the CertaSim SOLUTION™

Featuring:

Ballistic Modeling

Q1 - Q2

2018

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News and Events

CertaSIM at GTC-Nvidia Conference

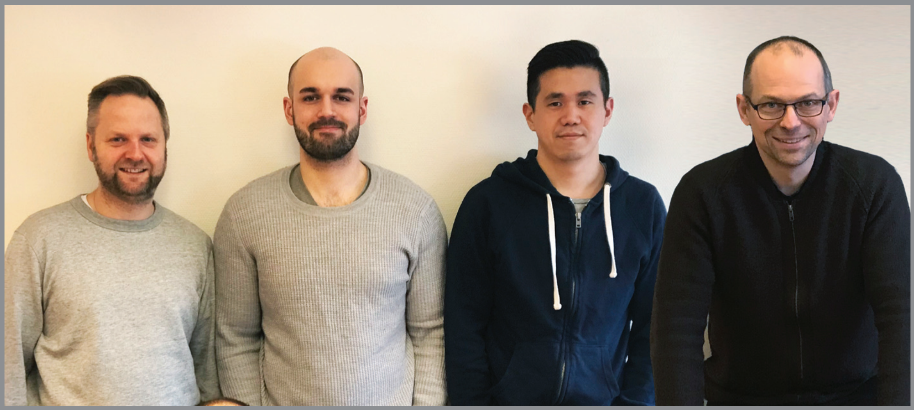
The NVIDIA GTC2018 Conference was held March 26-29th at the San Jose Convention Center. This is the 7th year that CertaSIM has attended the conference and participated in the technical sessions. Dr. Mindle, CertaSIM's Director of Sales & Marketing presented a paper entitled "Multi GPU Parallel Processing with NVLINK". The presentation is available from CertaSIM and NVIDIA also records the audio from the presentation and makes it available to hear online. GPU technology is at the heart of the massively parallel processing capability of the IMPETUS Afea Solver® and so keeping up with the current GPU hardware is a must for CertaSIM.

10th Ground Vehicle Systems Engineering and Technology Symposium (GVSETS)

Showplace in Novi Michigan. (http://www.ndia-mich.org/events/gvsets).
The conference includes participants from DoD, TACOM, Research, Development and Engineering Command (RDECOM), Program Executive Offices (PEOs) for the Army and the Marine Corps for ground vehicles as well as leaders from industry and academia. The trade show has grown considerably over the last 4 years and provides a great venue to meet many of the companies that work with the US Army with regard to ground vehicle development. The overriding tone of the conference is the mission to design and build vehicles to better protect the "Warfighter". One of the highlights of the non-technical sessions is the panel of warfighters which brings together combat experienced warfighters to discuss the pluses and minus of the current technology and what they need to better carry out their mission. CertaSIM will attend the conference and hope to see many of you there.

CertaSIM's CTO Visited the IMPETUS Office in Sweden

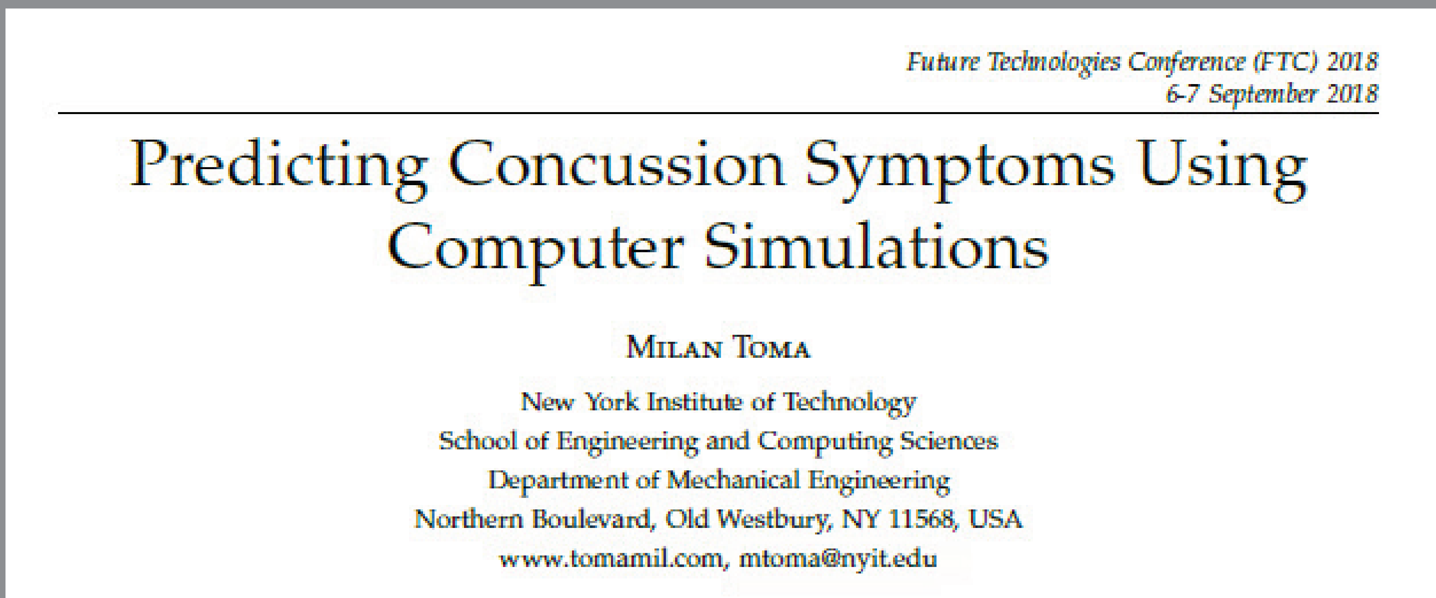
Again this year, CertaSIM's CTO, Dr. Morten Rikard Jensen visited the IMPETUS Research and Development Center in Huddinge just outside Stockholm, Sweden. The main focus during his three weeks stay was further development of the IMPETUS Hybrid III 50th Percentile Male Blast ATD. The visit included discussions about side blast on vehicles and newly developed techniques to reduce re-meshing when modeling the process of metal rolling.



"It is important that our customers know that CertaSIM has direct access to the IMPETUS Afea development teams in both Sweden and Norway. During these visits we are a part of the IMPETUS office and are included in brainstorming sessions to discuss new options for the Solver. The second benefit is the opportunity to interact face to face and learn from their in-depth knowledge about the Solver. For our customers this improves our ability to provide a high level of technical support and to discuss your suggestions and future requirements for the software. We are very grateful to our Swedish colleagues for their hospitality and willingness to share their knowledge.", said Dr. Jensen.

Future Technologies Conference 2018

Dr. Milan Toma's work on modeling the human brain subjected to impact will be presented at the next "Future Technology Conference" (FTC) which takes place November 13-14, 2018, in Vancouver, BC, Canada. The work was conducted at New York Institute of Technology where a detailed brain model has been developed using the IMPETUS Afea Solver® The structural part takes advantage of the accurate high order elements and the Cerebrospinal Fluid is modeled with the γSPH Solver. The paper is entitled "Predicting Concussion Symptoms Using Computer Simulations".



Future Technologies Conference (FTC) 2018
6-7 September 2018

Predicting Concussion Symptoms Using Computer Simulations

Milan Toma

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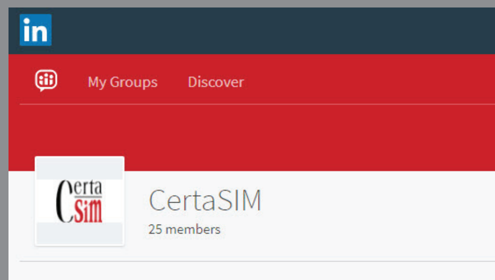
The validation of the numerical work was done with experimental work in the form of pressure responses.

CertaSIM's CTO Visited IMPETUS SAS Office in France

At the IMPETUS SAS office in Toulouse, France the γSPH Solver is developed and the company is a Software Development Partner to IMPETUS Afea. They are also a distributor of the IMPETUS Afea Solver. Dr. M. R. Jensen, CTO of CertaSIM met with his counterpart at IMPETUS SAS, Dr. J. Limido in a three day visit where he discussed the latest development of the γSPH Solver. This included Hydroplaning, Hypervelocity, Water-Slamming and Shaped Charge Modeling. Ideas about marketing, support and collaboration possibilities were discussed. "The γSPH Solver can really solve some very difficult problems and I am always very impressed with its performance in both accuracy and speed. As an example, take their modeling of a Shaped Charge which is extremely difficult to do with legacy solvers but is very easy to setup and runs very fast. I appreciate that the Team took the time for the meetings and on top of that showed me their beautiful city of Toulouse." - Dr. M. R. Jensen.

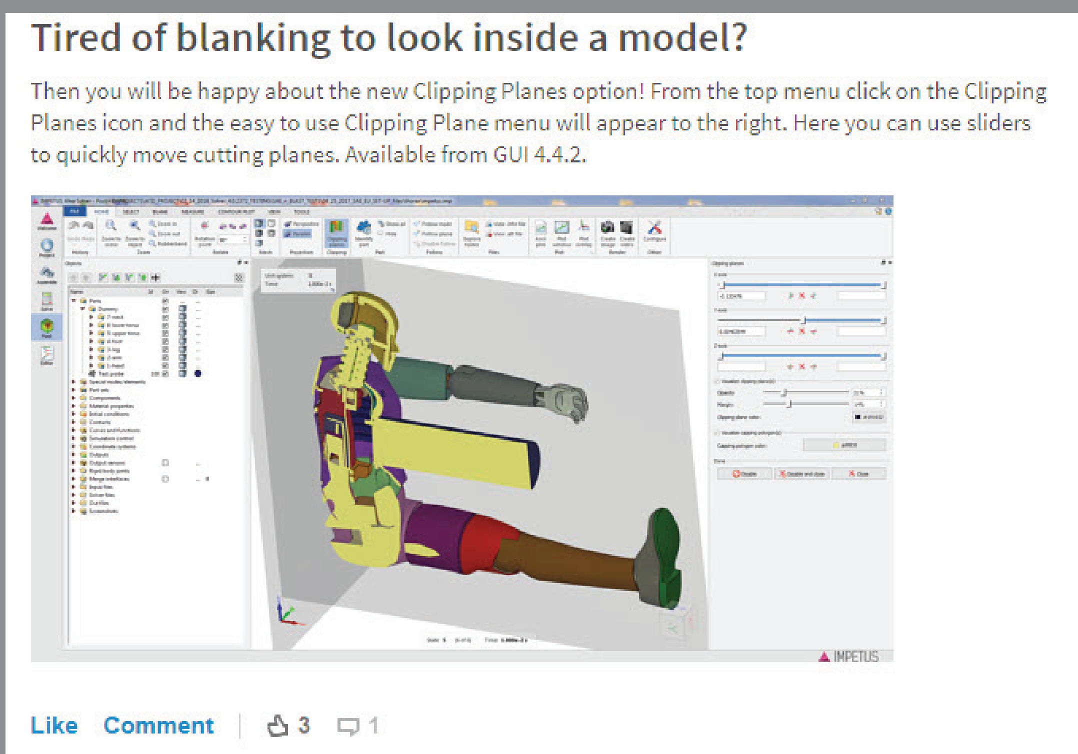
CertaSIM LinkedIn Group – Keeps You Informed

The number of members in the CertaSIM, LLC LinkedIn Group keeps growing!



