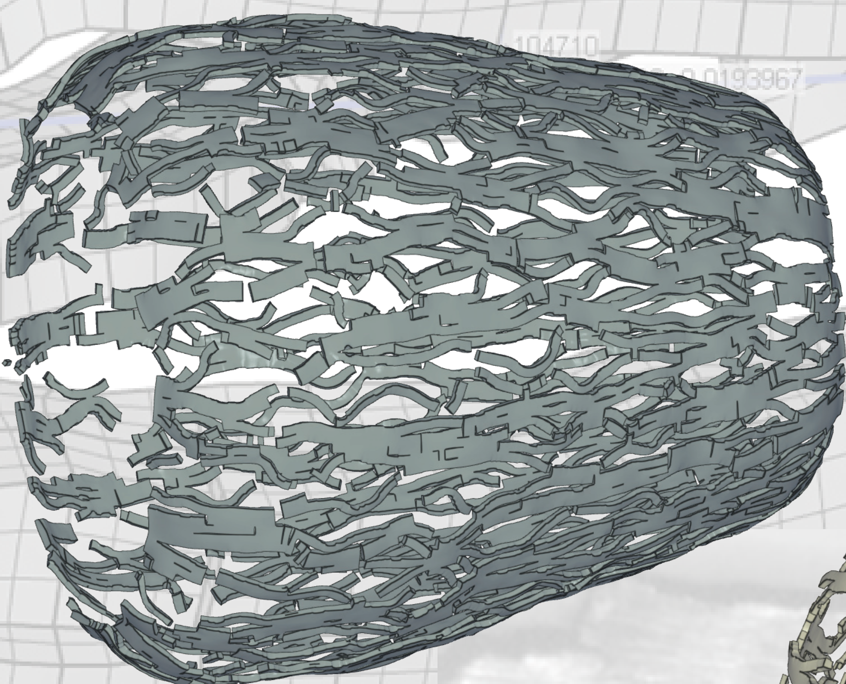
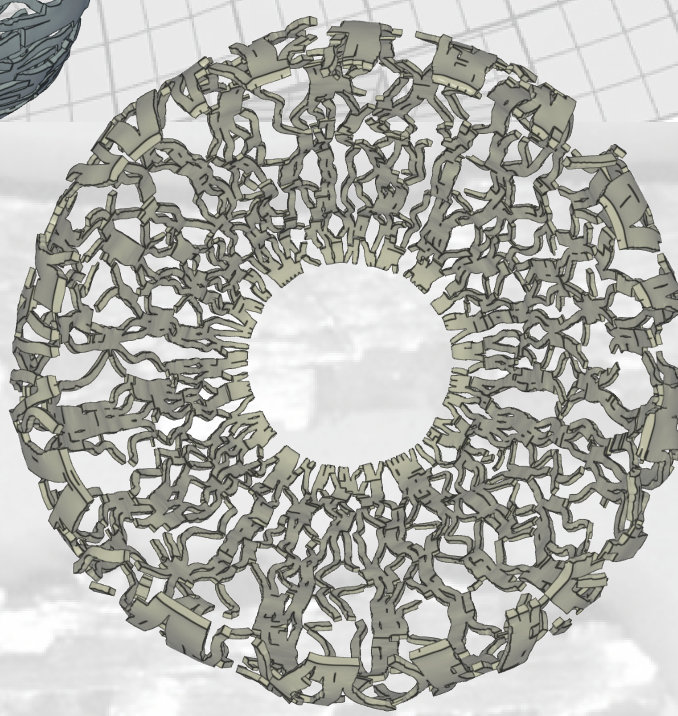
the CertaSim SOLUTION™

Featuring:

Fragmentation Modeling





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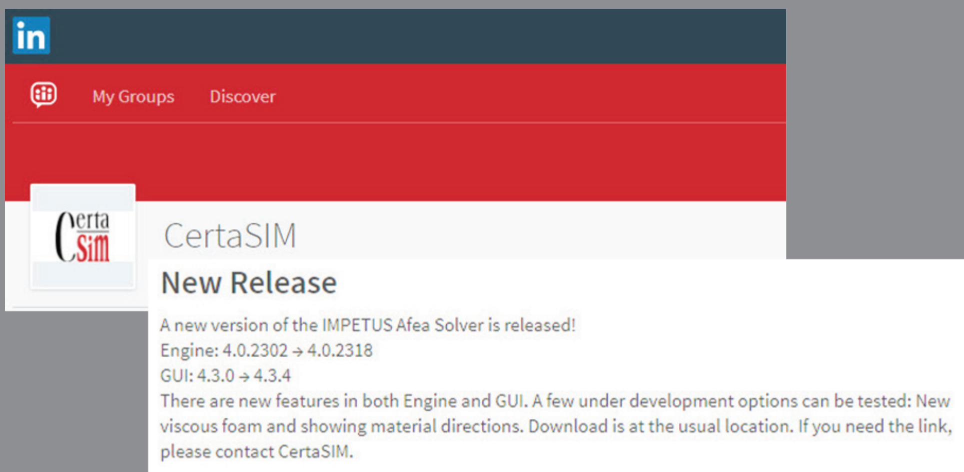
News and Events

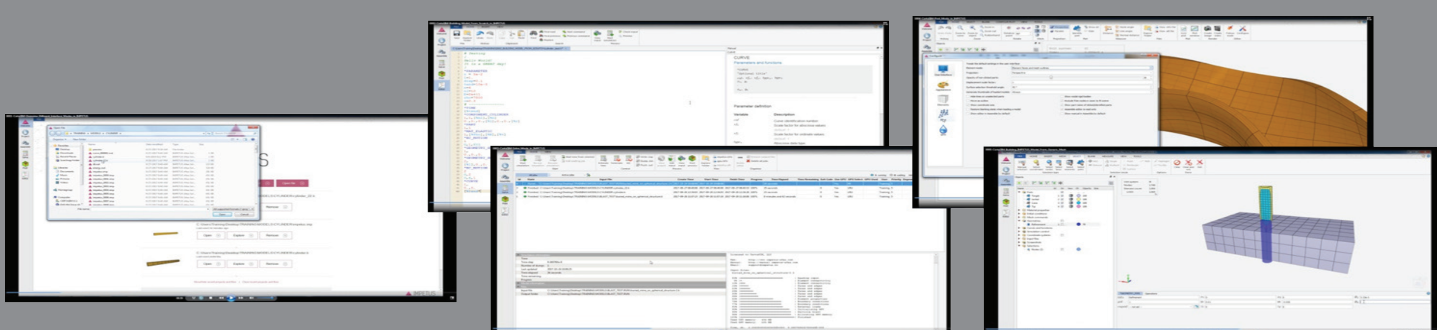
New CertaSIM Support Group on LinkedIn

To receive updated information about the products supported by CertaSIM, LLC a new user group has been established on LinkedIn. It is simply called CertaSIM. Activities related to the IMPETUS Afea Solver® are posted including notifications about Beta and Official releases of the solver. Of major interest to the users are details regarding new features to the Solver that are available for beta testing. Come join the CertaSIM Group to stay informed.



New Training Material from CertaSIM

At CertaSIM, LLC, we believe that good technical support is essential to customer success. A lot of effort and time is allocated to develop the best training material possible. CertaSIM's Support & Training staff have started a new Multi-Media Project that includes training videos on how to use IMPETUS, involving model building, running simulations and post-processing. The first five videos are out.



To get more information about these new videos and where to find them please contact support@certasim.com.

Multiple GPU Parallel Processing

GPU Technology for HPC (High Performance Computing) was launched more than 8 years ago at the Super Computer Conference SC09 held in Portland, Oregon:

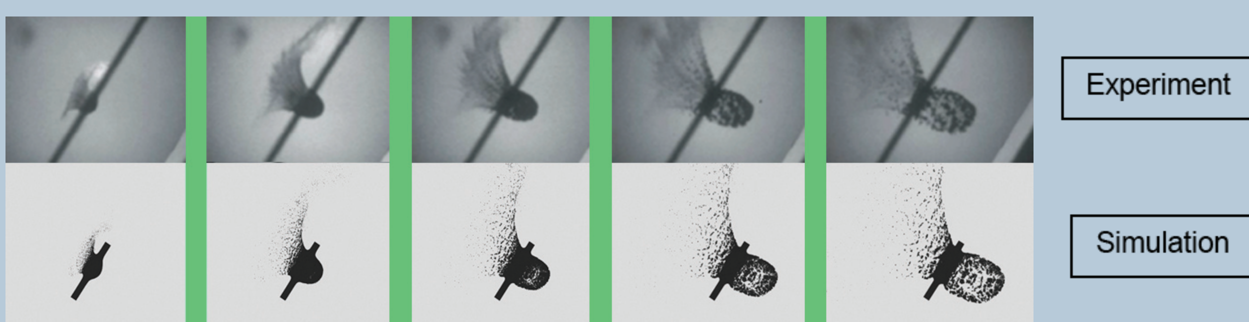
> *Nov. 16, 2009 - NVIDIA Corporation introduced the Tesla 20-series of parallel processors for high performance computing (HPC).*

Here we are in 2017, 8 years later and NVIDIA has introduced 4 new generations of GPU Technology since then and with each release came a significant leap in performance that includes faster processing, more cores and more memory, all on a single standard workstation or single node of a cluster. It is natural too consider using multiple GPUs to improve performance. Very early on IMPETUS included the capability to use multiple GPUs to run large models that require more memory than on a single GPU. In the last year the IMPETUS SPH development team has been working on Multi-GPU capabilities for improving performance on models that would normally run using a single GPU. CertaSIM, LLC has been testing the alpha version of the SPH Solver with various NVIDIA GPU processors. The problem chosen for the performance study is one of Hypervelocity impact, similar to what a spacecraft or satellite might see in space. In particular, the oblique impact of a particle on a plate. The chosen problem has been demonstrated experimentally in a lab environment and the test data has been published. The results from the IMPETUS model matches the test data very well so the focus here will be on GPU performance.

