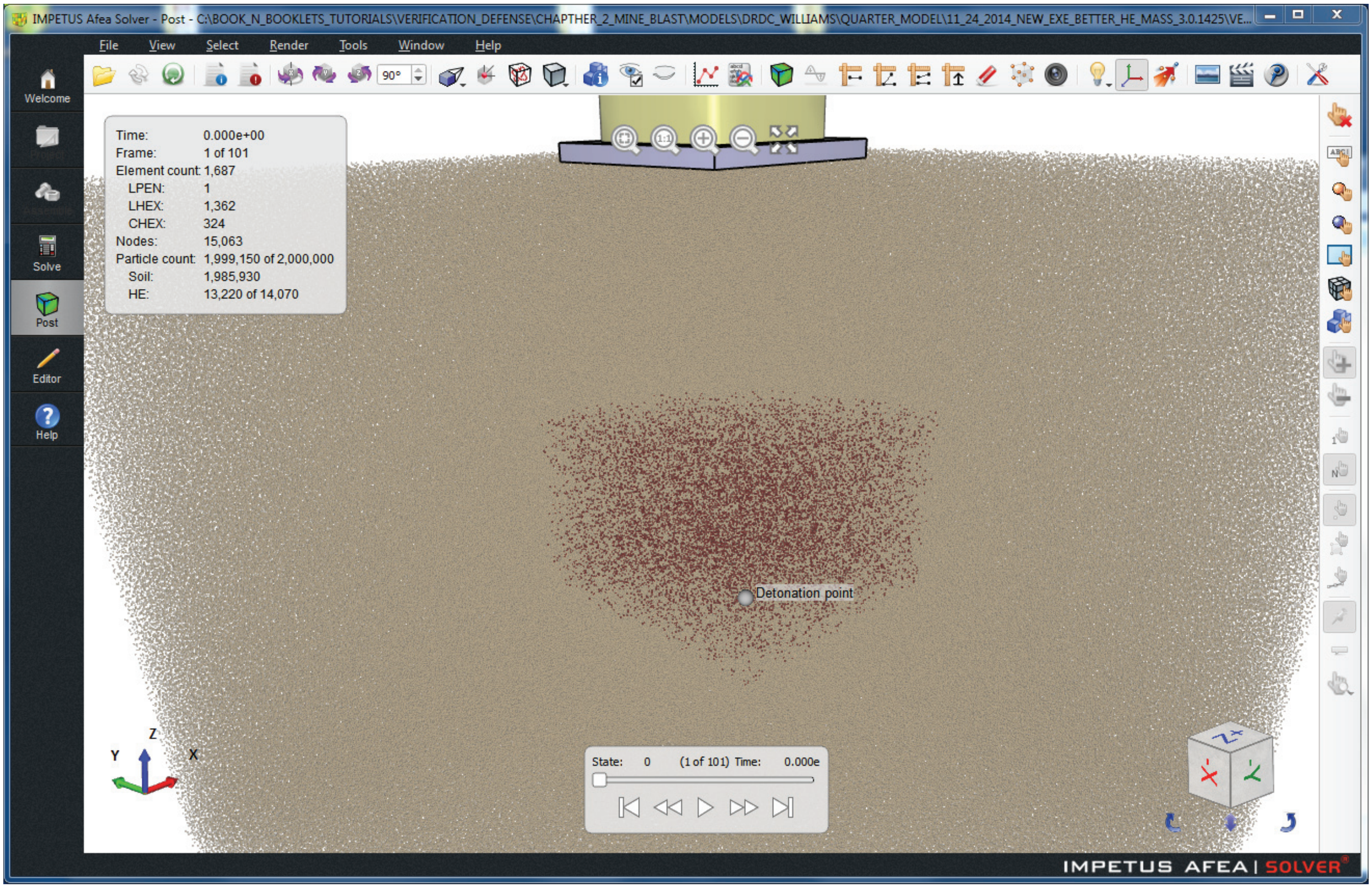
From our perspective this was a very necessary step and the answer was to let the solver generate the SPH elements at runtime rather than require the user to create the elements from a pre-processor which would have to generate a command file with potentially 10's of millions of lines of input that would subsequently have to be read in by the solver. So we came up with a methodology wherein the solver would only require that the user define what geometry to fill. What this did was to enable the user to easily change the SPH element resolution by merely specifying element density. Therefore rerunning the solver to check for convergence is then an easy process by just changing one number.