If you have interest in the IMPETUS Afea Solver® or even better are a user of the Solver, then don't miss out on signing up for the group. New features and modeling tips are discussed, creating an interactive platform for support.
Find it at LinkedIn:

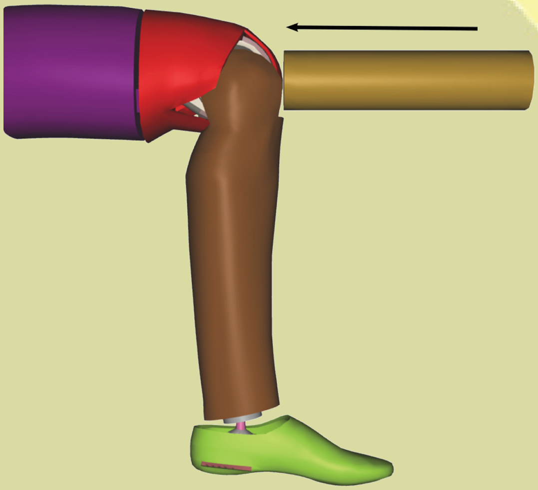
https://www.linkedin.com/groups/4746846

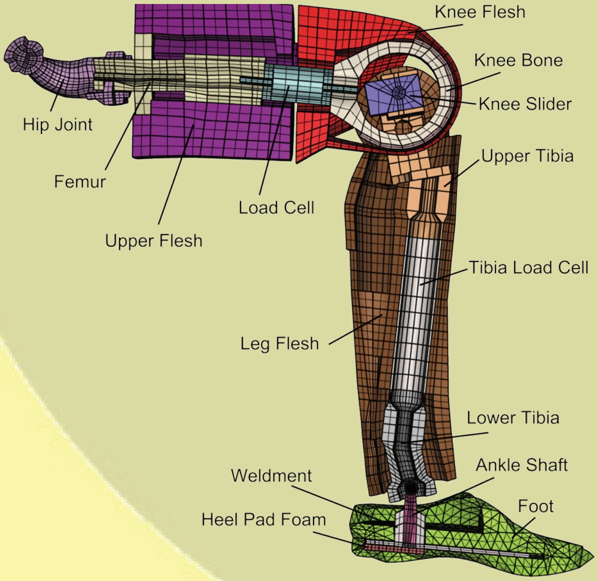


ATD Calibration for Crash – Knee Impact Test

With continued military conflicts in the world one of the most dangerous situations for the warfighter is the attack from an Improvised Explosive Devices (IEDs) which results in extensive damage to their vehicles and therefore a threat to their life. 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 Knee Impact Test.

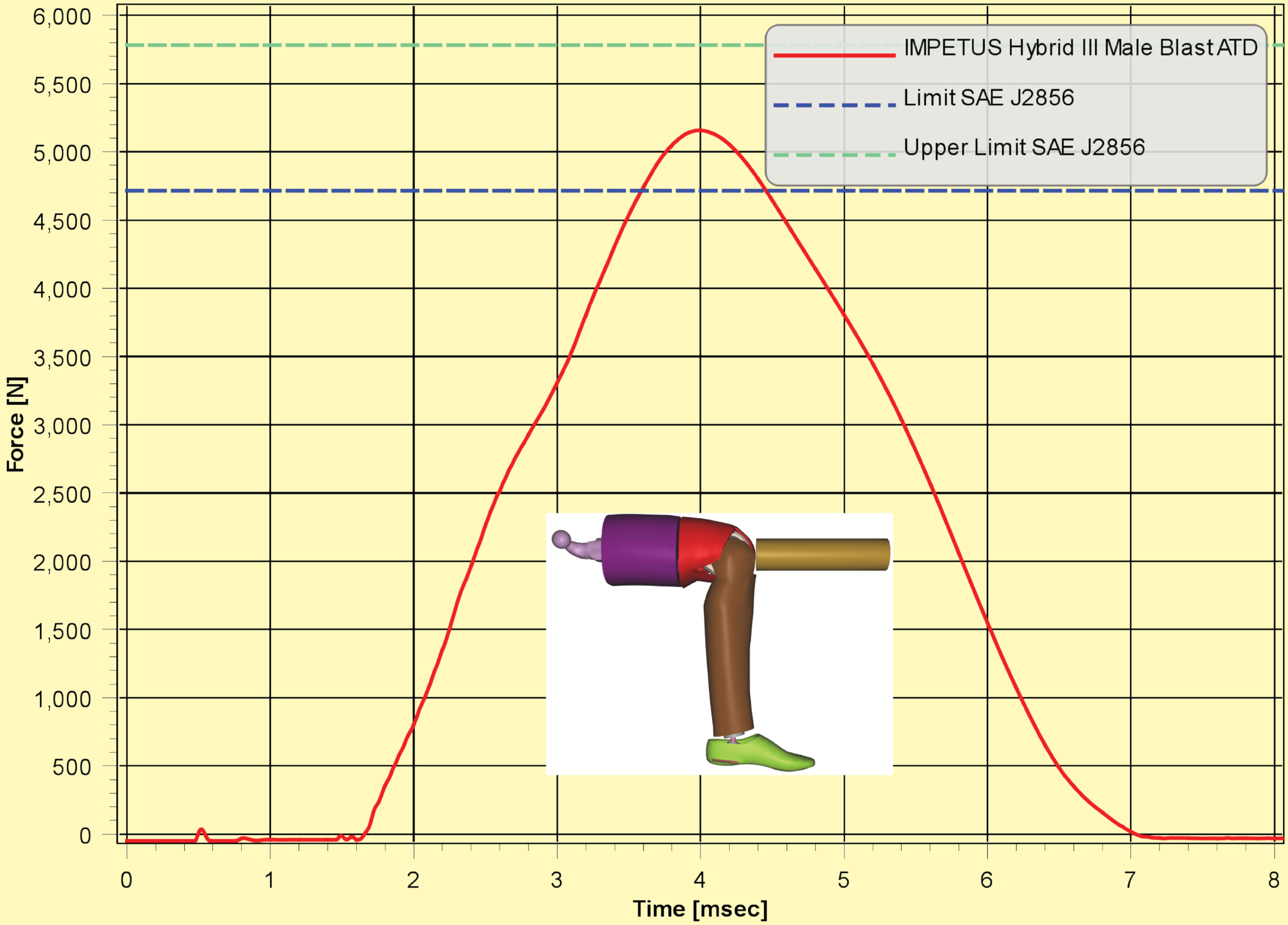
The Knee Impact Test is defined in [1]. The leg is impacted by a 5 kg rigid probe with an impact velocity of 2.1 m/s.





The knee assembly consists of several parts where some of the optional parts mentioned in the standard [1] are selected for the model. The main parts involve the knee components: knee flesh, cap, bone, etc. since the test focuses on behavior of the knee from a frontal impact.

The impact force is used as the response parameter for calibration of the model. The peak force on the knee needs to be between 4715 N and 5782 N. The results are found in the file *rigid.out*. The results come from the force in the global X-direction for part number 1. The maximum value of the force is well within the limits given with the peak at 5157 N.



Additional information about the IMPETUS Model for this test can be found in [2] which also covers the blast calibration done on the IMPETUS Afea Blast ATD.

References:

[1] SAE International J2856 September 2009, "User's Manual for the 50th Percentile Male Hybrid III Dummy".
[2] M. R. Jensen, "The IMPETUS Hybrid III 50th Percentile Male Blast ATD", CertaSIM Report # CS-0052-09012017.

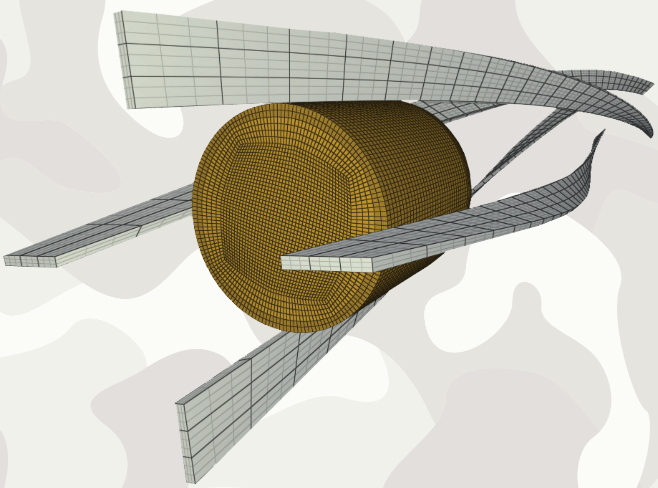
Modeling Engraving of a Small Caliber Projectile

When firing a firearm the projectile travels through the gun barrel and during this event there is a tight contact between the projectile and the barrel. There can be a large amount of friction in this contact which can lead to wear of the barrel. Furthermore, the travel down the barrel can have significant influence on the behavior of the projectile when it exits the barrel affecting the velocity and motion before impacting a target. As a result this can influence the efficiency of the weapon and thus advanced Finite Element modeling of the process can improve the weapon design phase.

CertaSIM, LLC completed a project with the US Army ARDEC Picatinny Arsenal to demonstrate how the IMPETUS Afea Solver® can accurately model engraving of a projectile. The project involved engraving of a small ammunition copper bullet.

Engraving is a process categorized under Interior Ballistics and is described as the phase where a projectile travels through the weapon barrel. This interference can apply a significant load to the barrel and in extreme cases lead to cracking and failure of the barrel [1]. Understanding this process is of virtual importance when designing weapons and projectiles. This knowledge is best acquired with a combination of numerical and experimental analyisis.

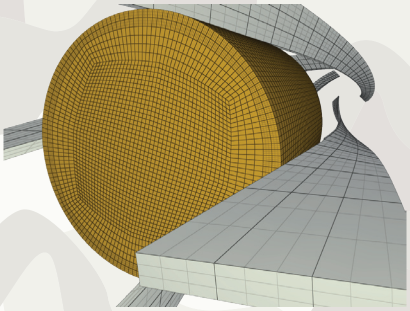
The Rotation Band (Driving Band) on the projectile provides a seal to prevent gasses from passing around the shell. The Rotation Band is often made of a soft material and can deform significantly. For small caliber ammunition, the whole projectile often has a copper jacket and hence it is a Rotation Band in itself.

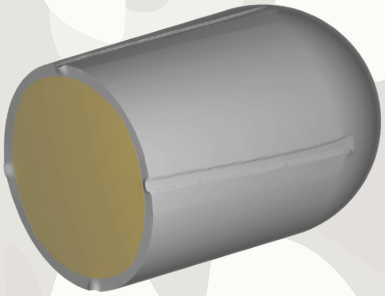


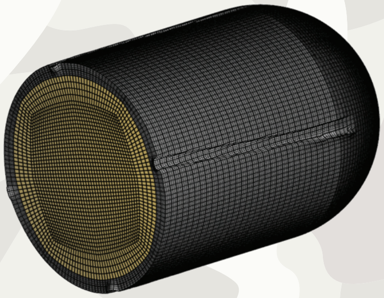
Engraving is very difficult to model in Legacy Finite Element codes, especially due to the use of linear elements that cannot provide accurate contact during the process. In [2] many of these issues are highlighted through the use of LS-DYNA®†, where the danger of having to include hourglass control is clearly observed and described. Stiffness based hourglass control gave poor stress behavior and viscous based hourglass control led to a bad energy balance. As stated in the paper the use of fully integrated elements was not possible since it increased the computational time by 40%. In [3] it is illustrated how the different element types, shells versus solids in Abaqus††, strongly effected the Bore Resistance Curves as well as the problem of significant contact noise.

The projectile in the ARDEC/CertaSIM test case has a diameter of 0.25 inches and hence it is small caliber ammunition and the projectile itself is then the Rotation Band. The motion is defined by an applied pressure history curve at the backend of the projectile. It travels inside the barrel and makes contact with the Lands that have a width of 0.0106 inches. For this, mesh refinement is important where the Lands contact the side of the projectile and if impact with a target is modeled, then the front of the projectile is also a critical area for mesh refinement.