Oblique Impact Parameters

Sphere Diameter = 3.0 mm   Velocity 4050 m/s

Plate Thickness = 2.0 mm with a 32^0 Tilt



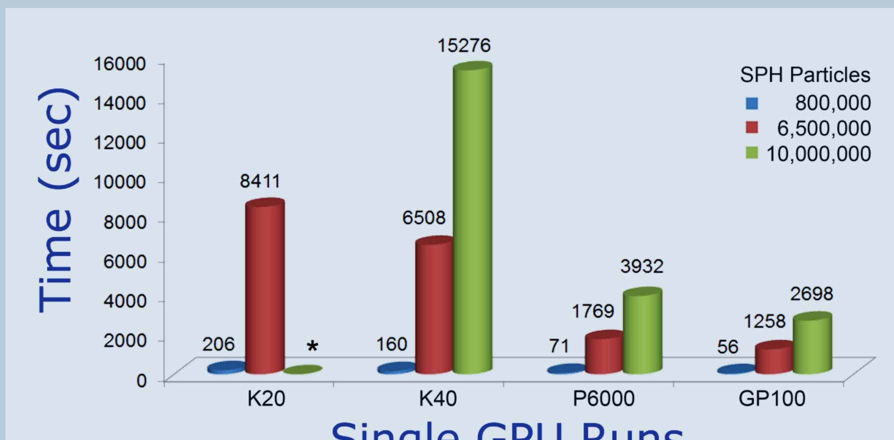
The hardware configuration consisted of a Ciara Technologies KRONOS 840-G3 workstation with an Intel i7-5960X (8 cores accelerated to 4.4 GHz) and 64 GB of RAM with PCI-E 16x slots for the GPUs. The SPH solver is particularly well suited to GPU Technology and runs all calculations only on the GPUs. SPH particles were used to model both the projectile and the plate. The GPUs that were chosen for the tests include 2 generations of GPUs: The older Kepler and current Pascal GPU processors. The Kepler GPUs include the **Tesla K20 and the K40 GPUs**. The Pascal GPUs include the **Quadro P6000 and GP100**. As with any processor be it CPU or GPU there are many factors that affect peformance. The key compoments for the GPU are memory size and type, number of CUDA cores, clock speed and memory transfer speed, etc. Note that the clock speed has been significantly increased with the release of the Pascal Processors as well as the memory and the core count. The flagship GPU for workstations is currently the GP100 with the latest memory HBM2 (High Bandwidth Memory) and the addition of an NVLINK connection between GP100s which will be discussed later.

GPU	Memory (GB)	CUDA cores	Clock Speed (MHz)		PCI-E
			Base Speed	Boost	
K20	5 GDDR5	2496	706	758	2.0
K40	12 GDDR5	2880	745	875	3.0
P6000	24 GDDR5X	3840	1417	1530*	3.0
GP100	16 HBM2	3584	1380	1441*	3.0

*Pascal Processors provide an automatic boost of the clock speed

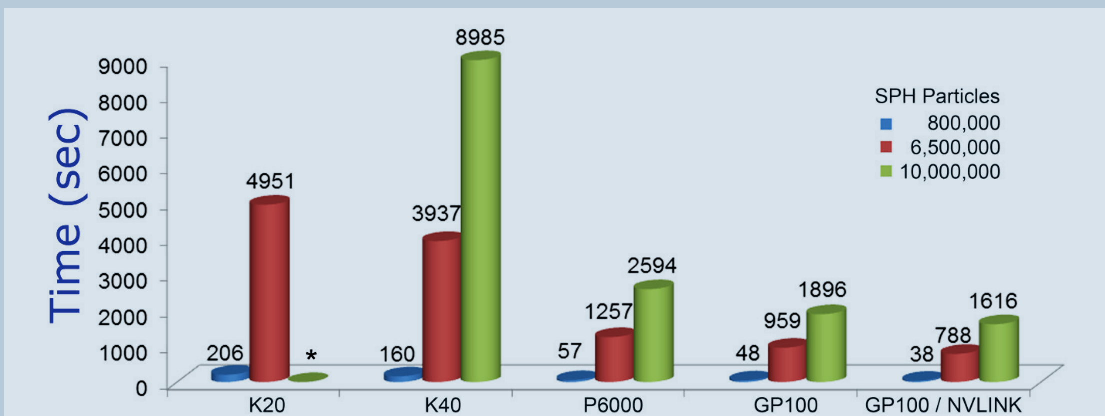
The memory transfer between the dual GPUs is accomplished through the CPU/PCI-E slots on the motherboard. The current motherboards support PCI-E 3.0, however the K20 is the only GPU tested that only supports PCI-E 2.0 transfer speed. The theoretical bandwidth for PCI-E 2.0 is 8 GiB/sec and PCI-E 3.0 doubles that speed to 16 GiB/sec. The GP100 has the added advanatage of an NVLINK connection. NVLINK bypassses the PCI-E communication path which goes through the CPU and allows for a physical connection between the GPUs. The GP100 configuration was tested with and without NVLINK. In order to show the benefit of using dual GPUs the same model was run using a single GPU.

The first chart shows the single GPU performance. The Pascal processors clearly show better performance as one would expect since they are newer technology. The results for the Dual GPU runs are presented in the next chart. The GP100 again provides the best performance and the NVLINK connection improves on that as well. And **yes** the DUAL GP100 NVLINK run was 38 sec for the 800K model, which is remarkable, not to mention the speed for running the much larger models. As a final test we did run a 32 million particle model which only ran on the P6000 because of the memory required, recall the P6000 has 24 GBs of memory. The run time was 7 hr 8m. To our knowledge no other commerical solver can run such a high resolution model!



Single GPU Runs

*K20 does not have enough memory to run 10M Model



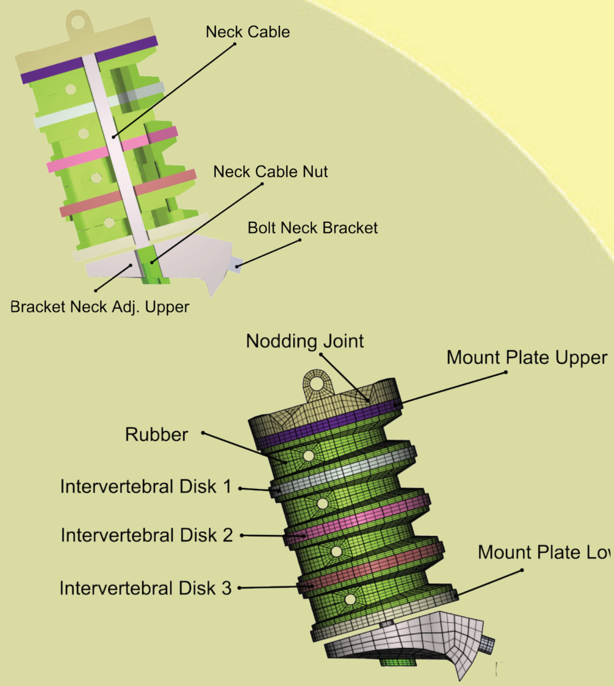
Dual GPU Runs

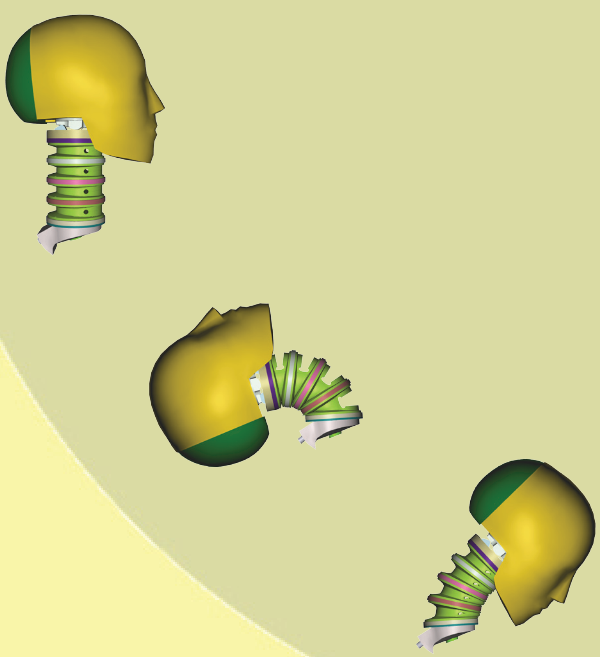
*K20 does not have enough memory to run 10M Model

ATD Calibration for Crash – Neck Extension Test

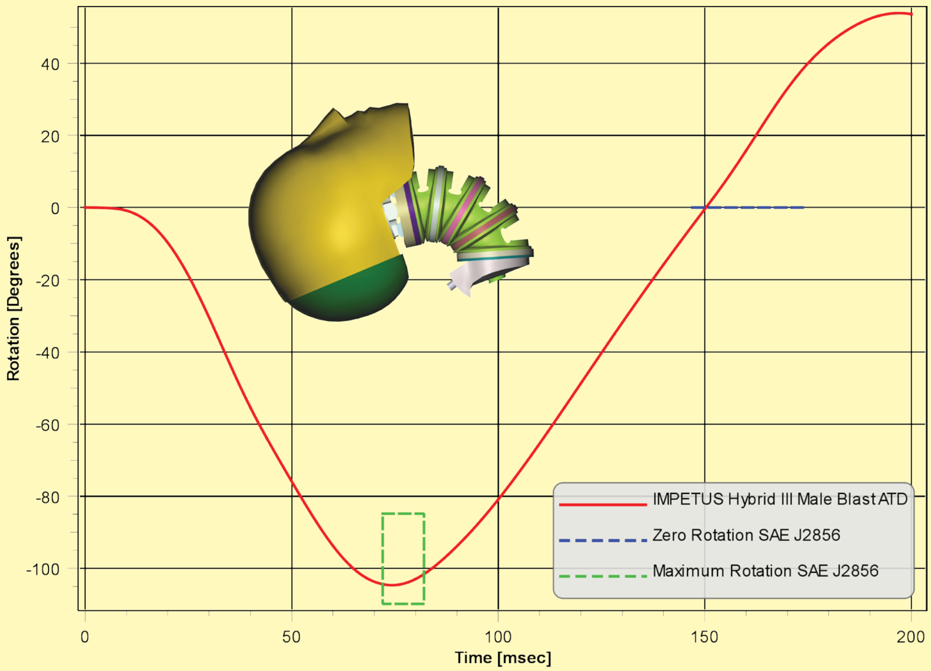
With continued military conflicts in the world one of the most dangerous situations for our warfighters is the attack from an Improvised Explosive Devices (IEDs) which results in extensive damage to their vehicles and therefore a threat to the life of the warfighter. To develop better protection for the vehicles it is necessary to include the effect that blast loading has on the warfighters that occupy the vehicle. This is accomplished by including an Anthropomorphic Test Device (ATD) as part of the physical test. Simulation of this involves a computer model of the ATD. IMPETUS has developed a fully calibrated ATD model based upon the SAE standards but has, together with CertaSIM, extended the calibration to include the results from physical blast tests, which is something that has not been done before. This series of articles describes the different calibration requirements found in the SAE standards; the following presents the results for the Neck Extension Test.