Future Development

What is next? Everything has its purpose and we see SPH as the "F" in FSI, not as a replacement for the finite element solver because we have a very robust FE solver that includes very accurate and robust solid element technology. We recently implemented capabilities for modeling accurately Hypervelocity impacts and we see the possibility of modeling shape charges and ballistic impact of very hard materials like ceramics that are very brittle and would benefit from a particle based continuum method like SPH."

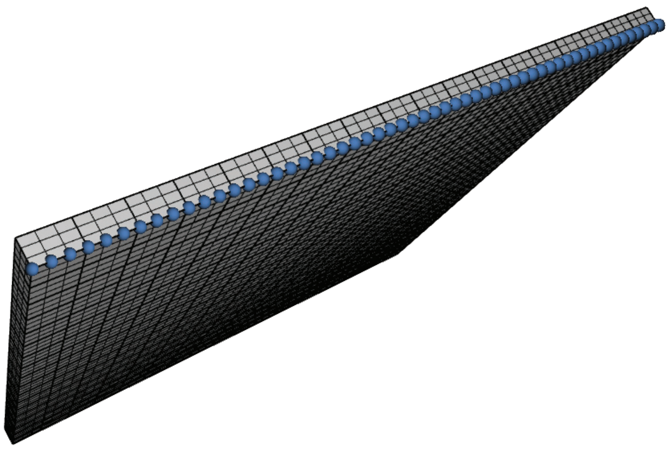
New Features in the IMPETUS Afea Post-Processor

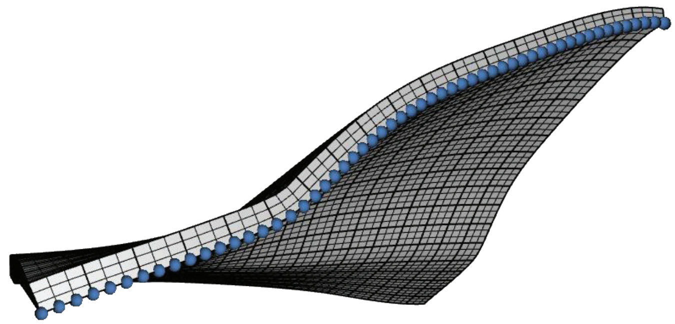
The IMPETUS Afea Post-Processor makes it easy to post-process blast events since options are implemented to easily find blast impulse on the structure and other relevant entities for this application. A newly implemented entity is to visually highlight the location of the HE Detonation Point, which is displayed by default.