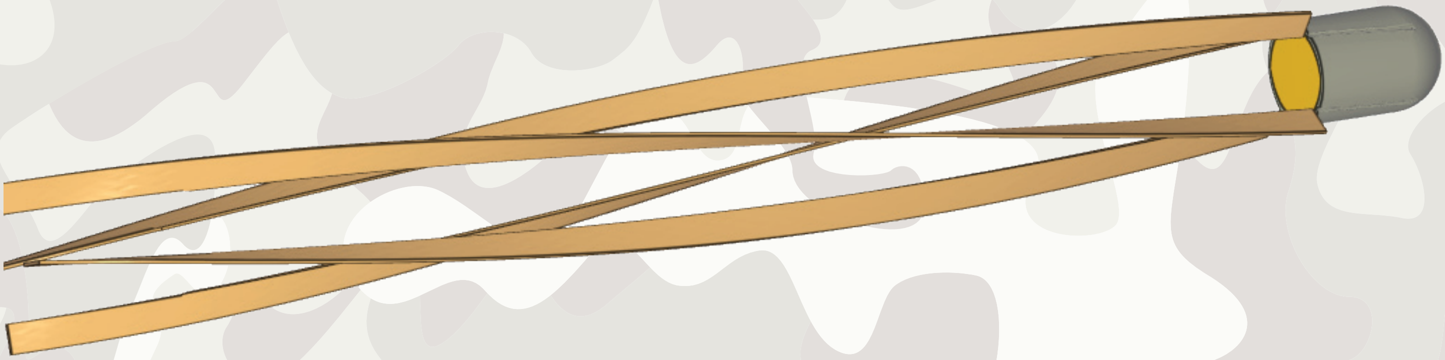
The projectile is modeled with two layers of cubic ASET™ Elements along the surface to capture the deformation and the core is represented by linear elements. The scoring of the projectile is clearly observed and the engraving is very smooth which would not be possible if linear elements had been used for the projectile surface.







The IMPETUS model utilized GPU Technology using a NVIDIA P6000 GPU processor that resulted in the whole scoring process taking only 2 hours and 20 minutes. This is to be compared to the timing for engraving models listed in [4] where a LS-DYNA® run took 96 hours on a 4 CPU machine and [3] a reported 6 hr 50 min runtime for a linear element Abaqus run using 32 cores.



Future Research includes a sensitivity study of the friction with reference to the work done by Montgomery [5] and study of Wear in the contact where the IMPETUS Wear function will be used as a part of the objective function in design optimization of the barrel. The test example is for small caliber ammunition but it is natural in the future to model large caliber guns with Rotating Band and include a study of Wear for them as done in [6].

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

References:

[1] T. D. Andrews, "Projectile Driving Band Interactions with Gun Barrels", Journal of Pressure Vessel Technology, May 2006, Vol. 128, Page 273-278.

[2] J. South, B. Powers and M. Minnicino, "Evaluation of Computational Techniques for the Engraving of Projectiles", Computational Ballistics III, WIT Transactions on Modelling and Simulations, Vol. 45, 2007, Page 193-202.

[3] R. Chaplin and D. Gubernat, "Factors Affecting Bore Resistance in the Structural Analysis of Interior Ballistics", 29th International Symposium on Ballistics, Edinburgh, Scotland, UK, May 9-13, 2016, Page 905-916.

[4] Q. Sun, G. Yang and J. Ge, "Modeling and Simulation on Engraving Process of Projectile Rotating Band Under Different Charge Cases", Journal of Vibration and Control, 2015, Page 1-11.

[5] R. S. Montgomery, "Friction of Rotating Band Material During Engraving and Initial Projectile Travel", Technical Report ARLCB-TR-78002, US Army Armament Research and Development Command, 1978.

[6] B. Wu, J. Zheng, Q. Tian, Z. Zou, X. Chen and K. Zhang, "Friction and Wear Between Rotation Band and Gun Barrel During Engraving Process", Wear 318 (2014) 106-113.

Notes:

† LS-DYNA® is trademark of Livermore Software Technology Corporation.
†† Abaqus is a trademark of Dassault Systèmes.

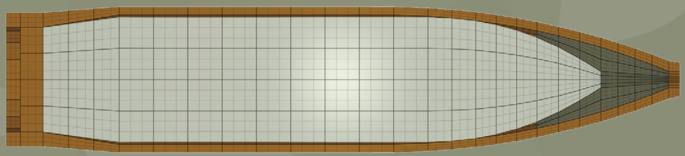
Ballistic Penetration of Armox 500T

Resistance to ballistic penetration of military vehicles is as important as protecting against a buried mine. Fragmentation that results from ballistic impact is a scenario that has engineers looking for effective solutions. Armox high strength steel is one solution that has been used and the IMPETUS development team has developed recommended modeling practices to guide users in developing their models.

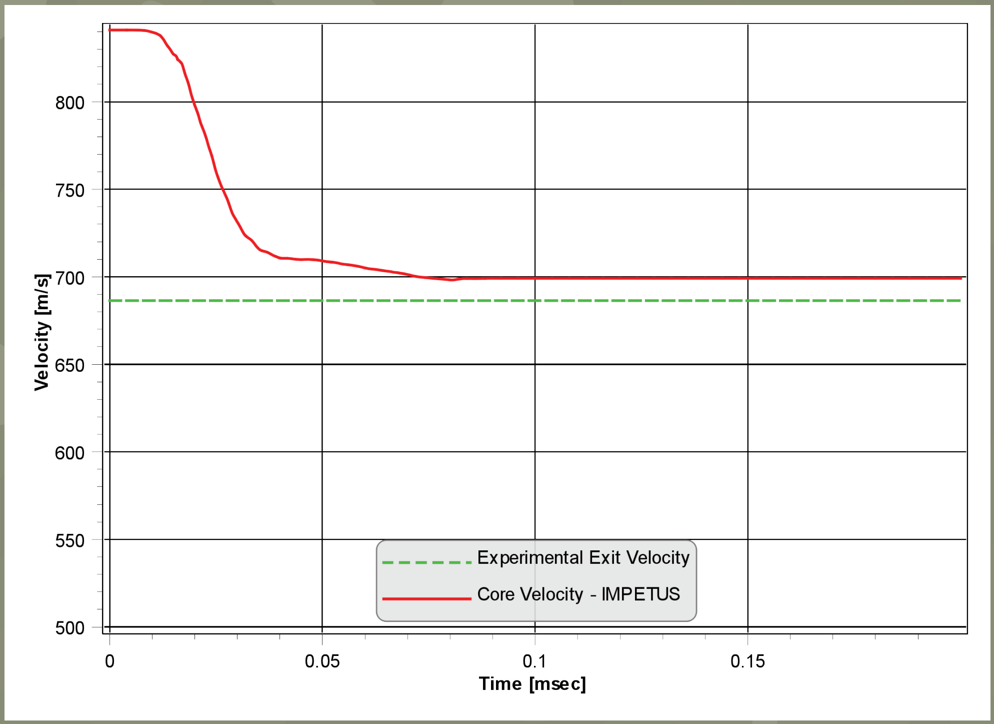
In search of improved ballistic performance the Armox materials were developed. They are produced by Swedish Steel AB, Sweden also known as SSAB. Taken from the product datasheet for Armox® 500T [1] it states: "Armox® 500T is the world's toughest protection plate, having nominal 500 HBW hardness, for use in vehicles, buildings and many more applications." These materials have high toughness as well as very high hardness and are used in vehicles. As mentioned in [2] the influence of the hardness on the ballistic behavior for armor materials is not new but was already shown in 1995 by Rapacki [3] at the International Symposium on Ballistics where it was found that penetration resistance is a non-linear function of hardness. Experimental testing results are showcased in [2] and [4] where V50 results are presented.

In order to take full advantage of Armox, as with any material, it must be modeled accurately. Finite Element modeling of ballistic events is not an easy task since it involes large deformation, strain rate effects, temperature and strong non-linear behavior just to mention a few of the challenges. The work presented in [5] has a set-up where the Strike Face is Armox® 500T. In their numerical work they used Abaqus/Explicit† and had early on to convert the Lagrangian elements to SPH particles due to the behavior of linear elements under large deformation. It continues to say that the use of the SPH particles led to "a rapid increase in computing time".

IMPETUS Recommended Modeling Practice # 5 [6] is about verification of ballistic impact models. In total seven different references are investigated and many test cases are developed based on these, resulting in a large span of different setups. One of them is the work by Iqbal [7] where Armox® 500T is studied by considering 15 different cases. Among these is the setup of a 10 mm thick plate which is impacted by a 12.7 mm Armor Piercing Incendiary with a Strike Velocity of 841 m/s. It is a three part bullet with a jacket, core and tip. The experimental Residual Velocity is listed as 686.4 m/s.



The mesh was created so that the high order cubic elements are used wisely in order to optimize the computational time. Also, quarter symmetry is applied in this model. The simulation results compared very well with the experimental data with only a 1.85% difference, well within the experimental scatter.



Further information about this ballistic event can be obtained by contacting support@certasim.com.

References:

[1] SSAB, "Data sheet 195 Armox 500T 2017-04-19", SSAB, Sweden. Downloaded online.

[2] D. D. Showalter et al., 2008, "Ballistic Testing of SSAB Ultra-High-Hardness Steel for Armor Applications", Army Research Laboratory Report# ARL-TR-4632.

[3] E. J. Rapacki et al., 1995, "Amor Steel Hardness Influence on Kinetic Energy Penetration", 15th International Symposium on Ballistics, 21-14 May, Jerusalem, Israel, 1995.

[4] W. A. Gooch et al., 2004, "Ballistic Testing of Swedish Steel ARMOX Plate for U.S. Armor applications", 21st International Symposium on Ballistics, 19-23 April, Adelaide, South Australia.

[5] V. Shanel et al., 2014, "Ballistic Impact Experiments and Modeling of Sandwich Armor for Numerical Simulations, 37th National Conference on Theoretical and Applied Mechanics and the 1st International Conference on Mechanics.

[6] IMPETUS Afea, "RMP005 – Ballistics - Version: 4.0.2452 - April 26, 2018.

[7] M. A. Iqbal et al., 2016, "An Investigation of the Constitutive Behavior of Armox 500T Steel and Armor Piercing Incendiary Projectile Material", International Journal of Impact Engineering, Volume 96, 2016, Pages 146-164.

Notes:

† Abaqus is a trademark of Dassault Systèmes.

Acknowledgement:

Mr. Marcus Menchawi, IMPETUS Afea AB, Sweden kindly provided the IMPETUS ballistic model shown in this article.

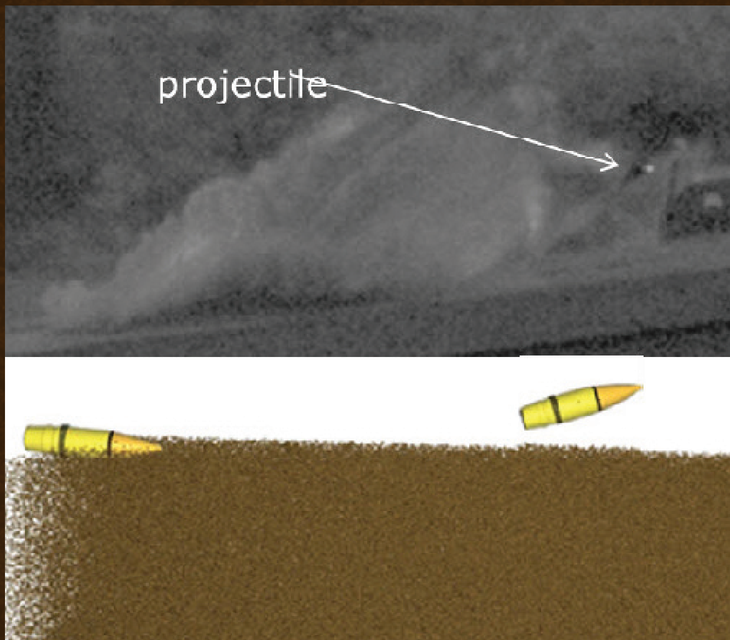
Penetration into Soil

Penetration into soil is an important application area as modern warfighting often involves missile impacting soil. Both on the attack side as well as for defense it is important to know how deep a penetrator travels as well as to assess the impact on a concrete structure buried in soil. The IMPETUS Discrete Particle Method, iDPM, provides the accuracy and ease of setup to model soil penetration problems. It is robust, fast and very easy to set up.