The Neck Extension Test consists of the Neck and Head assembly mounted on a pendulum which includes the brackets. The Head and Neck assemblies were discussed in Q3 2017 of the CertaSIM Solution Journal and are also described in [1].





The test results in a motion that initially bends the neck backward then forward.



The requirement for the impact velocity is a range from 5.94 to 6.19 m/s. The SAE standard [2] then provides the acceptable values when the pendulum is decelerated.

The performance specifications require that the maximum rotation of the head must be between 81° and 106° and which must occur between 72 msec and 82 msec. The decay part of the rotation versus time curve must cross the zero angle line between 147 msec and 174 msec. The rotations are found in the rigid.out file. The results fulfill the requirements of the SAE J2856 standard. The maximum value is -104.6°, occurring at 74 msec.

Furthermore, there are requirements for the moment about the global Y-axis of the head D-plane with respect to the occipital condyles. The maximum value should be between -52.9 Nm and -80.0 Nm and it should occur between 65 msec and 79 msec. In the IMPETUS model this is found from values in the rigid_body_joint.out file. The graph shows that the numerical results are within the requirements.

References:

[1] M. R. Jensen, "The IMPETUS Hybrid III 50th Percentile Male Blast ATD", CertaSIM Report # CS-0052-09012017.

[2] SAE International J2856 September 2009, "User's Manual for the 50th Percentile Male Hybrid III Dummy".

Modeling Fragmentation

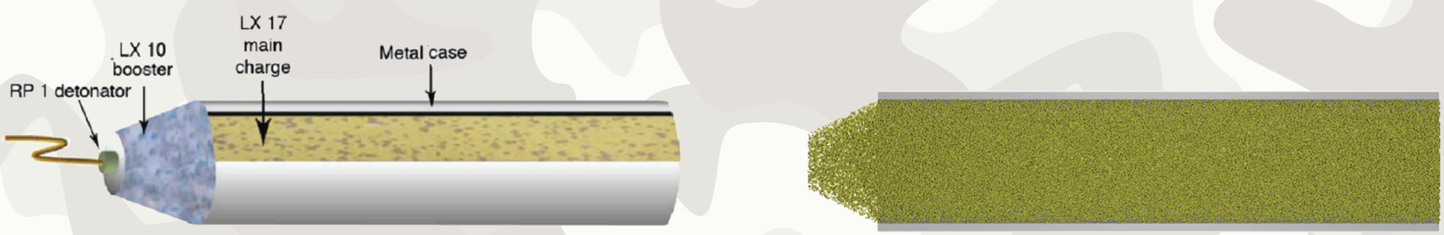
Fragmentation occurs in many different applications, e.g., ballistics, buried mine blast, impact on windows, etc. It can be difficult to predict numerically and in some cases challenging to quantify experimentally, especially for high velocity scenarios. In military applications it is important to consider both for protection but also for efficiency of weapons. This article describes some of the publicly released work carried out for modeling this event with the IMPETUS Afea Solver®. With successful modeling of the application, knowledge about the process and optimization in design can be achieved.

The engineering discipline of Fragmentation is not new and extensive work has been done in this area, e.g. the work by N. F. Mott which was presented well in D. Grady's book [1]. Special interest is in Defense related applications, both as protection against fragmentation but also to design the most efficient weapons, e.g., warheads or grenades. A significant amount of experimental tests have been carried out, most of a classified nature and little is made available to the public. Developing a good Finite Element Model has been shown to be difficult since the fragmentation process involves very large deformation, high pressure and velocity, fracture, high strain rates and often a need to model the High Explosive (HE). In [2] Lagrangian and ALE simulations where carried out on fragmentation of an explosively driven cylinder reporting problems in both cases with mesh convergency and for the ALE models advection problems. A well known problem for the Lagrangian method is that the large element deformation requires elements to be removed to obtain a stable numerical model. However, this element deletion also removes physical mass and hence the formation of fragments which are non-physical leading to difficulties when comparing fragment count and size with experimental Arena Tests.

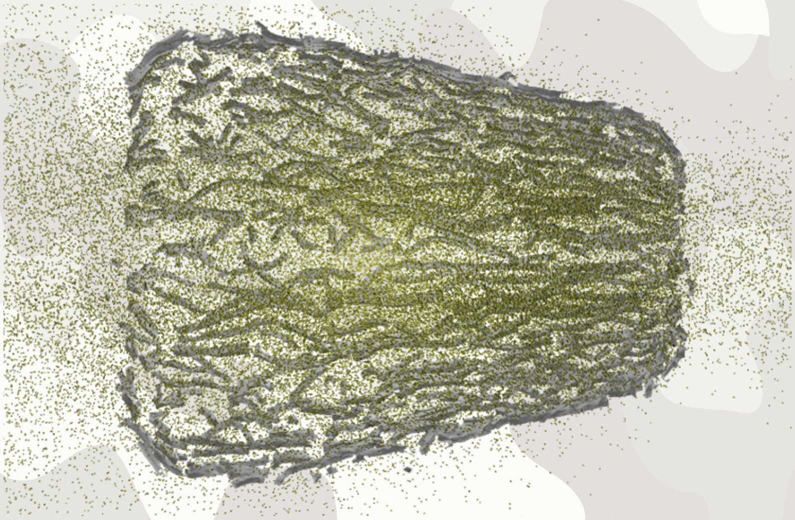
Users of the IMPETUS Afea Solver® have used the Solver to model different types of fragmentation where the IMPETUS Node Splitting Algorithm has been applied in conjunction with the ASET™ family of high order elements, leading to successful modeling of the fragmentation process. Fragmentation of expanding warheads was modeled by Nammo Raufoss and the Norwegian Defense Research Establishment [3-5] where they compared results from other Finite Element software with IMPETUS and found that the Node Splitting Algorithm was very promising.

Fragmentation of Warhead [4]

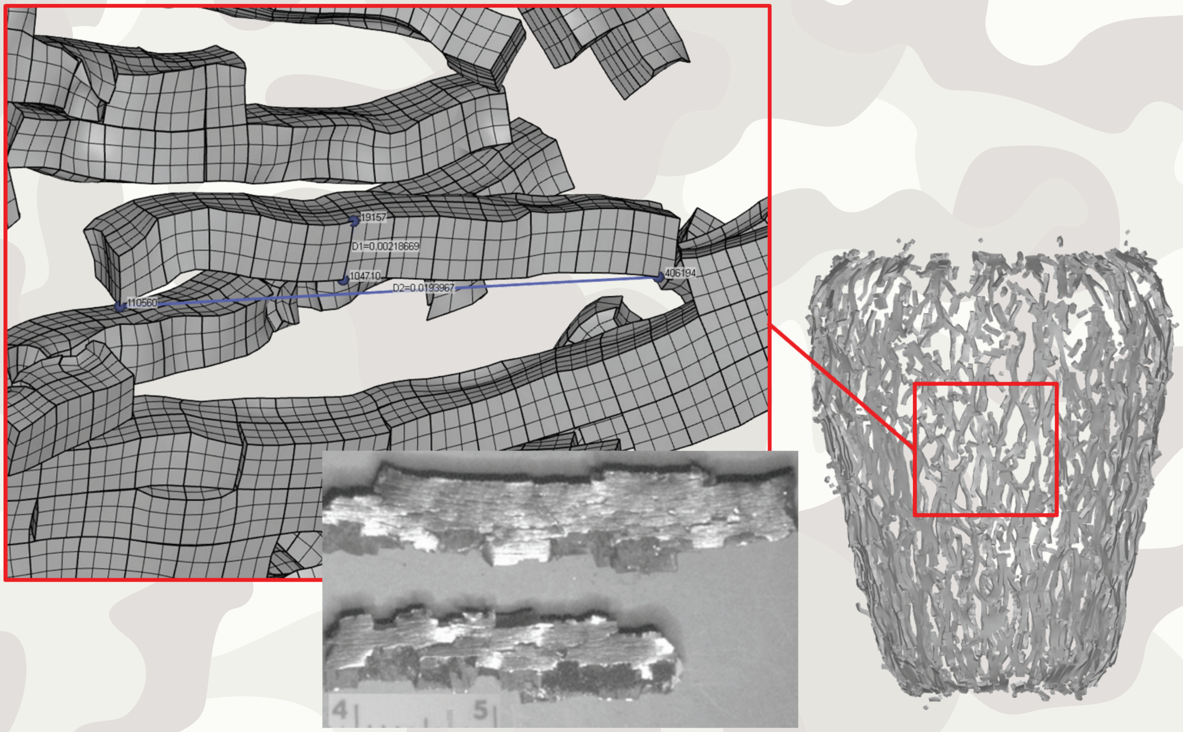
Collé and co-workers applied IMPETUS on several examples. First they tested the cubic high order elements in the Wriggers' Pinched Cylinder Test and fragmentation behavior in Petit's Electromagnetic Compression test, Warhead fragmentation test at MBDA, Taylor bar test and Goto cylinder explosion test [6-8].
The experimental work by D. Goto [9-11] is of special interest since the results were made public and are well documented. The experiments were conducted at Lawrence Livermore National Laboratory in the US for metal cylinders filled with the HE LX-17 from LLNL.



