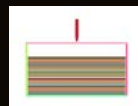


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Ballistic **S**imulation Method for **L**ithium **I**on **B**atteries(**BASIMLIB**) using Thick Shell Composites (TSC) in LS-DYNA

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Motivation & Background



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Motivation/Technical Background

- There are four main causes of battery failure
 - Mechanical, Electrical, Thermal & Immersion
- The DOE's Vehicle Technologies Office (VTO) initiated the Computer Aided Engineering for Electric Batteries (CAEBAT) activity in FY 2010 and TARDEC joined the efforts to co-sponsor the program with more focus on battery performance at extreme conditions and mechanical destructive behavior
- National Renewable Energy Laboratory (NREL) has been actively in the CAEBAT from the inception
- MIT has been studying the mechanical properties and behavior of the cells through experimental and modeling at their crash worthiness laboratory
- Most of the simulation work on the batteries are at a single cell level and gap exists to simulate the batteries at their full pack capacity
 - Firstly, requires an enormous amount of computational capability due to very large number of elements associated in modeling the full pack
 - Secondly, thickness of the anode, cathode, and active materials are in micro scale, adds more complexity in modeling such a small scale



Objective

- Objective and focus of this work is to develop a
 - Robust simulation methodology to model lithium-ion based batteries in its module and full pack capacity
 - Evaluate the developed methodology for mechanical failures i.e., bullet impact at oblique, vertical and horizontal loading conditions



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Background



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- Component state of understanding
 - ✓ Current collectors well understood
- Electrodes(active material)
 - ✓ not well understood
 - ✓ powder form held together by binders
 - ✓ high degree of porosity
 - ✓ low tensile load capacity
- Separator understood to some extent
- Electrolyte role uncertain
- Mechanics of interfaces between components
 - ✓ unknown

Information from <http://batterysim.org/> Oak Ridge National Lab SAE 2015 government /industry meeting

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Battery model

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Cell Layer (Anode+Current Collector+Seperator+Electrolyte+Cathode)