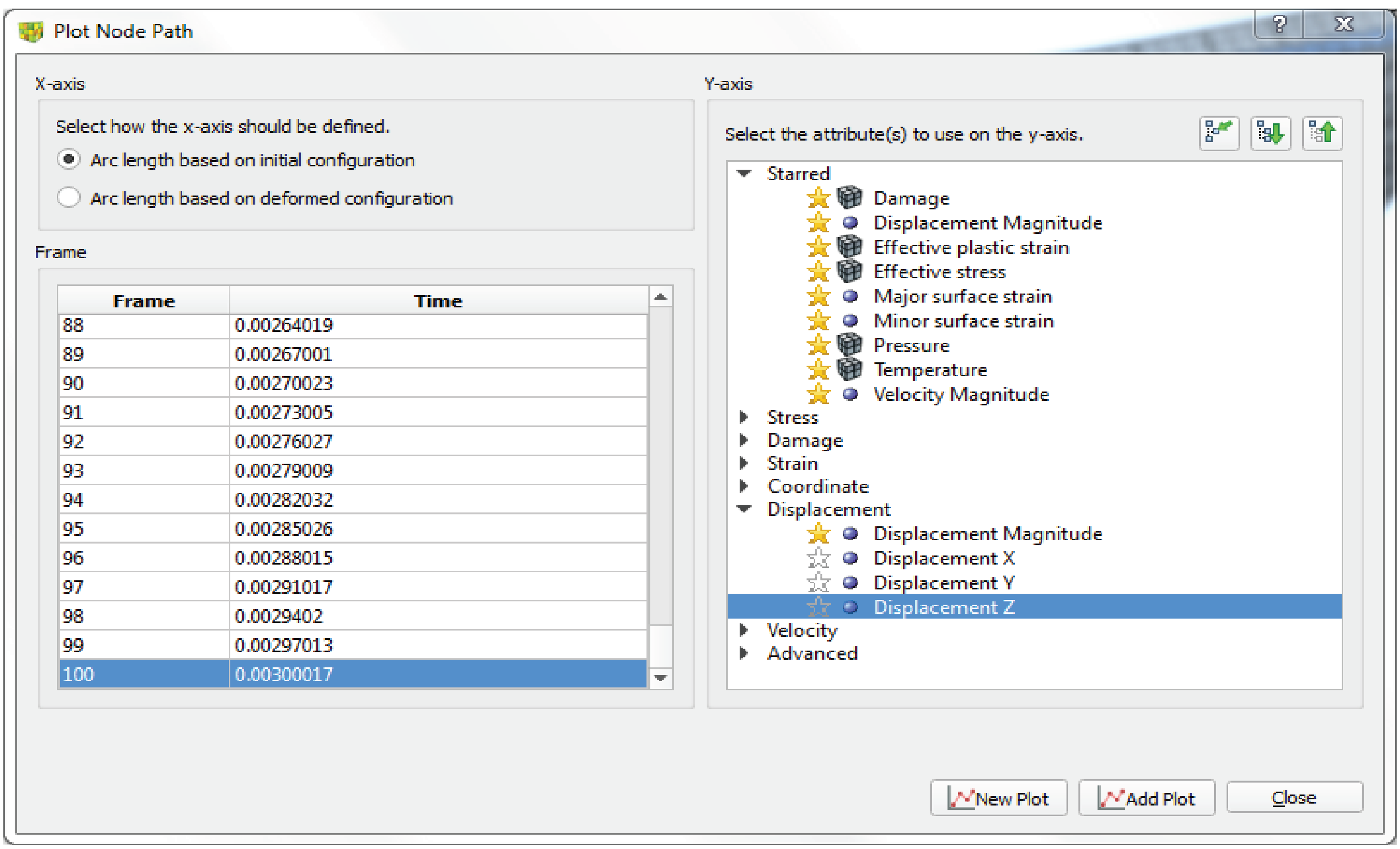
It can be turned off by left clicking on the Particle blast option in the Object tree (on the left) and then deselect the checkbox at the bottom.

In Sheet Metal Forming a common practice is to generate Process Signatures where an entity is plotted along a path on the drawn part. This is done in the Finite Element Model and compared with the experimental results. To find the Process Signature in experiments, grid analysis techniques can be used together with a computer vision system. Such profiles are also applied in blast experiments where the deformed plate is measured along different paths and permanent deflection is plotted. This concept is now available in the IMPETUS Afea Post-Procesor by using the Plot Node Path option. First the path is selected based on nodes. This is done by activating the Select Nodes Icon, . In the selection menu, click on the Path Selection Icon, . One can then select the nodes for the path. Often this is easiest to do in the undeformed configuration. The path can be automatically generated if a node at each end of an edge is selected. Then all the nodes in between are added to the path.