As mentioned in (Carlucci and Jacobsen, 2013) penetration of soils has gained more interest and importance in the terminal ballistics society since more military strong points are buried below grade. However, research in the area of projectile impacting into soil or sand is not new, see the work by Allen and coworkers (1957a),(1957b) it can even be tracked back to 1742 with a formula for penetration depth according to (Børvik et al., 2015). Traditionally, analytical penetration models have been developed, improved and used. These are often empirically based and can result in large errors in the predicted results. As in any other weapon design, numerical models will improve the efficiency if good predictable results can be obtained. However, granular materials comprise three phases – solids, liquid and air – and are often inhomogeneous and anisotropic. They therefore present the designer with a significantly more complex and variable medium than other target materials "Smith and Hetherington (2011)." Numerically it is a very difficult event to model since material is moved creating a path in front of the projectile. Standard Lagrangian models would require a lot of eroded elements and have problems handling the very large deformation. Applying the Abritary-Lagraingian-Eulerian approach is not trivial either, since a very fine ALE mesh is needed and often the soil domain is large, especially if the intent is to model an earth penetrator.

The IMPETUS Afea Solver® has a unique Discrete Particle Method, named iDPM which has been used extensively for modeling buried mine blast but has also been extended to model impact of turf in the golf industry. However, in recent years the feature has been applied to impact into granular materials where the impactor is a bullet, missile, etc. It is computationally fast since it utilizes GPU Technology. An example is the study by Moxnes and co-workers where they modeled penetration into sand, water and gelatin with the iDPM (Moxnes et al., 2016). They compared the performance of IMPETUS iDPM with the use of ANSYS® Autodyn®† and concluded: "Computer time was reduced by one to two orders of magnitudes when applying the Impetus Afea Solver compared to Autodyn code due to the use of the graphics processing units (GPU)." (Moxnes et al., 2016).

In Ødegårdstuen et al., (2016), IMPETUS was used to model projectile impact with sand for two different strike velocities, 550 m/s and 900 m/s. Furthermore, two different impact angles were tested, 5° and 25°. The research was backed by experiments where the Ricochet velocity and angle were measured and high-speed recording applied. As an example the projectile with impact angle of 5° and a velocity of 900 m/s showed very good correlation with experimental results having only a 7% difference.



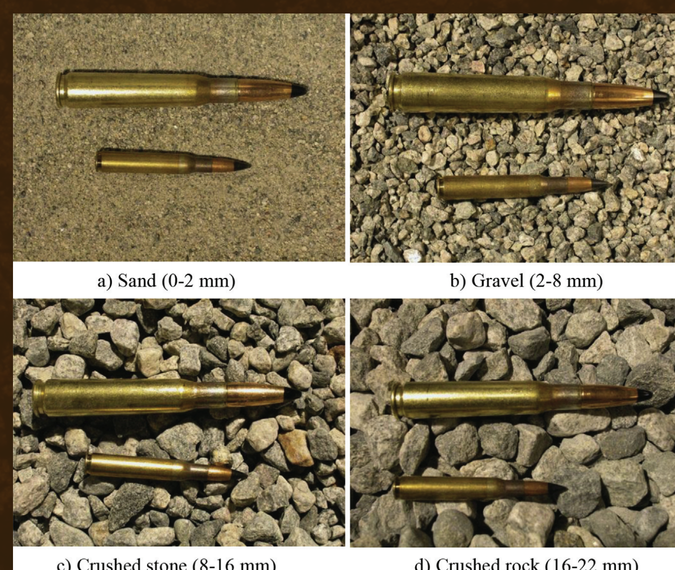
Experimental and numerical results for a velocity of 900 m/s under a 5° impact angle (Ødegårdstuen et al., 2016).

They concluded: "Conformity between the experiments and the simulations were very good, and we feel that the simulations in coarse features give a good trend on the ricochet phenomenon." and "By this study we have found that IMPETUS AFEA with good quality simulates impact and ricochet in sand for a rigid inert 25mm projectile for impact velocities at 550m/s and 900m/s and impact angles at 5° and 25°."

Four different types of granular materials as well as four different types of projectiles were tested and modeled in the work presented in (Børvik et al., 2015). The projectiles are small bullets and the paper covers extensive experimental work as well as simulation.

The bullets were all small-arm bullets and the granular targets were in a specially designed cylindrical container. Each experimental configuration was typically done 3 times or more.

The main Response Parameter was the penetration depth. For each configuration an average penetration was calculated. One very interesting finding was that independent of the bullet type, the penetration depth is considerably larger in wet sand than in dry sand which according to (Børvik et al., 2015) also has been observed by other researchers.



Configurations for ballistic tests performed in (Børvik et al., 2015).

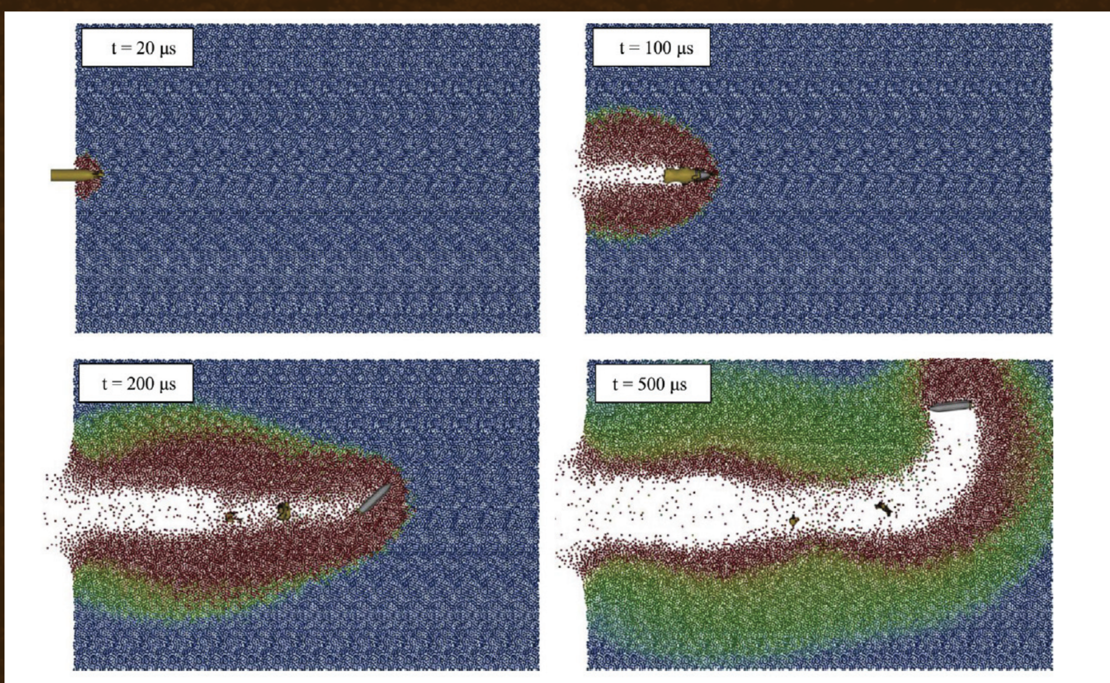
Granular material	7.62 Ball	7.62 AP	12.7 Ball	12.7 AP	12.7 AP-red
Wet sand (0–2 mm)	4	6	3	1	5
Dry sand (0–2 mm)	4	6	5	4	6
Gravel (2–8 mm)	3	5	5	8	4
Crushed stone (8–16 mm)	3	6	5	6	6
Crushed rock (16–22 mm)	6	6	6	8	5

Number of experiments (Børvik et al., 2015).

Filling material	7.62 Ball	7.62 AP	12.7 Ball	12.7 AP	12.7 AP-red
Wet sand (0–2 mm)	200 (10.0)	263 (9.4)	455 (33.0)	>1000 (–)	732 (86.3)[b]
Dry sand (0–2 mm)	98 (2.2)	202 (19.7)	306 (24.2)	505 (11.2)	498 (56.4)[c]
Gravel (2–8 mm)	100 (4.1)	212 (11.7)	316 (15.0)	628 (60.8)[a]	545 (28.7)
Crushed stone (8–16 mm)	100 (4.1)	182 (6.9)	278 (7.5)	400 (23.8)	423 (27.5)
Crushed rock (16–22 mm)	105 (5.0)	151 (10.2)	222 (12.1)	310 (9.4)	332 (35.4)

Experimental average penetration depth in mm (Børvik et al., 2015).

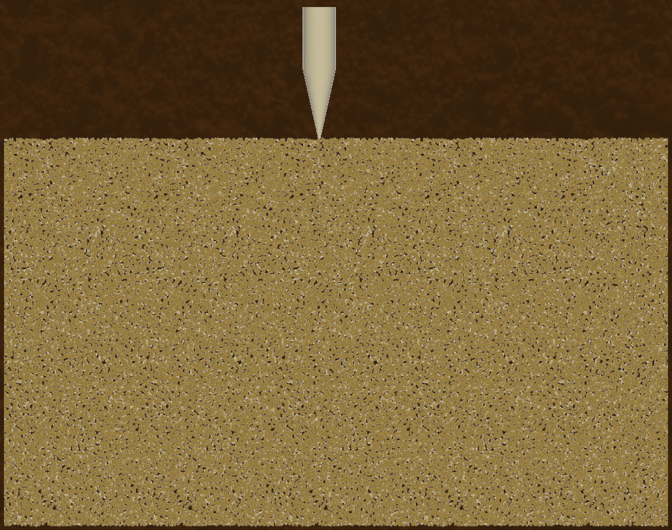
The experiments also confirmed that the relation between grain size and bullet performance is important in ballistics in granular materials. Further, it was found that the penetration depth is larger in gravel than in dry sand. They applied the iDPM module and the number of particles was studied with regard to the penetration depth. Convergence with the experimental results was obtained by increasing the number of particles. For the 7.62 mm AP bullet it was found that between 1-4 million particles should be used.

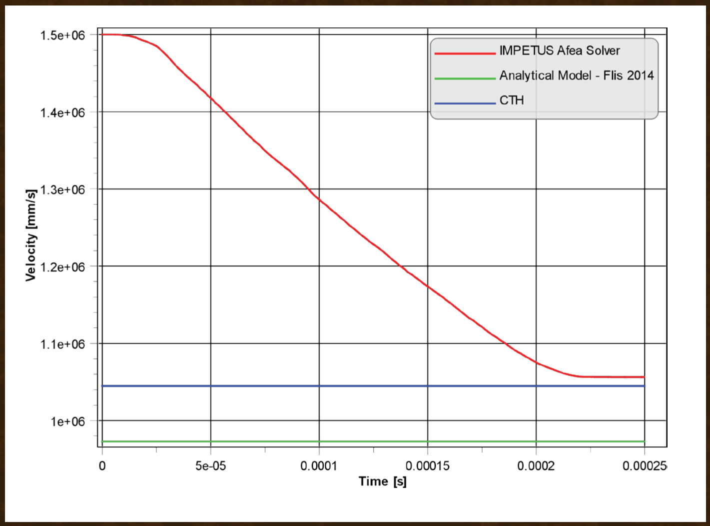


Velocity field for penetration in dry sand. The penetrator is a 7.62 mm AP bullet and the sand has 1 million particles (Børvik et al., 2015).

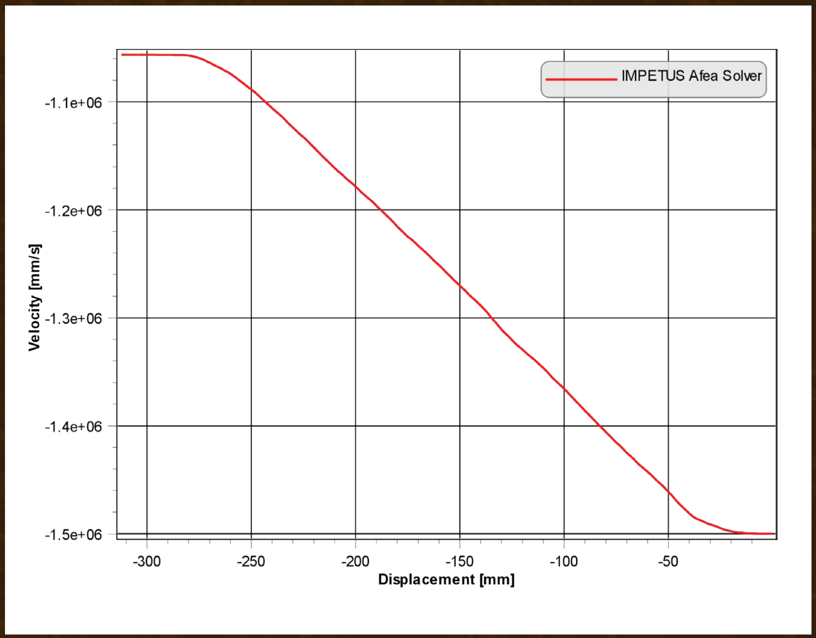
Based on the performed numerical simulations they concluded: “Taking the simplicity of the numerical simulations and the complexity of the investigated problem into account, good agreement between the experimental results and the numerical predictions is in general obtained.”