Single Pouch

Aluminum Heat Shield

Pouch

96.3 mm

Module

163 mm

Pouch cells can be modeled in two ways

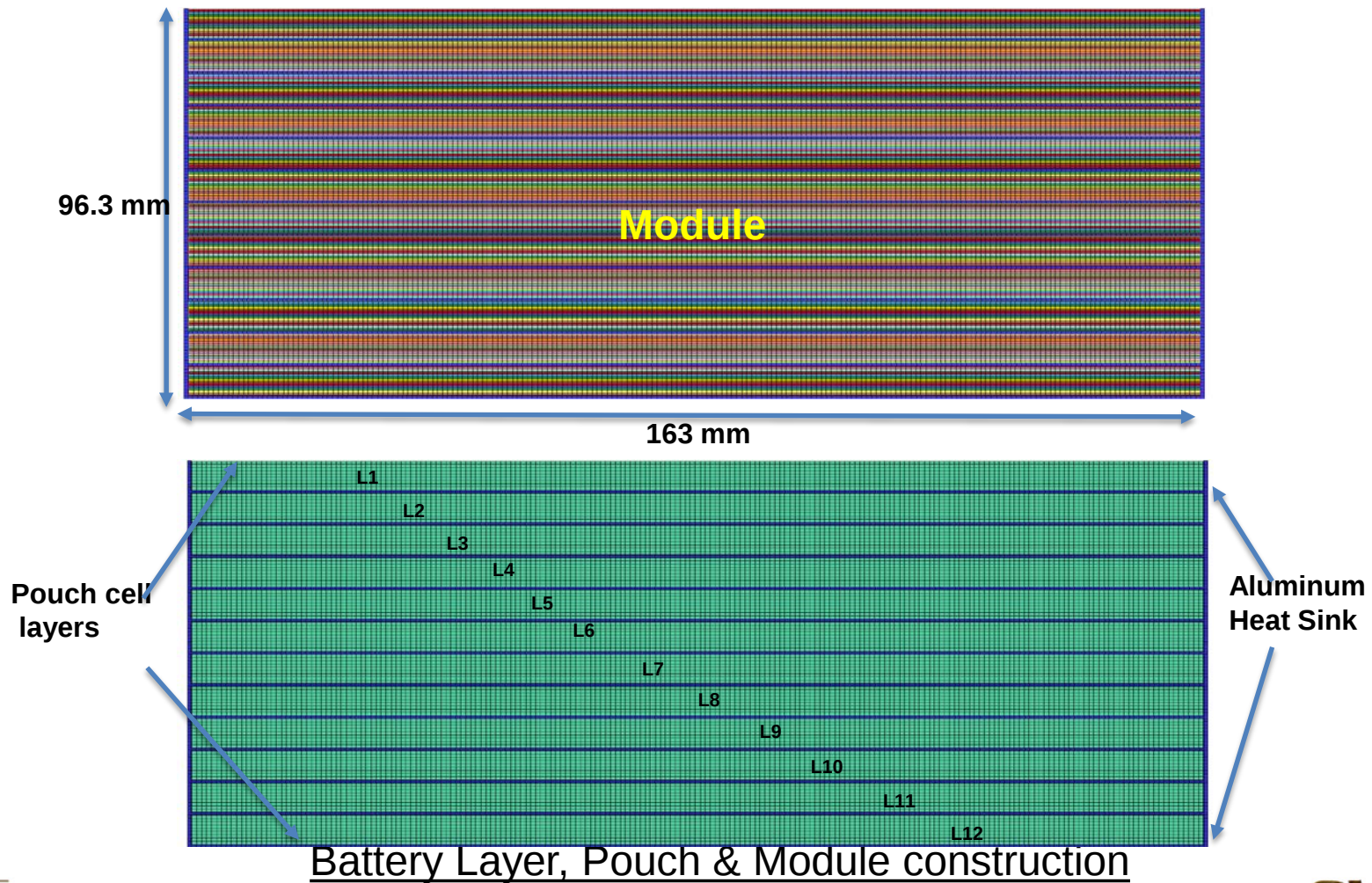
- ✓ All shell elements – 12.5 million elements
- ✓ Thick Shell Composites (TSC) – 2.5 million elements shown in this slide

Battery Layer, Pouch & Module construction

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Battery module model

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Battery Layer Thicknesses

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Positive Current Collector (Aluminum foil) = 20 μ

Graphite Anode = 95 μ

Separator (Polypro) = 20 μ

LiFePO4 Cathode = 100 μ

Negative Current Collector (Copper foil) = 20 μ

Separator (Polypro) = 20 μ

- ✓ General thickness and layer composition of a pouch cell battery is shown above
- ✓ Microscale thicknesses makes it difficult to represent the batteries as a micromechanical model.
- ✓ Thick shell composite part card is shown below.

*PART_COMPOSITE_TSHELL

\$# LiFePO4

\$#	pid	elform	shrf	unused	unused	hgid	unused	tshear
	1	2	0.000		1	0		
\$#	mid1	thick1	b1	tmid1	mid2	thick2	b2	tmid2
	1	2.0000E-5	0.000	0	2	9.5000E-5	0.000	0
	3	2.0000E-5	0.000	0	4	1.2500E-4	0.000	0

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Battery Material Properties

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<i>Mechanical Properties</i>	<i>Units</i>	<i>Aluminum current collector</i>	<i>Copper current collector</i>	<i>LiFePo4 Cathode</i>	<i>Seperator</i>	<i>Graphite Anode</i>	<i>Brass Bullet</i>
Density	kg/m ³	2,700	7,583	2,600	1,176	2,200	10,822
Elastic Modulus	Mpa	70,000	110,000	12,500	3,450	32,000	115,000
Yield Stress	Mpa	195	230	10	180	97	896