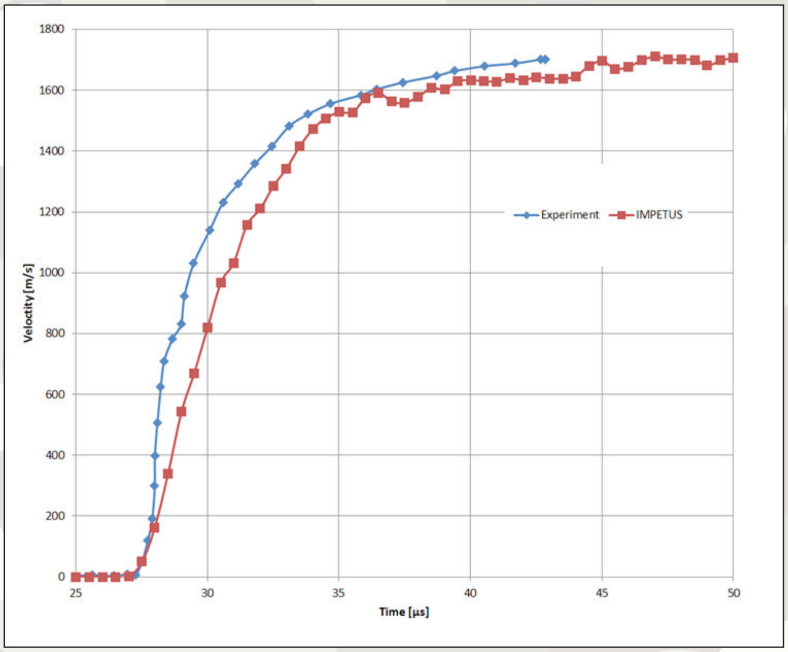
Set-up of Goto experiment at LLNL [10]

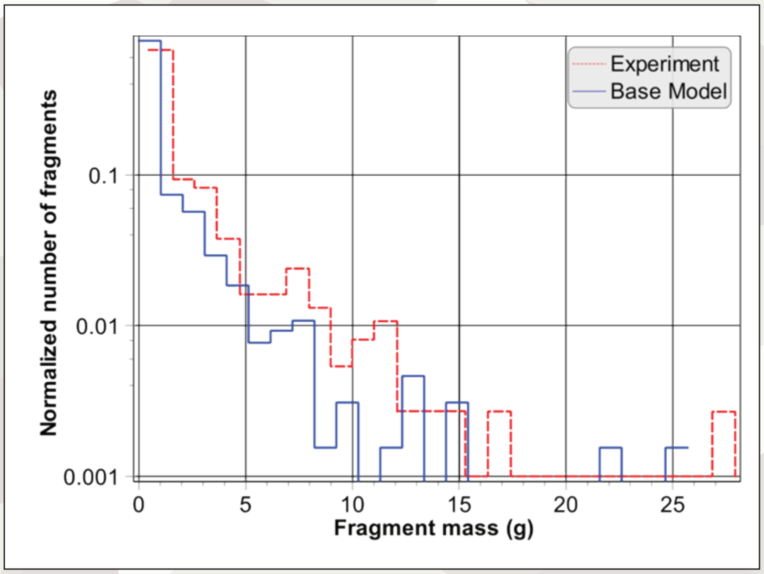


At CertaSIM, LLC the "Goto experiment" was modeled with IMPETUS, using an AerMet® 100 alloy cylinder. The fragments from the simulation were compared with the experimental results. In the experiment the mean fragment length was 16 mm and the width was only a few mm. A representative fragment in the model measured: L=21.9 mm and W=1.9 mm. This indicates good agreement between the experiment and the numerical results.



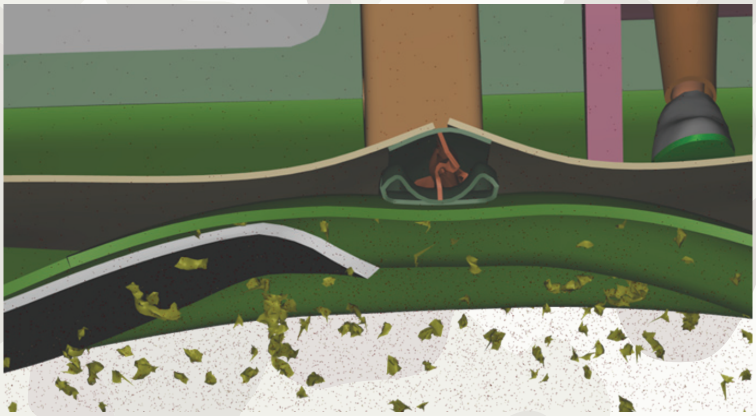
Goto [9] presents a velocity curve for the cylinder but it does not specify at what location on the cylinder it was taken. A node was selected on the cylinder from the IMPETUS simulation where the velocity starts at the time shown in the experiments (~27μs). The velocity history was then plotted and compared with a discretized curve based on the plot in [9], acknowledging the possible error in the discretization process and uncertainty about the location. A very good agreement was obtained.





The same experiments were used in [12] to conduct a very thorough numerical sensitivity study on the number of iDPM particles, mesh size, element types, random damage, Node Splitting Formulation and Blast Impulse Smearing. Some of these parameters had a significant influence on the number of fragments and their distribution. The results where compared to a Base Model that matched the experiments.

Fragmentation studies are also important in military vehicle design to protect the vehicle occupant against injuries. The fragments can come from many sources, e.g., the container of an Improvised Explosive Device (IED) which could be a common artillery shell. In [12], this was simulated with IMPETUS by modeling a 155 mm M795 artillery shell filled with 10.8 Kg TNT. It is a very difficult scenario to model since the HE is directly in contact with the casing which in turn is in contact with the soil. The initial fragmentation happens while the artillery shell is embedded in the soil and continues through the soil ejecta with the fragments ultimately impacting the under belly of the structure, in this case the TARDEC Generic Vehicle Hull Model.



This complex event was successfully modeled with IMPETUS and the results presented in [12]. Recently, a model was developed that showcases fragmentation of a hand grenade placed under a vehicle, here a model of a HUMVEE. The model is described later in this issue of the CertaSIM Solution Journal.

Fragmentation should be considered in ballistic models, at least for certain types of target structures. This has been a topic of intense research at Norwegian University of Science and Technology (NTNU). It is also the topic in the "In Review" Section found later in this edition of the Journal where Dr. Holmen discusses his extensive experience in this area.

Based on the fragmentation work done at CertaSIM, LLC, it can be concluded that the application is rather complex to model and many features influence the results, especially when it comes to the number of fragments. It is recommended to use higher order elements, the Node Splitting Algorithm, *INITIAL_DAMAGE_RANDOM or *INITIAL_DAMAGE_SURFACE_RANDOM. Furthermore, it is recommended to apply Blast Impulse Smoothing in time and location. This is done by specifying the parameters *cdec* and *xsmooth* in the command *PARTICLE_DOMAIN.

More information about the topic of modeling fragmentation with the IMPETUS Afea Solver® can be obtained by contacting support@certasim.com.

References:

[1] D. Grady, "Fragmentation of Rings and Shells – The Legacy of N. F. Mott", Springer-Verlag, 2006, ISBN 3-540-27144-9.

[2] C. W. Arthur and T. A. Dunn, "Investigation of the Fragmentation of an Explosively Driven Cylinder", Lawrence Livermore National Laboratory report, 2015, LLNL-TR-666136.

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[10] D. M. Goto, R. C. Becker, T. J. Orzechowski, H. K. Springer, A. J. Sunwoo and C. K. Syn, "Investigation of the Fracture and Fragmentation of Explosively Driven Rings and Cylinders", UCRL-JRNL-230155, Report LLNL 2007.

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http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijvp

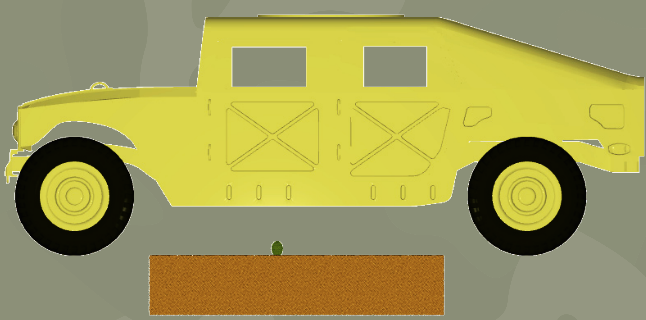
Acknowledgement:

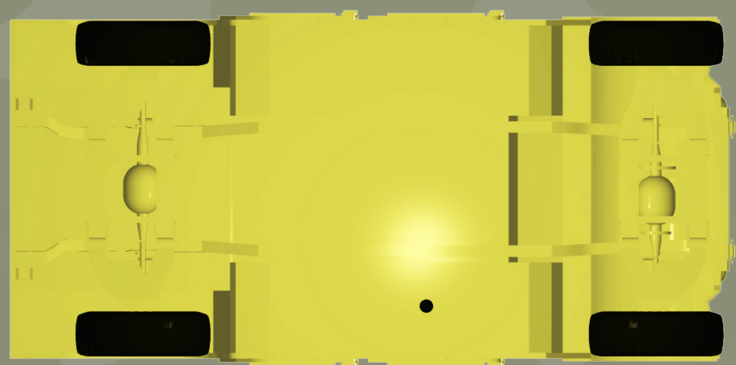
Thanks go to Dr. Jérôme Limido, IMPETUS Afea SAS France, for the conversations on the Goto experiments and about Mott's theory in general. David M. Gerst, Navistar Defense, is gratefully acknowledged for sharing literature and for general discussions regarding fragmentation.

Hand Grenade under HUMVEE

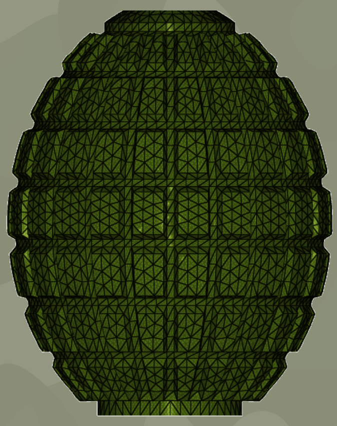
The effect of fragmentation in different scenarios is of vital importance for designing military vehicles. The analysis is complex and includes modeling the fragmentation itself and any of the following depending upon the scenario: Discrete Particle Method, contact, large deformation, etc. The difficulty surrounding a combined Finite Element Model is best shown by demonstration models that reflect real structures. The article describes a demonstration model where a hand grenade is detonated under a HUMVEE vehicle. The results demonstrate the model, the set-up and the fragments hitting the structure.