In Flis (2014) pointy-nosed projectiles were impacted into sand. It showcased an analytical penetration model as well as a numerical model using the Hydro Code CTH from Sandia National Laboratories. An axi-symmetric model was built in CTH with a 2 cm-diameter steel projectile having a 25° conical nose. The given initial velocity was 1500 m/s resulted in a residual velocity of around 1045 m/s. The analytical model predicts a residual velocity of 973 m/s. A full 3D model was developed for IMPETUS to show the simplicity in modeling this scenario and to compare directly with the results from the CTH code. The iDPM module was used with a user defined soil to match the soil density in Flis (2014). A total of 1,000,000 particles where specified and the simulation took only 3 minutes to complete the computation.



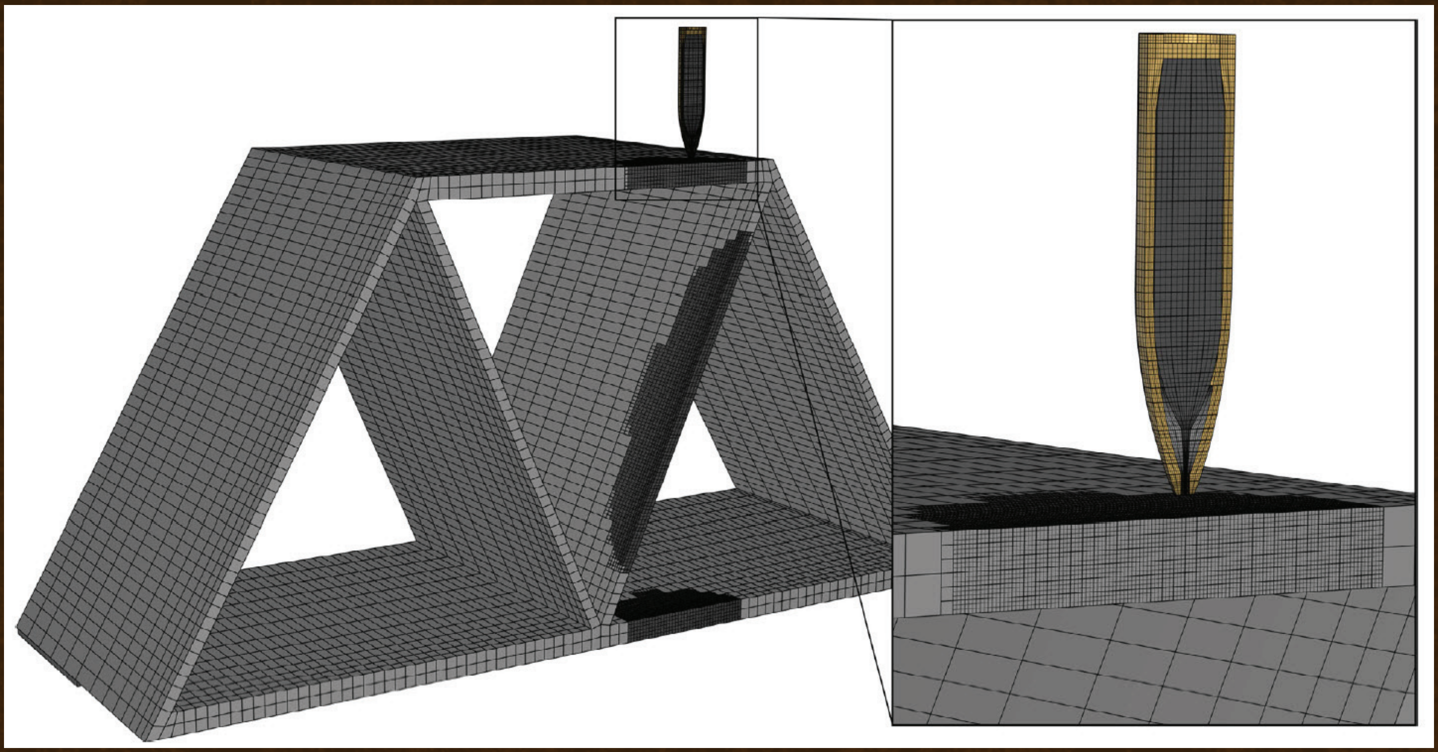


The exit velocity was found to be 1056 m/s, extremely close to the numerical result obtained with CTH. In fact there was only a 1% difference between the IMPETUS and CTH results. It should be noted that the creation of the IMPETUS model was very simple since the setup for the iDPM module requires very little input from the user. An interesting phenomena that was mentioned in Watanabe, et al. (2011) and Bless, et al. (2011) was the development of the penetration speed. If the penetration velocity versus penetration distance is plotted, the projectile initially penetrates at constant speed followed by a fast deceleration. This was also observed in the simulation results.

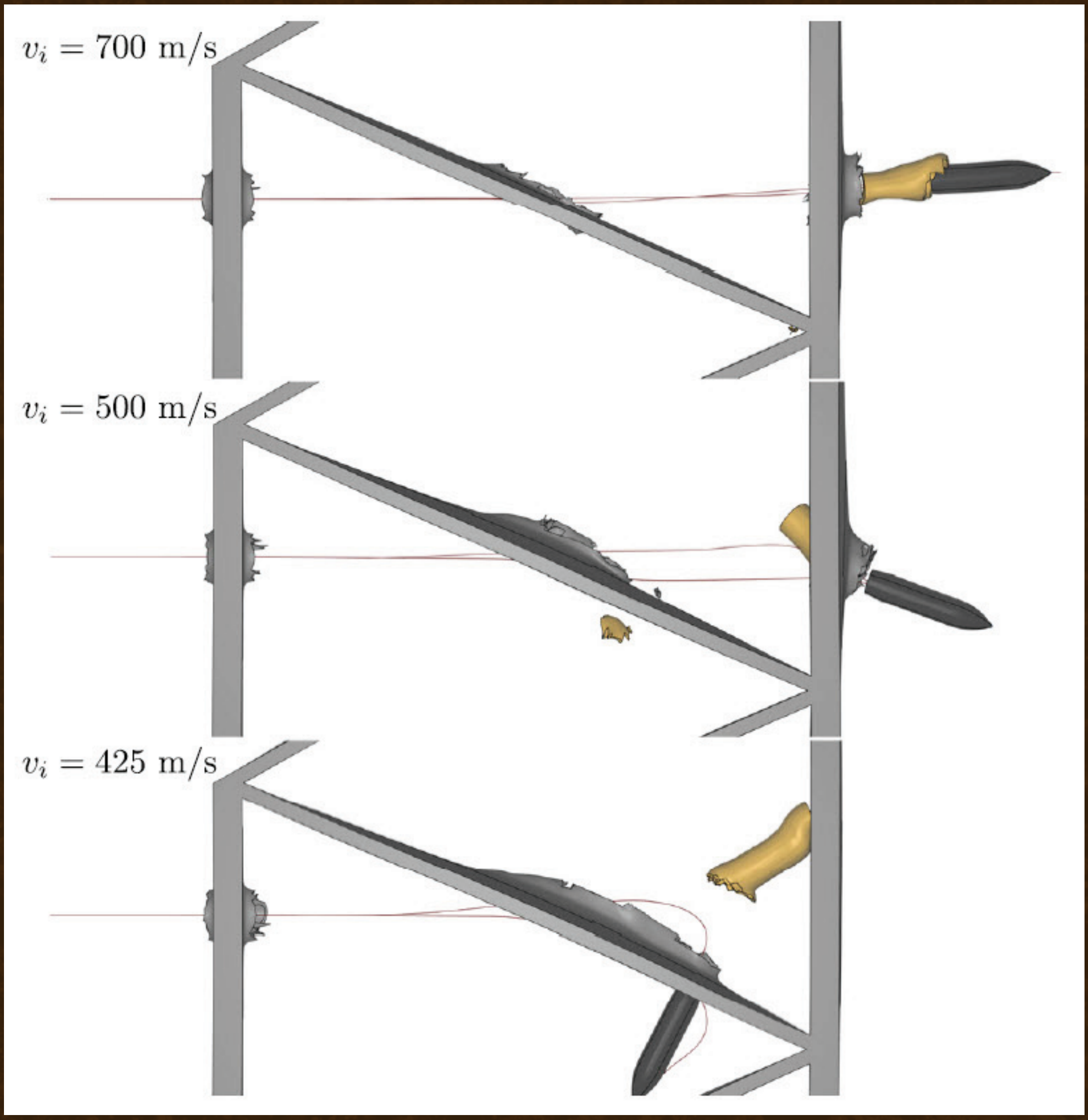


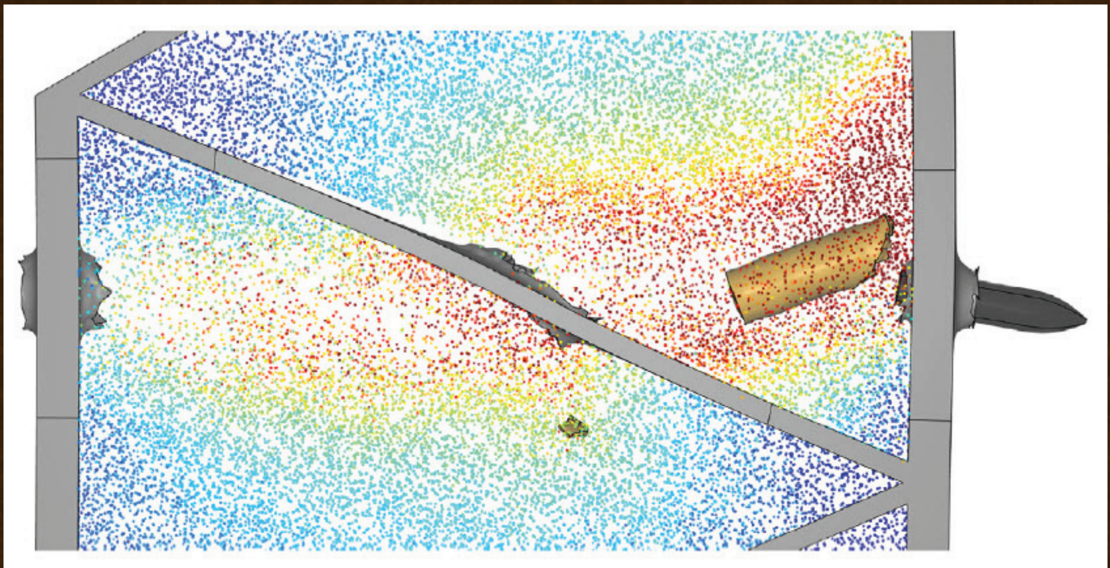
In Holmen, et al. (2017a) the IMPETUS Afea Solver® was used for ballistic impact of empty and sand-filled aluminum panels. The panels were filled with iDPM particles and the impactor was a 7.62 mm AP bullet. The striking velocities were between 400 m/s and 900 m/s. It was noted in the study that the authors made use of the unique Shadow Refinement feature in IMPETUS where critical areas, in this case the impact location, can easily be refined at runtime by the Solver.

The model captured the severe deformation of the aluminum panels and the interaction between the bullet and the sand.



Using the Shadow Refinement option to optimize the mesh for ballistic impact (Holmen et al., 2017a).