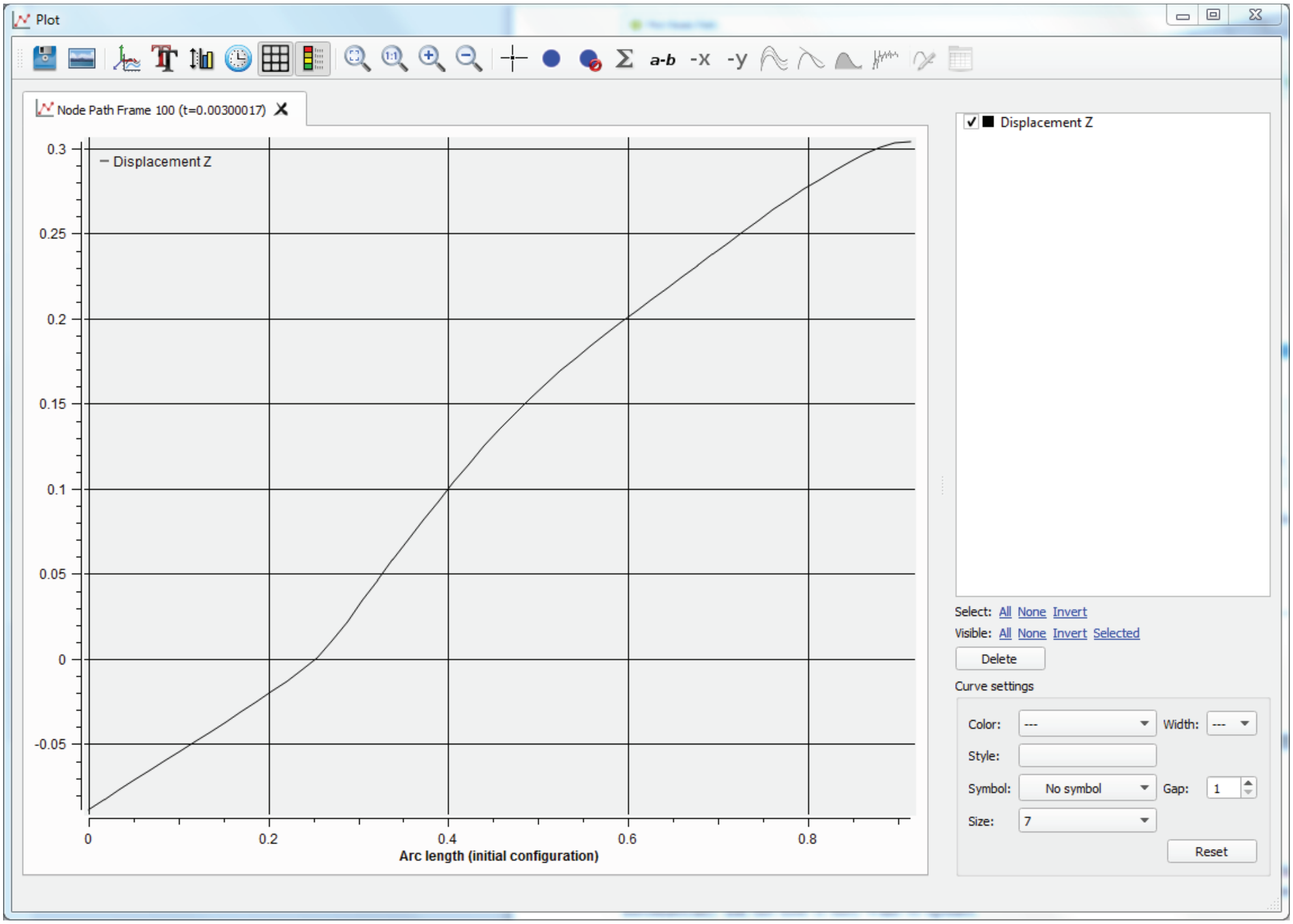




To the left in the interface, below the Object tree, the nodes are listed and at the end one can select the Plot Node Path Icon, . A dialog box will appear to the left side that allows selecting if the path should be based on the initial configuration or the deformed configuration and for which time frame the graph should be plotted.



To the right one selects the entity to plot, then selects New Plot or Add Plot to get the entity plotted along the path.



The latest version of the IMPETUS Afea Post-Processor can be obtained by contacting CertaSIM support but if the machine that is running the Post-Processor is on the internet, the program will automatically ask the user if they want to update.