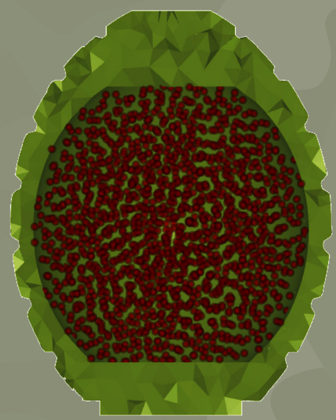
There is a large interest among U.S military vehicle manufactures to model and simulate the response of structures impacted by fragments. This can be from Improvised Explosive Devices (IED's), grenades, etc. Some of the efforts follow the guidelines in [1] and requirements in [2]. CertaSIM, LLC was involved in a project where a M795 155 mm Artillery Shell was used as an IED and the work showed the fragmentation of the casing, etc. The work is published in [3]. To continue developing demonstration models for fragmentation, a fragmentation hand grenade was modeled, placed on the surface of a soil bed and detonated under a vehicle. The location is under the belly but offset toward the driver's side. The hand grenade is pineapple shaped, resembling the famous MK II hand grenade.

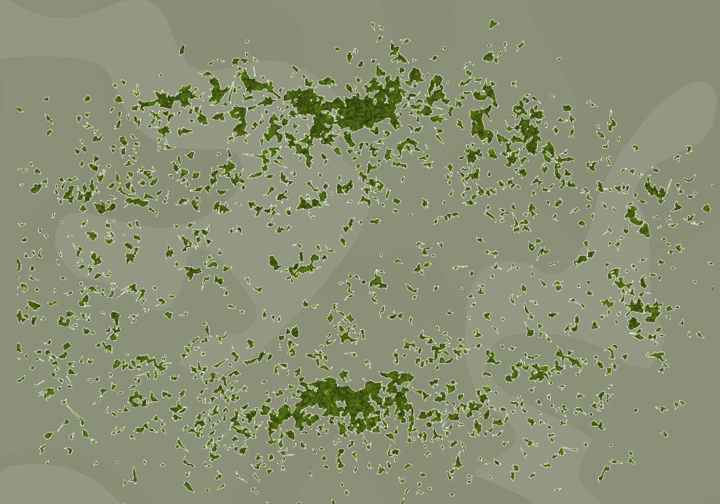




The grenade is filled with approximately 125 grams TNT High Explosive defined by the calibrated TNT model that is part of the IMPETUS Afea Solver®. The casing of the grenade is modeled as metal and damage is defined by *PROP_DAMAGE_CL using the Cockcroft-Latham damage parameter. For the fracture behavior the Node Splitting Algorithm is applied together with setting of the Fracture Energy parameter. The HE and the soil are modeled with the Discrete Particle Method using 3 million iDPM particles with approximately 3500 particles assigned to the HE. The termination time was set to 0.7 msec which reflects the short event time for this scenario.

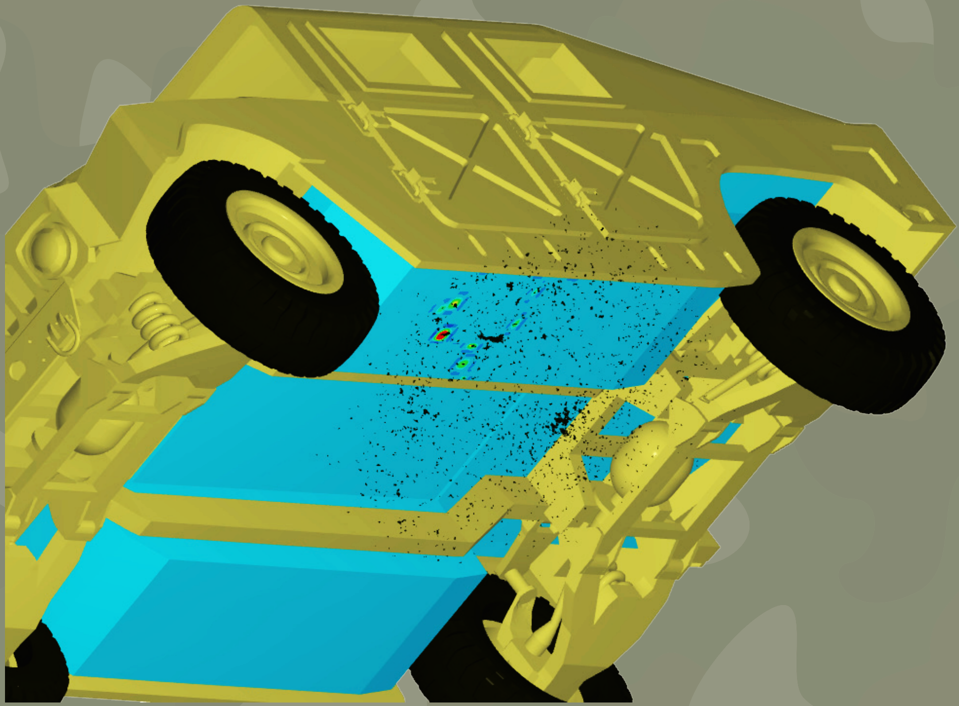


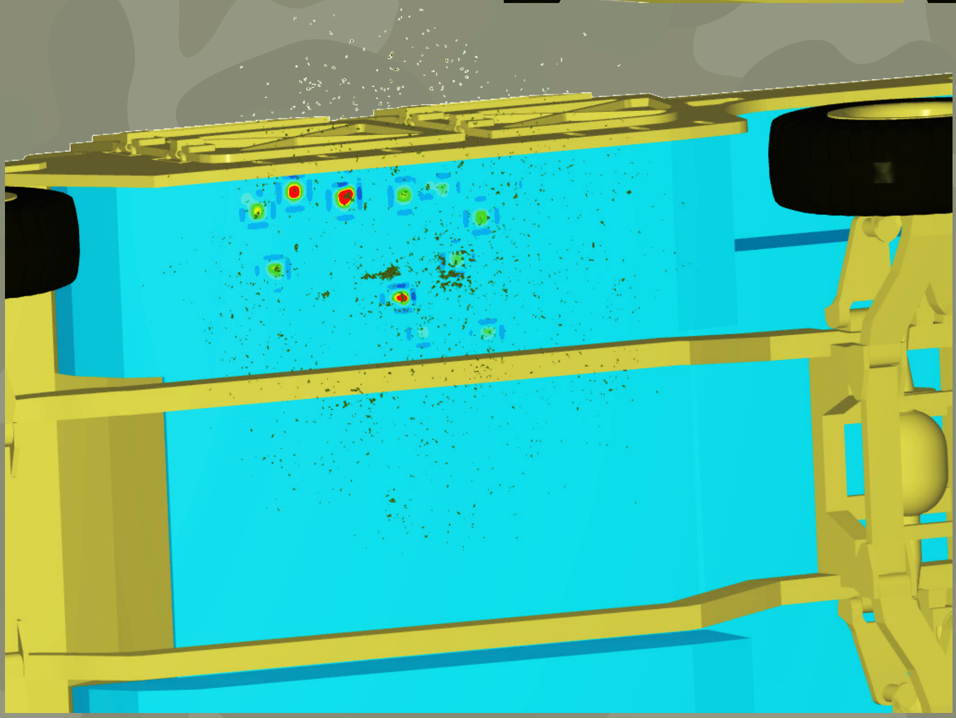




As the grenade detonates, the fragmentation process evolves and fragments are generated.

During the event the underbody of the vehicle will be impacted by the fragments and these are defined to be in contact, thus contact forces can be plotted, though there often will be spikes since the fragments bounce off the structure. A good visual approach to see the fragment impact is to make a contour plot of the contact pressure at the bottom of the vehicle. This will show the significance of the impact for each fragment and the damage can be considered.





During the post-processing phase one can use the Fragmentation Analysis Tool available in the IMPETUS Afea Solver GUI to plot the fragment mass distribution histograms. The resulting plot will reflect the fact that there are many small fragments due to the brittle material and behavior of the hand grenade.
Another scenario that could be considered would be to move the grenade to the side of the vehicle and also include a spall liner to investigate the liner's response to the fragments.

The model presented is available from CertaSIM, LLC by contacting support@certasim.com.

References:

[1] NATO/PfP, "Procedures for Evaluating the Protection Level of Armoured Vehicles – Volume 1: Kinetic Energy and Artillery Threat", August 2011, AEP-55, Volume 1 (Edition 2).

[2] NATO Standardization Agency, "STANAG 4569 (Edition 2) – Protection Levels for Occupants of Armoured Vehicles", 18/12/2012.

[3] J. Rasico, C. Newman and M. R. Jensen, "Modeling Fragmentation of a 155MM Artillery Shell IED in a Buried Mine Blast Event", International Journal of Vehicle Performance, In Press:
http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijvp

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Both the Hand Grenade Model and the HUMVEE Vehicle model were developed by MDG Solutions, Inc., under contract with CertaSIM, LLC.

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Jens Kristian Holmen is a researcher at the Center for Advanced Structural Analysis (SFI CASA) at the Norwegian University of Science and Technology (NTNU). At present, he mainly works with material calibration procedures and simulations of ballistic impact. He holds an MSc degree in Structural Engineering from NTNU and has spent a year as a visiting graduate student at UC Berkeley. After graduating in 2012, he worked for one year as a consulting structural engineer in Oslo, Norway. In 2013, he started his PhD dissertation "Modeling and Simulation of Ballistic Impact", which he defended in 2016. His dissertation was on evaluating novel numerical techniques and their potential for predicting the behavior of complex structures subjected to ballistic impact. He is familiar with most of the features of the IMPETUS Afea Solver®. Lately, his research focus has shifted to the general behavior of metallic materials and how to effectively calibrate material models. We are grateful that Dr. Holmen accepted our invitation to write about his experience with simulating fragmenting target plates.

"When it comes to ballistic impact and perforation of metal plates, most experimental campaigns show that you should increase the target strength if you wish to stop a high-speed projectile. But increasing the strength of the material without considering its ductility increases the probability of fragmentation and material ejection during the perforation process. Target fragmentation is unfavorable. Not only does it reduce the structure's capacity due to a reduced target thickness, but it induces a spray of secondary projectiles or fragment ejecta behind the protective target plate.