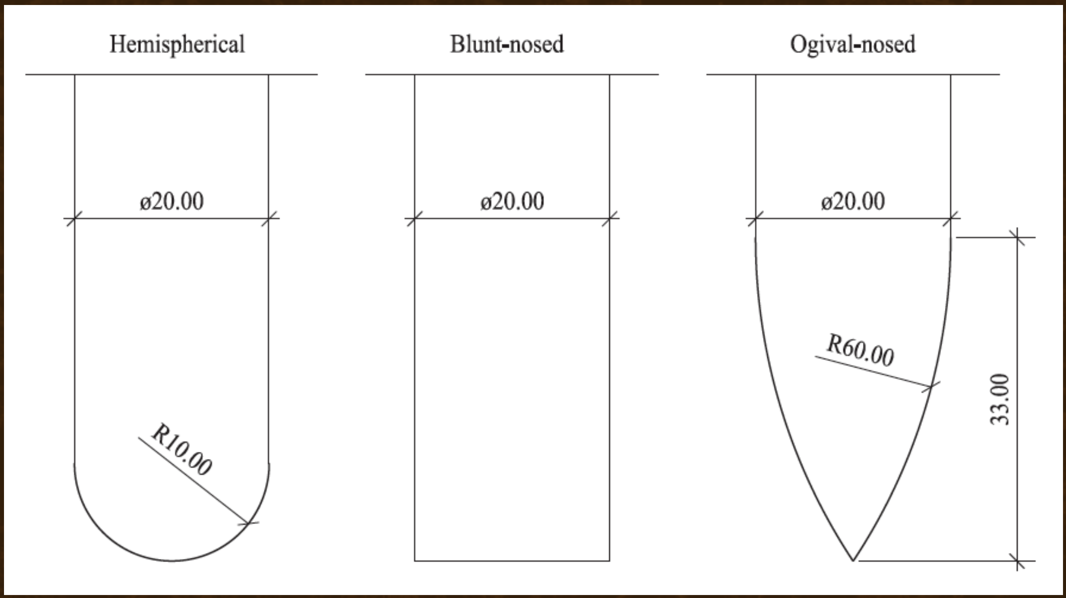


Large deformation of panels and bullets is seen, as well as interaction with the sand (Holmen et al., 2017a).

Holmen, et al (2017a) successfully modeled the ballistic set-up and matched the experimental data. They concluded:

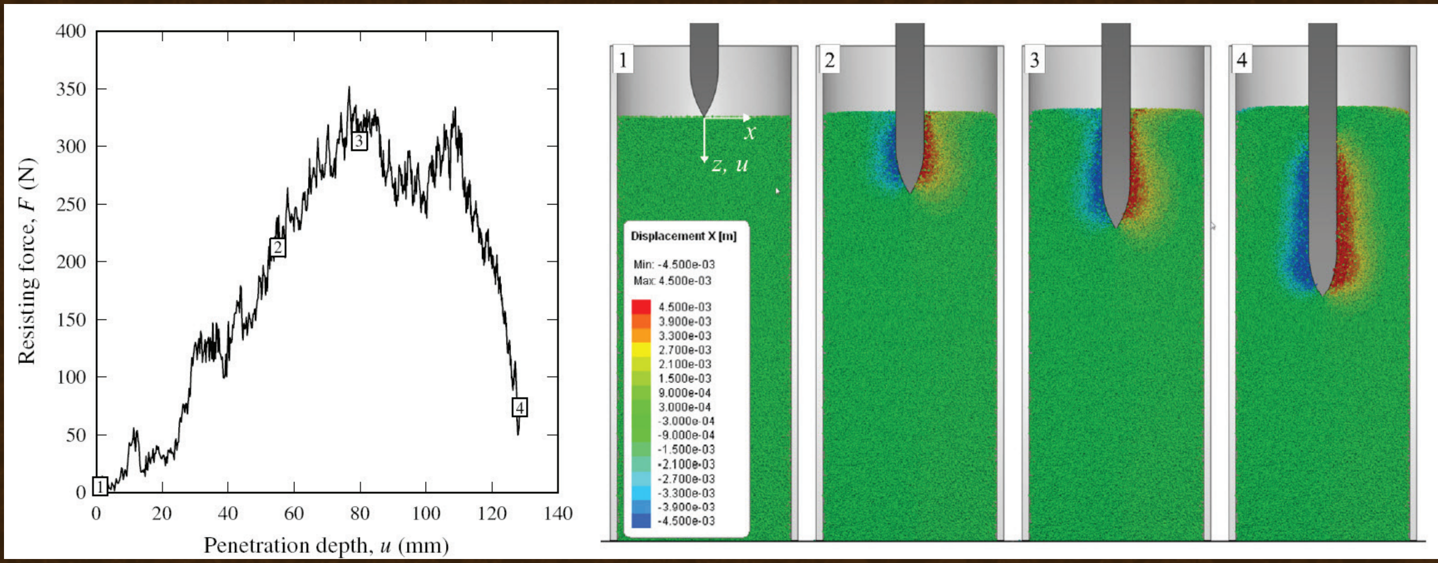
"Simulations of the empty aluminum panels predicted the perforation process and the capacity of the panels within 5% of the experimental values confirming that the behavior of the aluminum panels was adequately captured. The critical perforation capacity of the sand-filled panels was predicted within 11% of the critical velocity from the experiments, a good result when we recognize the complexity of the problem. Numerical simulations of protective structures consisting of a combination of granular and solid materials are challenging and require robust and advanced numerical algorithms."

So far the cases considered have been for higher values of striking velocities but research on lower velocity events have also been the focus of research. In Holmen, et al (2017b), twenty tests with three different projectile noses were used both in experiments and IMPETUS simulations. The velocities considered were 2.5 m/s and 5 m/s. The shapes of the projectiles were Hemispherical, Blunt-nosed and Ogival-nosed.



Different geometries used for low velocity projectiles impacting soil (Holmen et al. 2017b).

The main Response Parameter in this study was the Force-Penetration curves and it is worth noting that the shape of the nose had a significant influence on the penetration behavior. In Holmen, et al. (2017b) it is stated: "*The experimental tests in this paper showed that the shape of the force-penetration depth curves changes dramatically by changing the impactor nose shape. Blunt-nosed impactors have a force peak almost instantaneously after penetration before nearly complete unloading takes place. Hemispherical and ogival-nosed impactors display a gradual increase to the peak force that comes toward the end of the penetration process.*"



Development of the Force-Displacement curve for Ogival-nodes impactor at V0 – 2.5 m/s (Holmen et al., 2017b).

Again the iDPM feature in IMPETUS was successfully applied to model the soil. There was a reasonably good comparison between experiments and numerical results for the Penetration Depth. The conclusion in Holmen, et al (2017b) is:

"*Numerical simulations with a discrete particle method (DPM) were in general able to describe the behavior of the sand during penetration although the peak forces were underestimated by about 15% and the penetration depths were slightly overestimated. The results presented in this work suggests that this DPM can be used in simulations of low-velocity penetration.*"

More information about the simulations discussed in this article can be obtained from CertaSIM, LLC, by contacting support@certasim.com.

Notes:

†ANSYS® Autodyn® is a registered trademark of ANSYS, Inc.

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Ray Chaplin, Mechanical Engineer, US Army, ARDEC

Ray Chaplin is a mechanical engineer working for the Computational Modeling and Analysis team Small Caliber Munitions Technology Branch at Picatinny ARDEC. He has a Bachelors Degree in Mechanical Engineering from Lehigh University and a Masters in Mechanical Engineering from Stevens Institute of Technology. He is a Doctoral Candidate and an Adjunct Professor at Stevens Institute of Technology. He specializes in Finite Element Analysis of small caliber munitions using multiple software packages.

We are grateful that Mr. Chaplin accepted our invitation to write about his many years of experience with simulating ballistics applications.

"The Small Caliber Division at the US Army Armament Research Development and Engineering Center (ARDEC) uses Multi Scale Finite Element Analysis (FEA) to model many aspects of interior, exterior, and terminal ballistics. The new generation of small arms ammunition currently being fielded in theater are the first to employ the heavy use of structural computational mechanics during their development cycle, and the simulations have resulted in a vastly improved product over traditional ammunition. Modeling and simulation has also allowed us to visualize many phenomena that we were unable to capture in live fire testing even with the use of high speed cameras. The additional data from these FEA models has resulted in a vastly improved knowledge base of the physics behind small arms ballistics.

Launch models performed by the group capture pressurization, engraving, and acceleration of the bullet that occurs from the time of powder ignition until the projectile leaves the barrel. The structural response of the projectile, bore resistance, and predicted muzzle velocity are the typical desired outputs from the model. However, accurate modeling of interior ballistics presents multiple challenges, some related to artificialities within the FEA codes, and others related to our lack of ability to quantify the above metrics. While muzzle velocity is easy to obtain from experimental methods, quantification of bore resistance and in bore structural failures are far more puzzling. Due to the opacity of gun barrels high speed cameras tell little about in bore structural failures until multiple pieces, from the projectile breaking up, exit the muzzle. When structural failures do occur examination of strain within the FEA model provides insight into areas of the projectile which are in need of structural reinforcement even if the model does not capture the exact failure mode.

One of the first issues encountered with proper launch model set up is establishing the load conditions encountered. Pressure time curves obtained from instrumented test barrels are often used as a starting point and applied on all surfaces up to where the bullet will engrave. This can provide a quick evaluation of structural response at loads close to what will be expected. However, these curves are one way in nature resulting in the same value of pressure regardless of changes in bore resistance between projectile, bore obstructions, and propellant changes. When higher fidelity within the model is required, ARDEC has coupled lumped mass interior ballistics codes with structural FEA codes [1]. This dynamic coupling between the codes allows for real time changes in the pressure time curve based off of the structural response of the model.

We have experienced difficulty in obtaining accurate measurements of small caliber projectile bore resistance due to engraving and frictional forces with experimental methods. Estimations are usually obtained through the FEA models but without experimental validation of the models the results are questionable. Our large caliber counter parts here at ARDEC developed a novel method for the direct measurement of bore resistance during launch [2] through the use of pressure transducers and accelerometers embedded within the projectile. Pressure transducers embedded in the base of the projectile capture the real time pressure driving it down bore, while the accelerometer captures the true acceleration. A simple F=ma calculation can be completed from the test data to obtain the true bore resistance. We have examined similar methods within small caliber ammunition and unfortunately the amount of available real estate within the projectile does not allow for the embedding of the necessary instrumentation. Our team is planning future experimentation employing the use of in bore radar to quantify the velocity from which the acceleration profile can be numerically derived. This coupled with pressure transducers within the barrel providing the estimated base pressure will provide bore resistance measurements. While we do not expect this to be as accurate as a direct measurement it will provide a valid starting point for model validation. As advances in sensor technology develop direct instrumentation of a small caliber projectile can be revisited in future years.

Within the FEA code discretization of geometry into a linear mesh often leads to overlapping radii between the lands and the bullet which results in the calculation of overly stiff contact pressures during bullet engraving. When artificial contact pressures approach certain levels "node snagging" can occur *often leading to the artificial introduction of large plastic strains and, in the cases of element inversion, termination of the analysis. Mesh refinement can provide relief from some of the discretization issues but complete elimination of the problem typically requires a mesh that is so fine that it becomes computationally prohibitive. Initial testing with enriching the mesh along the engraving surface with high order cubic elements offered in IMPETUS has yielded promising results. The figures below show the engraving surface of the same launch model using the same mesh within two different codes. The node snagging and artificial strains are evident in the first code as shown by the inversion of elements along the engraving surface. In this example linear, 8 noded,reduced integration, hexahedral elements are used. The second example uses the IMPETUS Solver 64 node / 64 integration points, fully integrated cubic hexahedral elements which are used to model the engraving surface of the jacket. As shown in the figure the proper deformation is captured in this analysis with no artificial strains or node snagging evident.*

Continued experimentation and refinement in our launch models is leading to greater predictive capability for our team. Bore resistance data obtained from live fire testing will allow us to determine accurate friction coefficients as well as evaluate that material models are capturing the proper high strain rate response during engraving. Continued experimentation with high order elements along the engraving surface will ensure that model results are not contaminated by artificialities in contact algorithms and that the proper material deformation is captured."