What piqued my interest in simulation of fragmentation was a serendipitous observation during a large experimental test series where plates of different tempers of aluminum alloy AA6070 were subjected to ballistic impacts (impact velocities from 200 m/s to 900 m/s) by a selection of projectiles. The tempers (O, T4, T6, and T7) were designed to exhibit varying yield stress, work hardening behavior, and ductility, while at the same time keeping the grain structure unaltered. We soon discovered that our normally reliable and standardized finite element models were not able to capture the trends from the ballistic tests. The simulations of the weak and ductile tempers were accurate, but when the strength increased and the ductility decreased, the simulations started overestimating the capacity of the plates. It turned out that the simulations overestimated the capacity because they simply could not predict target fragmentation, which was one of the dominant perforation mechanisms in the tests of the high-strength aluminum plates.

Material failure and fracture are essential in numerous engineering applications (including ballistic impact). Hence, failure initiation criteria are plentiful in literature. Some approaches utilize a failure locus, some are driven by plastic strain, while others are driven by void growth. When it comes to introducing failure into a numerical simulation, it is element erosion, otherwise called element deletion, which is the most common method. Conventional simulations with element erosion require a fine element mesh to give consistent results. To capture fragmentation, an even finer element mesh is required, preferably in combination with a statistically based failure criterion. In my experience, a good correlation between conventional simulations and respective experiments involving fragmenting target plates is nearly impossible to obtain.

An alternative to conventional methods is "Node Splitting". Three-dimensional Node Splitting is available in the IMPETUS Afea Solver® and is a conceptually straightforward improvement of element erosion. Instead of deleting an element at material failure, you split the nodes and create new element surfaces. Invoking Node Splitting does not require remeshing of the model, just setting a flag in the input to tell the Solver to allocate the appropriate amount of memory. By invoking the ASET™ Element Technology that provides accurate high order finite elements, in combination with Node Splitting, a coarse mesh can be used. The higher order cubic ASET™ elements can accurately describe extreme deformations with a rather coarse element mesh without being plagued by issues like element inversion. Three-dimensional Node Splitting technology allows for crack growth between large elements while conserving mass and energy throughout the simulation. Due to the large elements and GPU Technology for massively parallel processing, the model run (clock) times are more than reasonable. More importantly, we found that this approach predicted the correct perforation mechanism from our tests. The visual correlation between the ballistic tests and the simulations using the ASET™ elements and Node Splitting was excellent, not only for the strong/brittle target plate, but also for the weak/ductile target plate. In contrast, conventional element erosion could only describe the ductile perforation mechanism. Being able to predict the correct perforation mechanism, whether it was ductile hole growth or fragmentation, meant that the accuracy of the predicted target plate capacity was significantly improved with the ASET™ elements and Node Splitting.

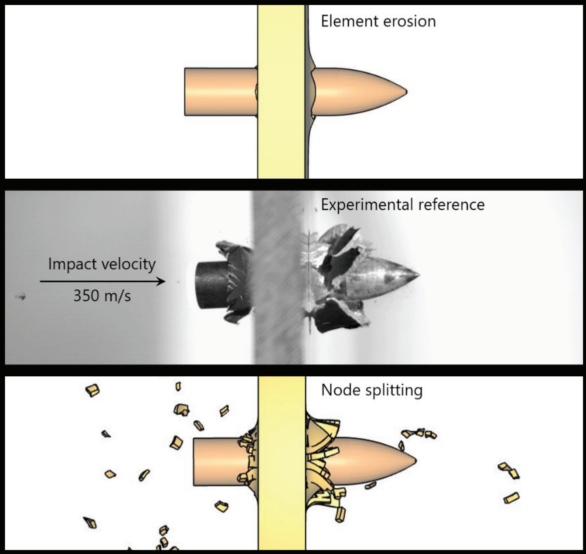
There are still challenges related to the use of Node Splitting when it comes to describing this type of target fragmentation. Since 3D Node Splitting is a new feature in commercial codes, it has not been tested and validated to the same extent as element erosion. In certain cases, such as plugging dominated problems, a more refined mesh may be required to ensure sufficient resolution of the crack path. This will affect the runtime but the benefit of avoiding element erosion more than makes up for the artificial loss of mass. I would not hesitate to use the combination of ASET™ elements and Node Splitting in my simulations of ballistic impact. In my experience, it gives just as good, or better, results compared to other methods, especially when fragmentation is involved. By refining the crack propagation algorithms and delamination laws that control how fast and in which direction the crack grows, the 3D Node Splitting Algorithm becomes increasingly effective and advantageous. This opens additional areas of application. As an example, Node Splitting can be used to simulate windshields and security glass that are frequently designed to withstand extreme loads. Here, predicting correct initiation of fracture is important, but so is the propagation of the cracks, delamination of the security glass, and the fragment velocity and size distributions.

To predict the correct capacity of a component or structure, it is essential to describe the correct failure mode. For ballistic impact, the correct perforation mechanism must be captured by the simulation to obtain an accurate prediction. The accuracy of the prediction is dependent on the constitutive model, failure criterion, element size, and numerical parameters such as friction, but also on the finite element solver. I have experienced that ASET™ Element Technology combined with Node Splitting captures the correct perforation mechanism in ballistic impact problems. This improves my simulation results and ensures better correspondence with the experimental test data."

Additional Reading:

J. K. Holmen, J. Johnsen, O.S. Hopperstad and T. Børvik, "Influence of fragmentation on the capacity of aluminum alloy plates subjected to ballistic impact", European Journal of Mechanics A/Solids 2016, 55: 221-233.

J. K. Holmen, J.K. Solberg, O.S. Hopperstad and T. Børvik, "Ballistic impact of layered and case-hardened steel plates", International Journal of Impact Engineering 2017, 110: 4-14.



Fragmentation Analysis in the IMPETUS Afea Solver GUI

Due to the increased use of the IMPETUS Afea Solver® for fragmentation studies, new tailored options for this application have been developed for the IMPETUS Afea Solver GUI. These options save significant time, increase productivity and reduce risks for errors encountered when manually processing fragmentation data.

Fragmentation data is written to the binary imp files when *fragment*=1 is set in *OUTPUT.

OUTPUT

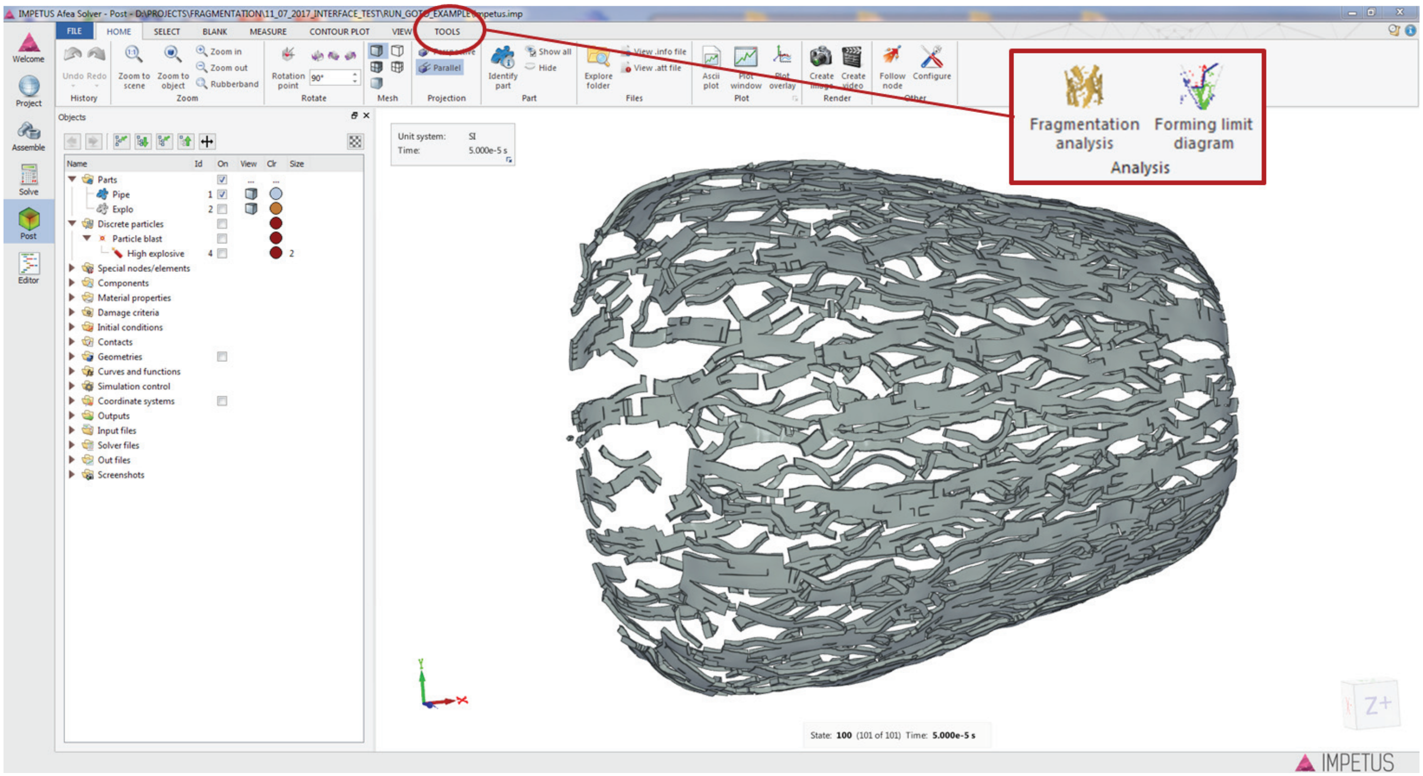
Output

```
*OUTPUT
Δt_imp, Δt_ascii, Δt_db, fragment
nfilter, efilter, entype_res, enid_res
```

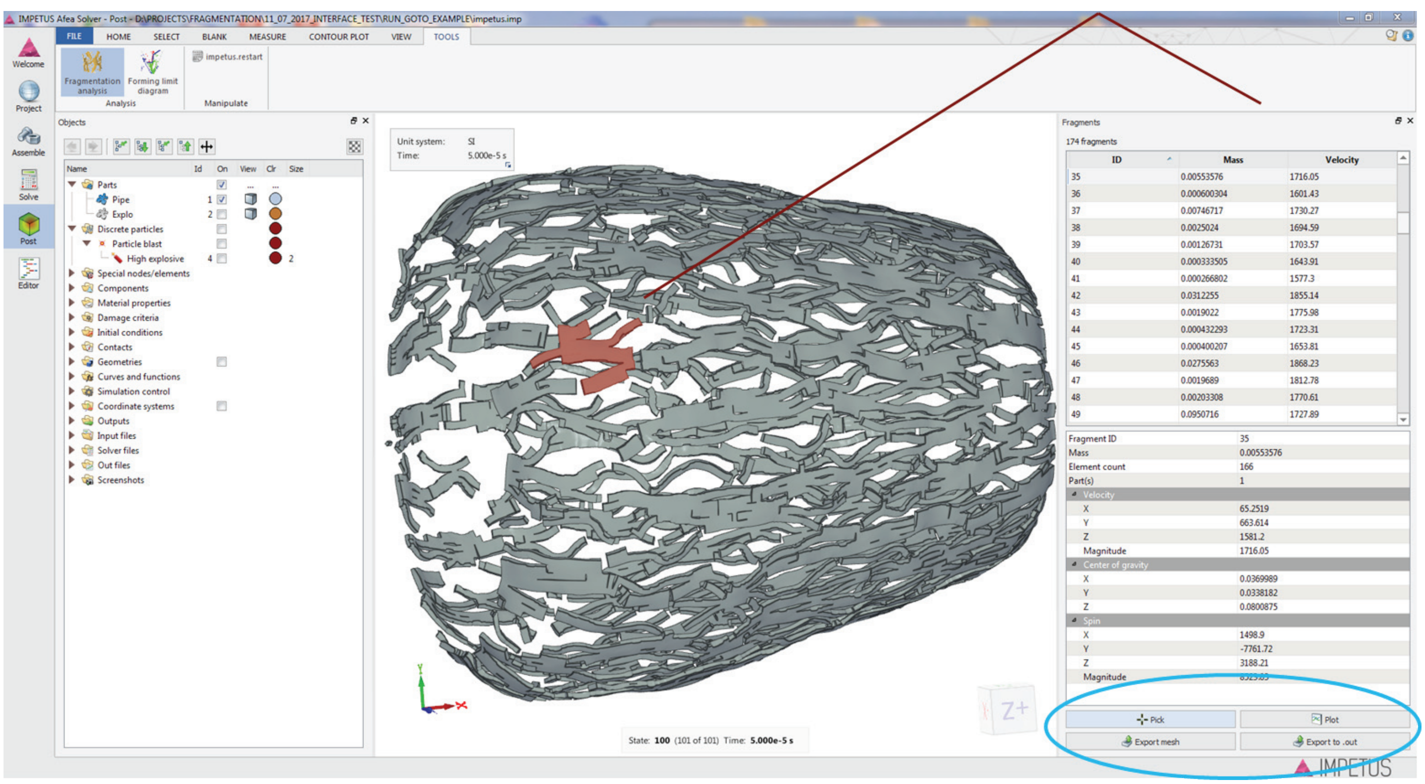
Parameter definition

Variable	Description
Δt_{imp}	Output interval for complete model (.imp-files) *default:* $\Delta t_{imp} = t_{term}/100$
Δt_{ascii}	Output interval for ASCII data (see list of .out-files in General section) *default:* $\Delta t_{ascii} = t_{term}/1000$
Δt_{db}	Output interval for model database and state files. No database or state files will be output if Δt_{db} is larger than t_{term} (see TIME) *default: a database file is generated at* t_{term}
$fragment$	Flag to activate fragment list generation (only applicable when having node splitting activated) *options: 0 (no fragment list generation), 1 (fragment list is written to .imp-database)*

With this algorithm activated the post-processing is done in the usual manner and the Fragmentation Analysis can be selected from the Tools Menu. 

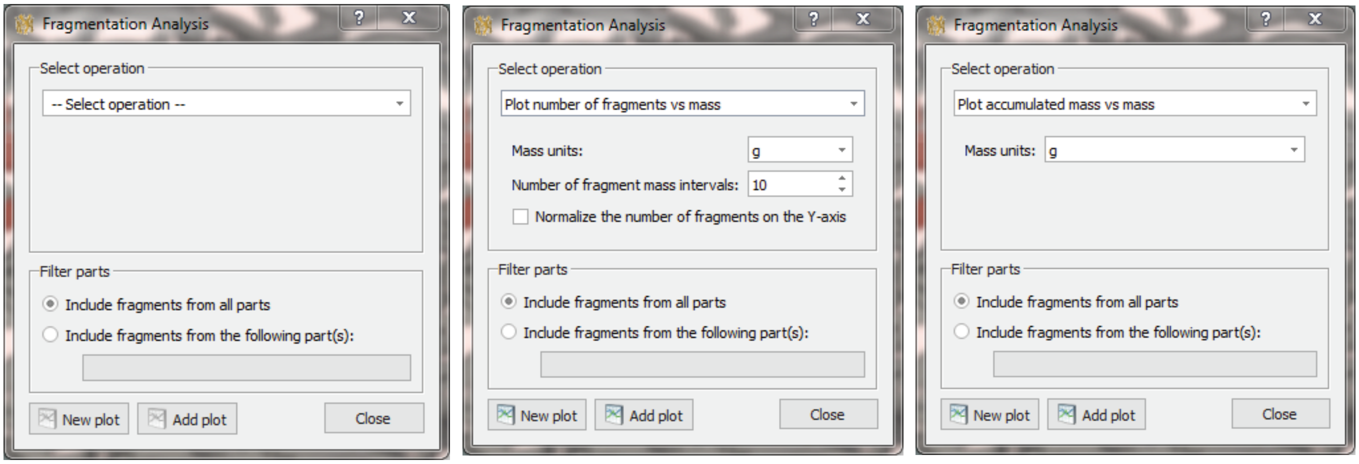


The interface for the Fragmentation Analysis brings up a list of fragmentations for the given state and shows the information about each fragment. The information is location, velocity, COG, mass, etc. One can interactively click on a fragment in the graphic window. The fragment is then highlighted both on the model as well as in the list.

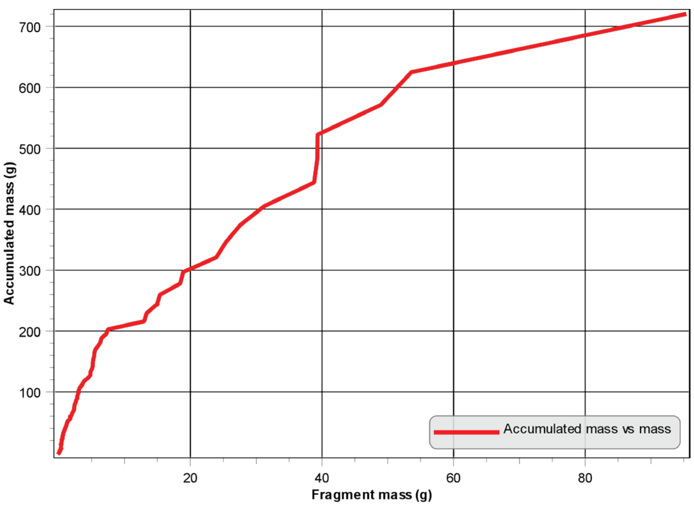


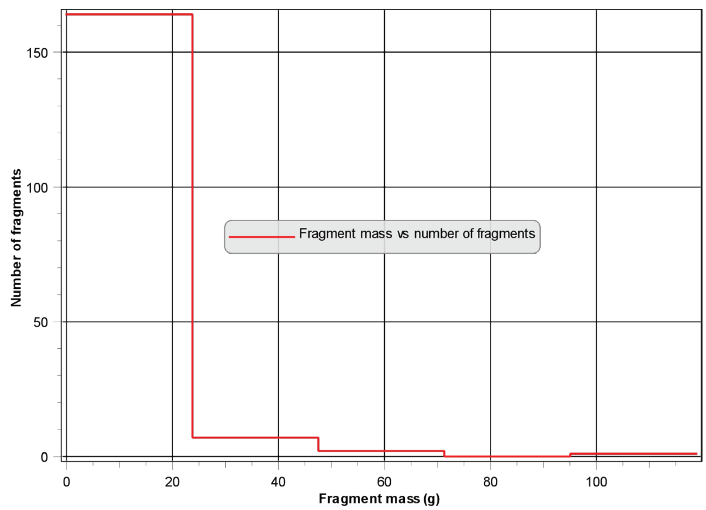
There are specific plots that are often used when characterizing a fragmentation process. Among these are the Number of Fragments versus Mass and Accumulated Mass versus Mass.

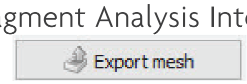
These are implemented in the new Fragmentation interface. The number of fragment intervals can be set along with normalization of the curve.



The plots will appear in the regular plot interface and can be edited, printed, saved, etc.