8 Node Linear Hexahedral Reduced Integration Elements

64 Node / 64 Integration Point, Cubic Hexahedral Fully Integrated Elements

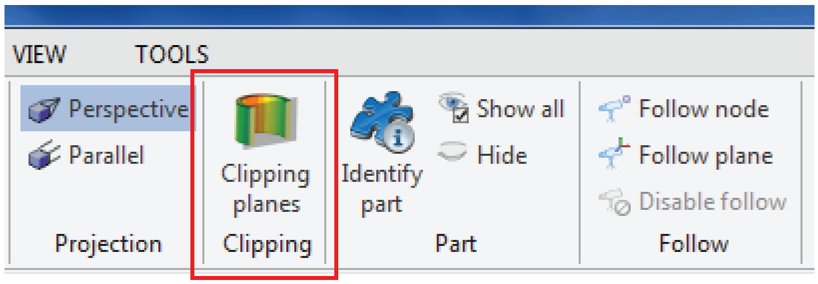
[1] A. Blot and R. Chaplin, "Coupling of a Lumped Mass Interior Ballistic Code with the Structural Finite Element Code ABAQUS", August 2014, International Ballistic Symposium proceedings.

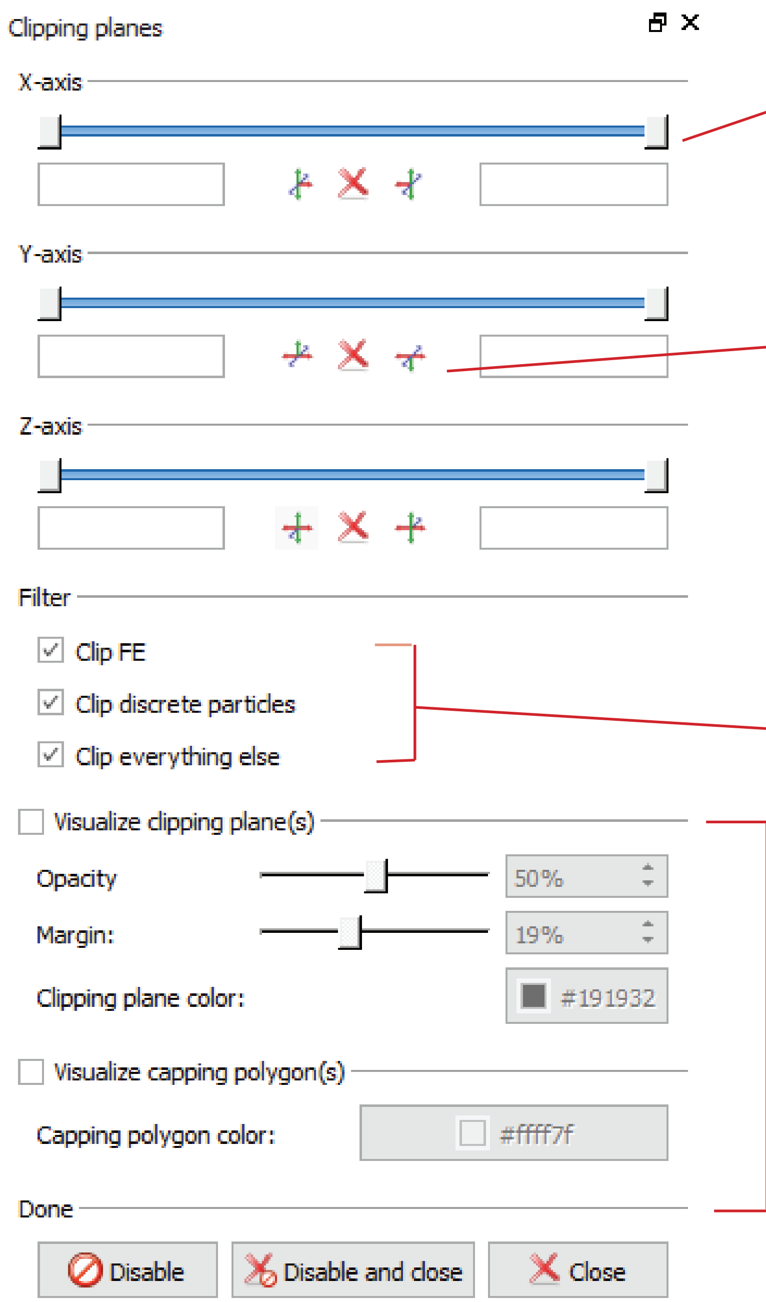
[2] D. Carlucci, J. Vega, M. Pocock, S. Einstein, C. Guyott and R. Chaplin, "Novel Examination of Gun Bore Resistance – Analysis and Experimental Validation", April 2007, International Ballistic Symposium proceedings.

New Features in the IMPETUS Afea Solver GUI

Clipping Plane in the IMPETUS Afea Solver GUI

The New clipping plane interface makes it very easy to clip the model.





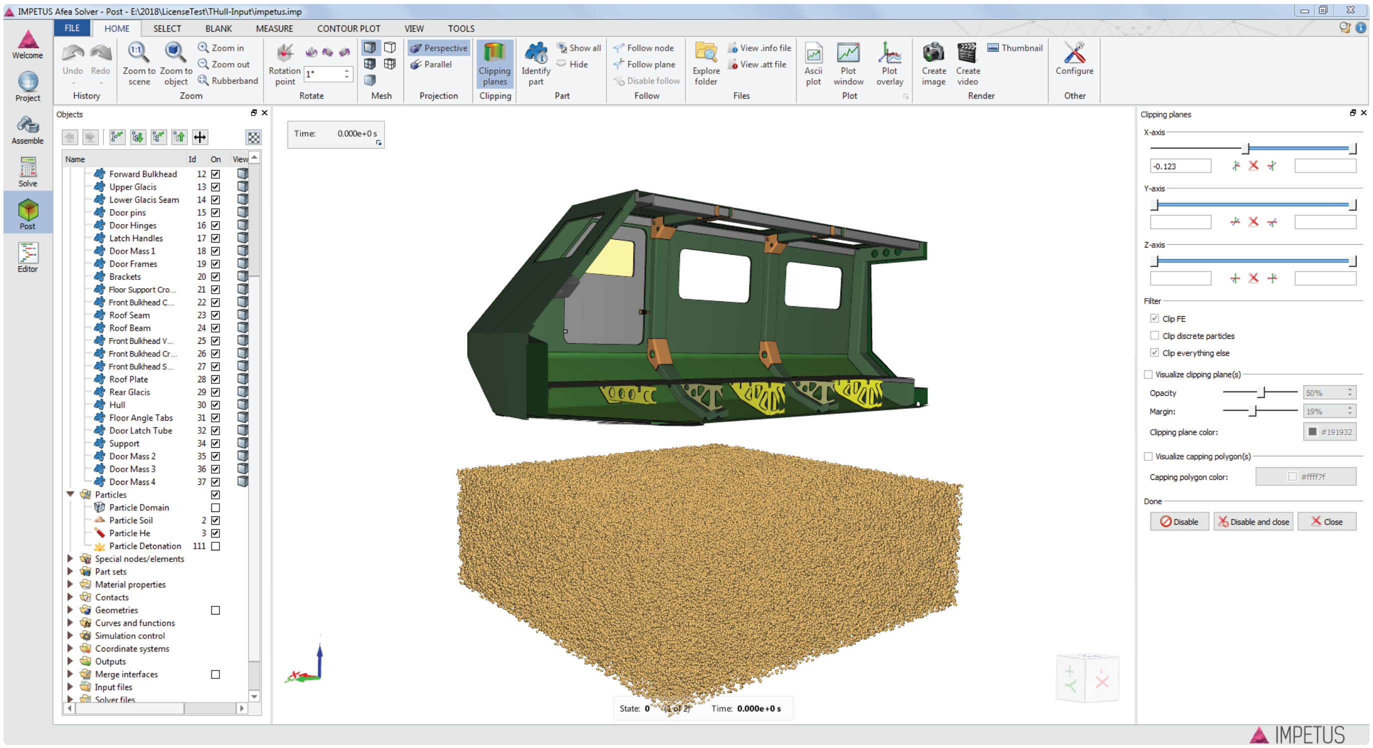
Sliders are used to dynamically clip from either direction along each coordinate axis.

or

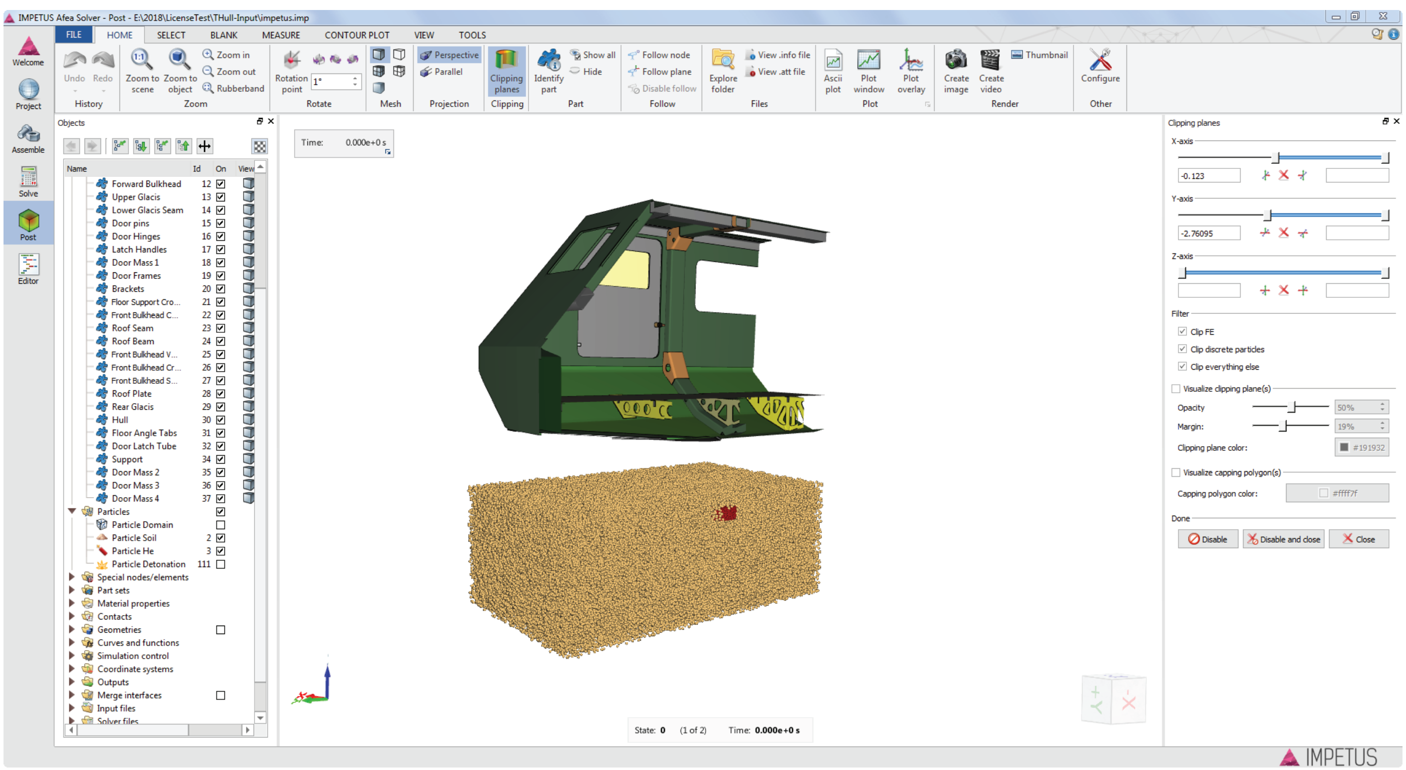
Select the + / - half plane

Choose what part of the model to clip

Adjust Visualization Options



Clip along 1 axis
Only the FE Part of the Model

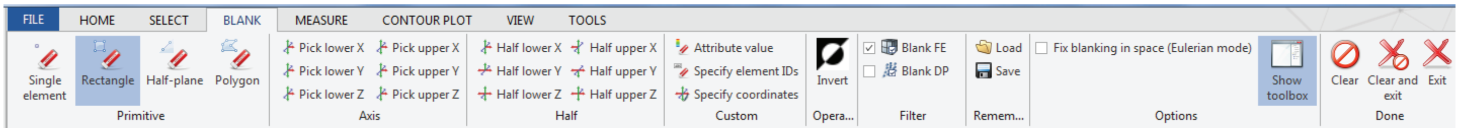


Clip along 2 axes
Both FE and Discrete Particles

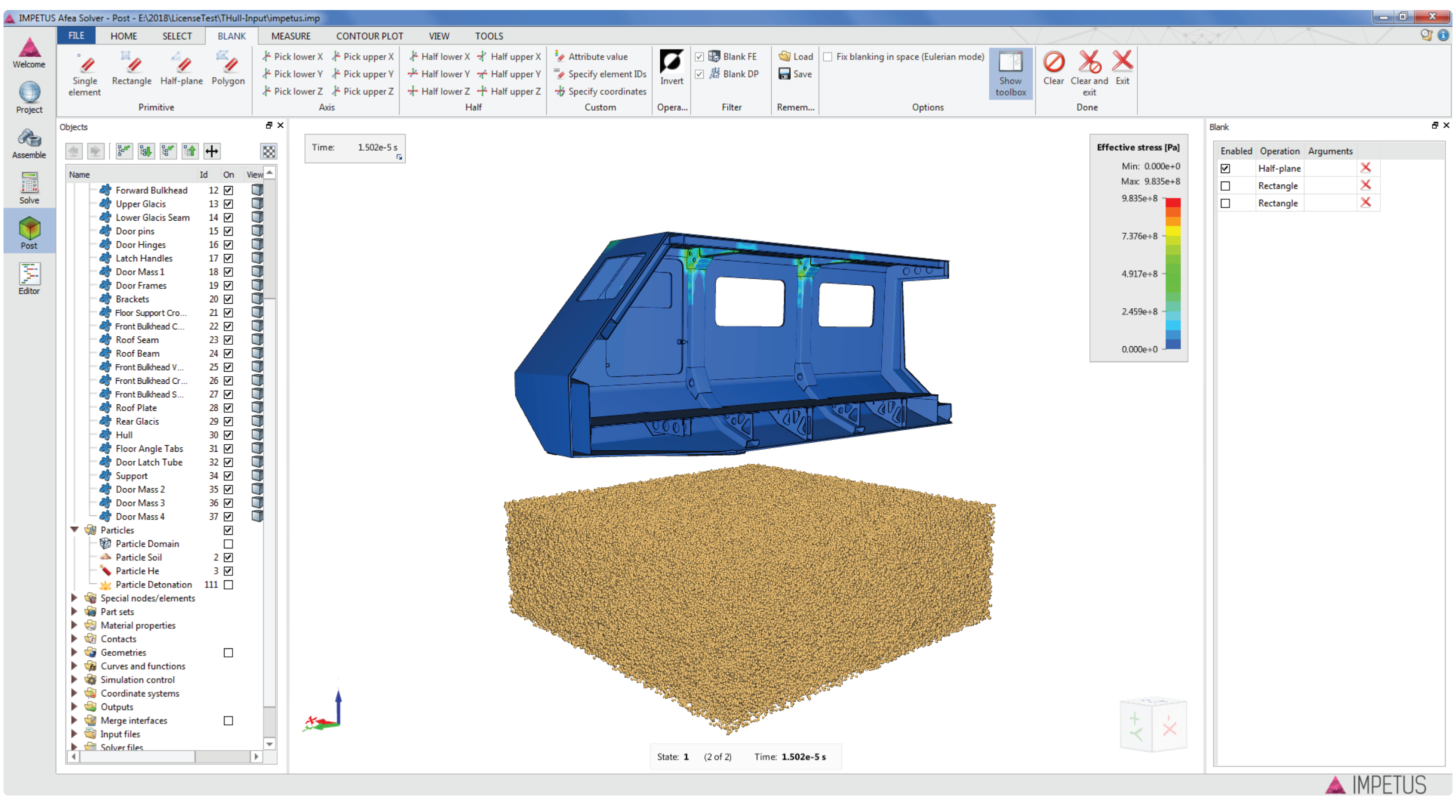
Blanking in the IMPETUS Afea Solver GUI

The new Blanking Interface has many options:

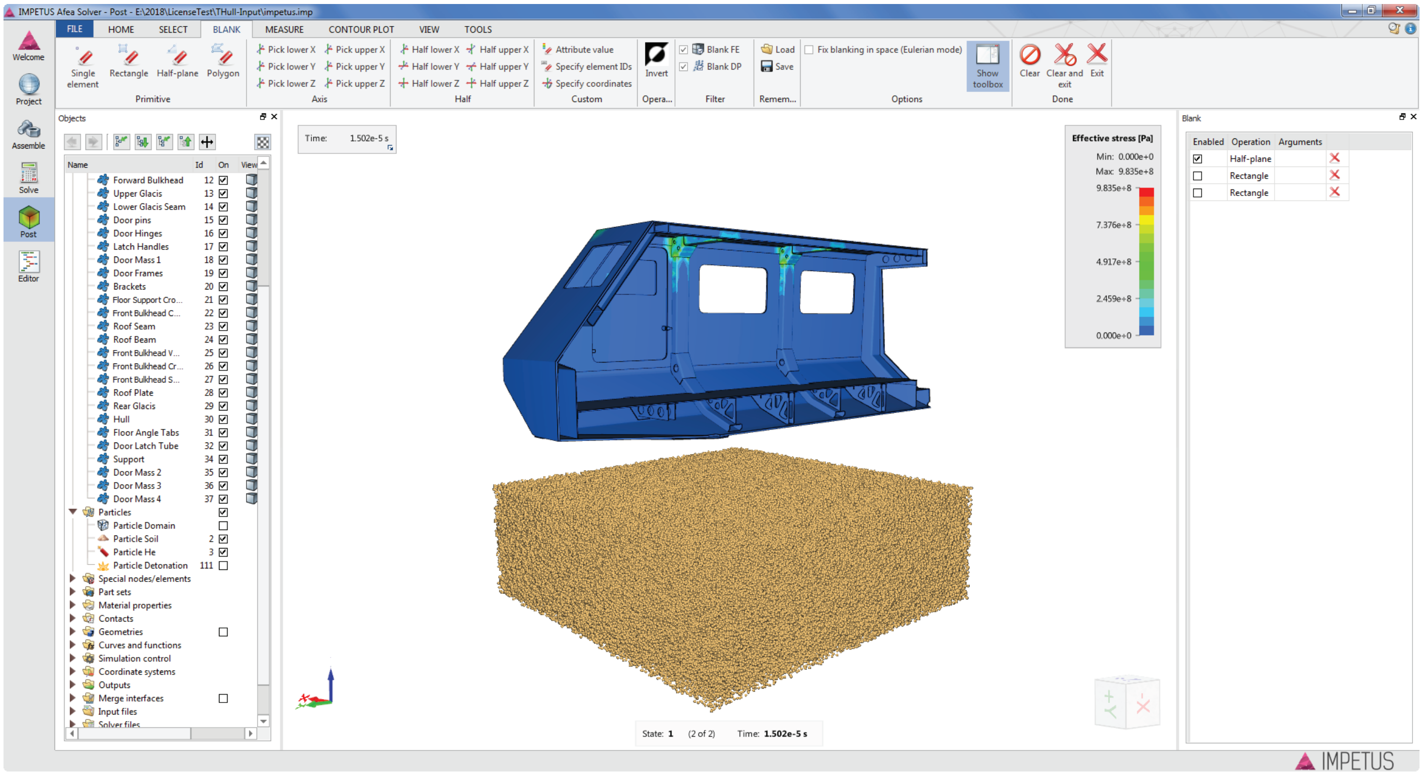
There are many ways to blank a model including single elements, rubber band type selections, upper or lower quadrants. The user can select to only blank the FE part of the model or just the Discrete Particles. Every time a blanking option is used it is saved in a list on the right side of the screen which allows for easily turning on and off the various selections. One very nice feature is the ability to save the blanking options so that they can be reloaded in the future.



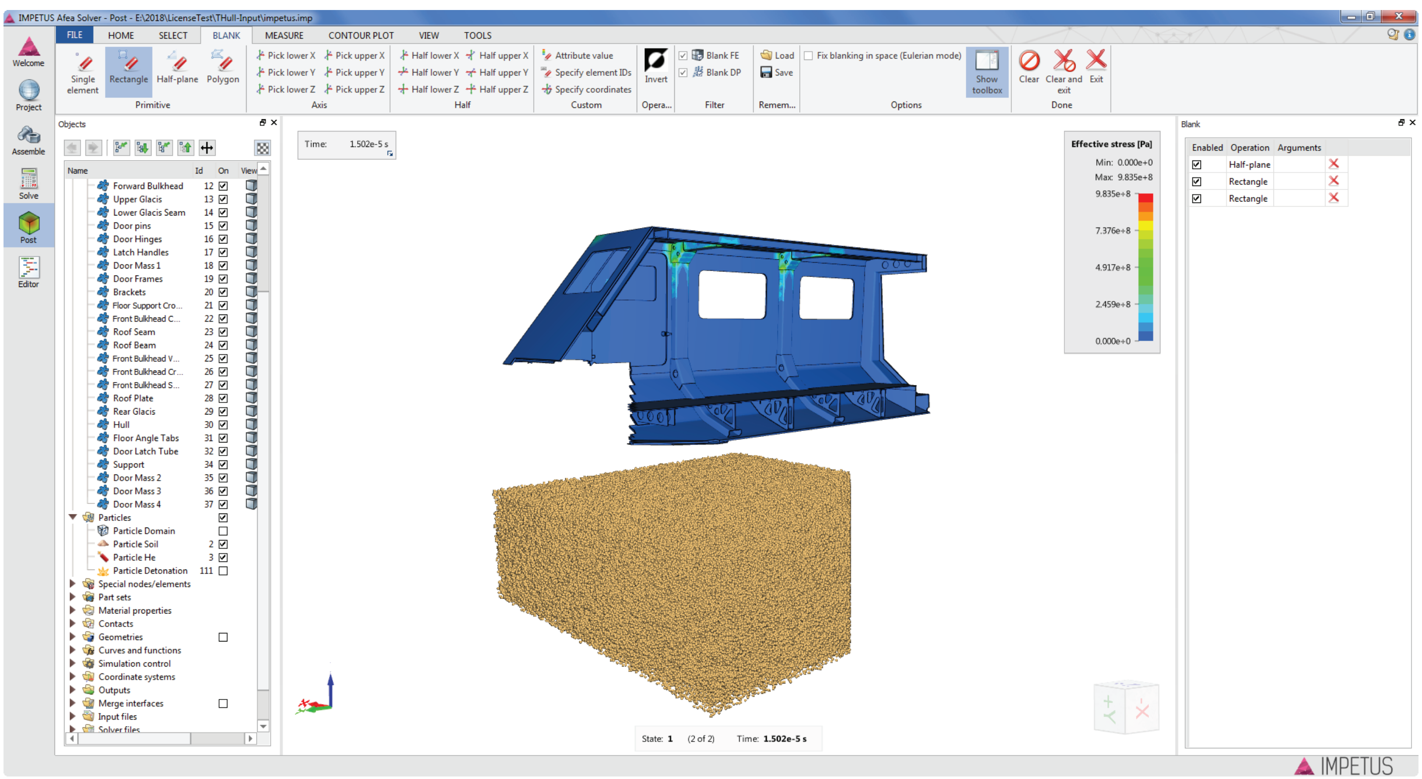
Blanking Interface



This shows 3 Blanking Selections on the right side of the screen



The first selection in the list blanked only the FE portion of the Model



The 2 remaining entries blank part of the Soil Domain and another part of the FE Model