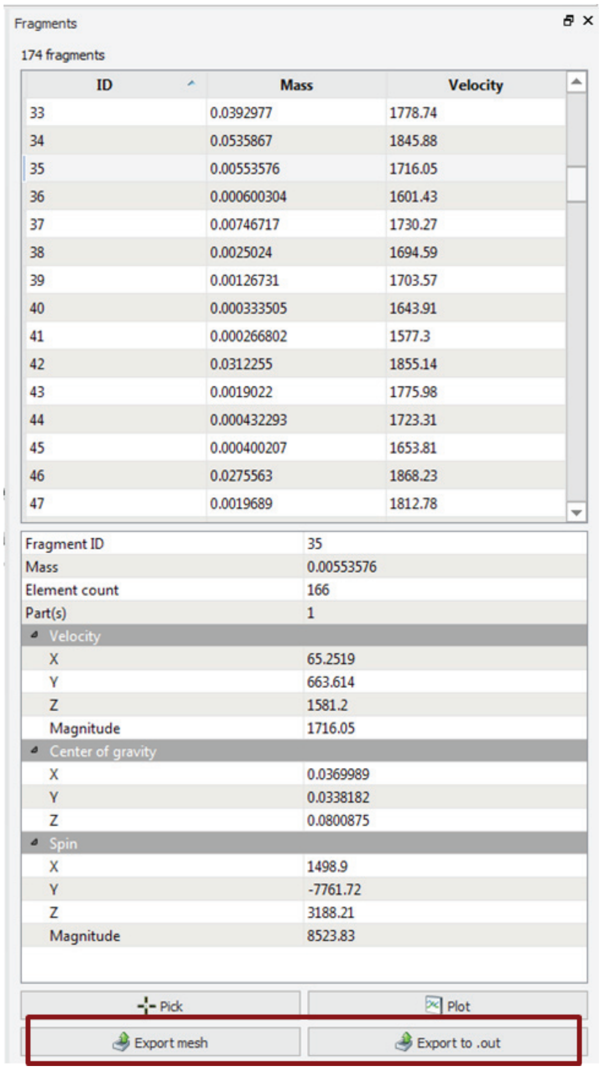


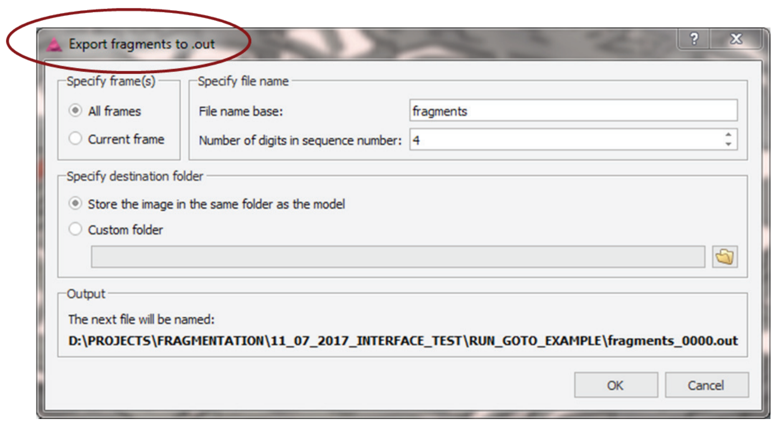


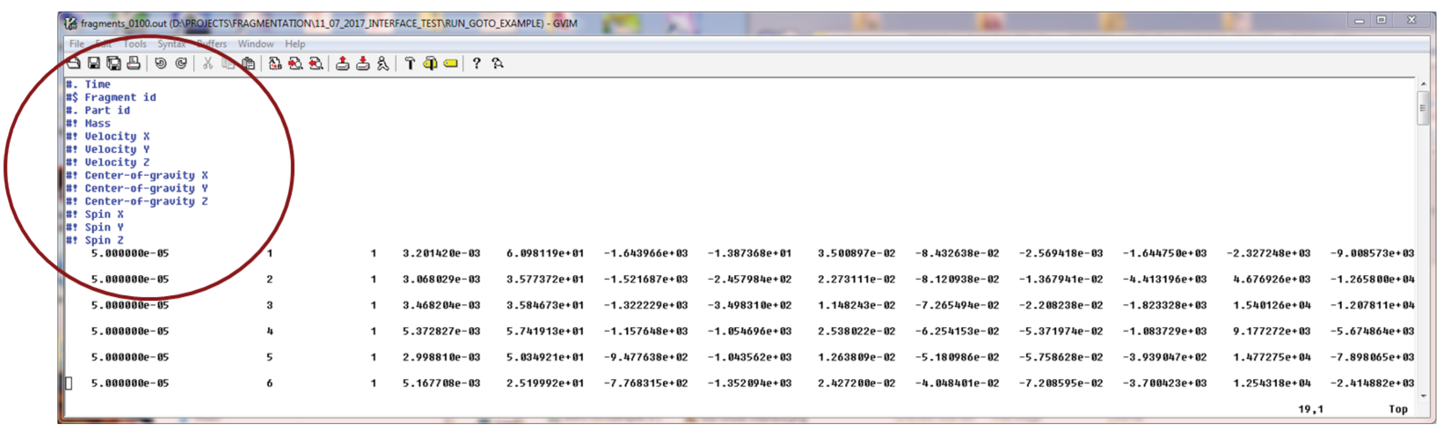
Often in the design phase different configurations of a structure are validated to optimize the performance of the structure. If the engineering task is to design a structure to be resistant to impact from fragments, then it can be beneficial to only model the fragmentation process once and then use this information in a second step to run with different designs. That is, to have the size, mass and velocities of the fragments from the fragmentation process and let them impact a different structure. This is done by exporting the data from the first simulation. This option is available in the Fragment Analysis Interface. At the bottom of the Fragment List Interface there are two options, Export to mesh 

and Export to .out 

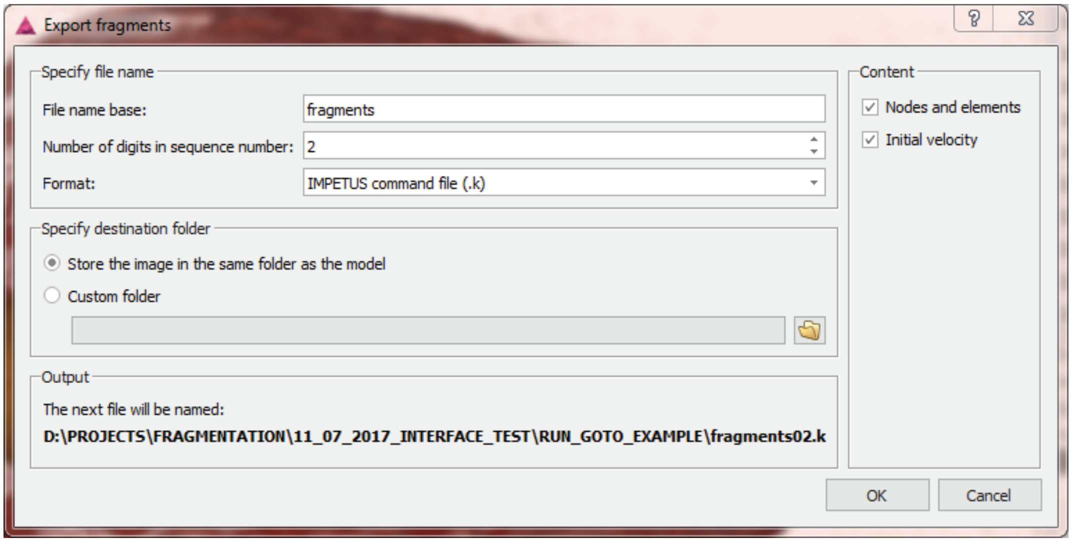
. The later generates an ASCII file with a list of the fragments and their relevant attributes. One can select to write a file for the current state only or write files for all states with one file for each state in the model.



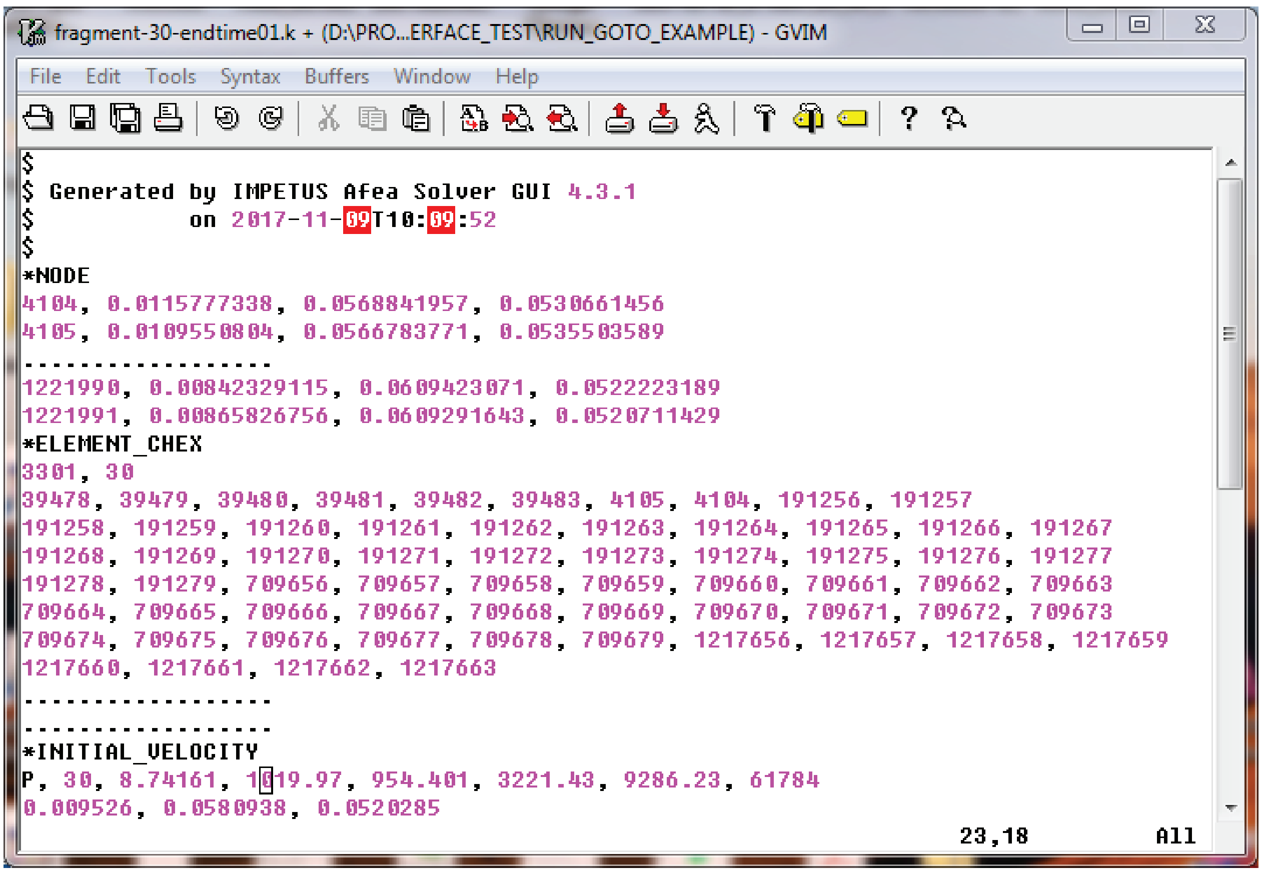




The other option of exporting the mesh includes the option of include or exclude nodes/elements and initial velocities.



The file is written for the selected time, determined by the current state shown in the graphic window. One selects the fragments to use, so it is very flexible.



Notice that each fragment has a unique Part ID which has to be specified in the command file. This means a *PART and *MAT command needs to be specified for each fragment. However, the IMPETUS Afea Solver® has a very flexible and easy way to do this in a few lines instead of thousands of identical commands. As input simply use:

```
*PART
[1..MaxID], MID
```

Where MaxID is the ID number (Part ID) of the last fragment. The MID is only defined once to reference the *MAT_option which is the material model applied in the first run.