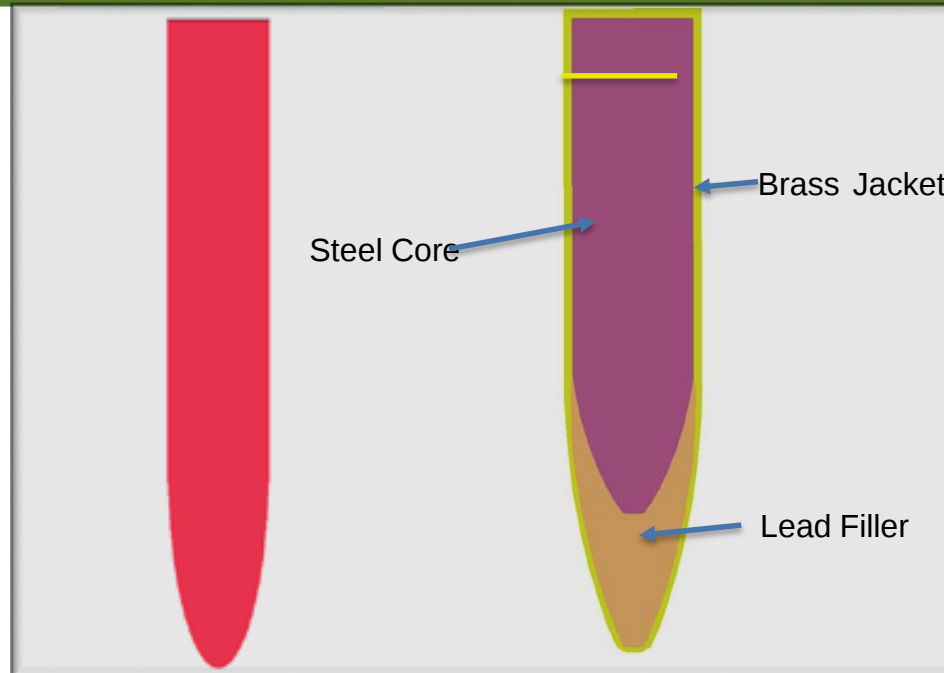
☐ Material properties used in this analysis is derived from previous CAEBAT project conducted by Department of Energy's (DOE) National Renewable Energy Laboratory (NREL)

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Bullet model

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NATO 0.308 Caliber bullet model

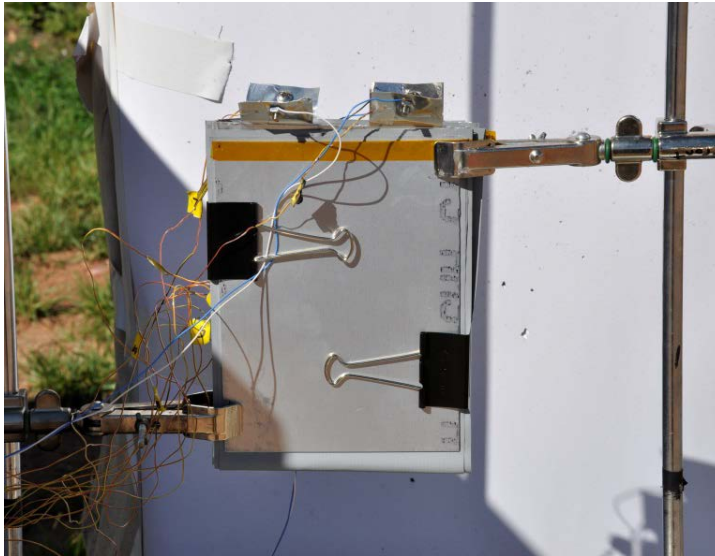
- ❑ NATO 0.308 caliber full metal jacket with 7.62 mm in diameter and 51 mm in length is used in this analysis
- ❑ Initial velocity of the bullet was set at 762 m/s for pouch cell test & 825 m/s for module test
- ❑ DEFINE_ADAPTIVE_SOLID_TO_SPH is activated to capture the fragmenting bullet particles

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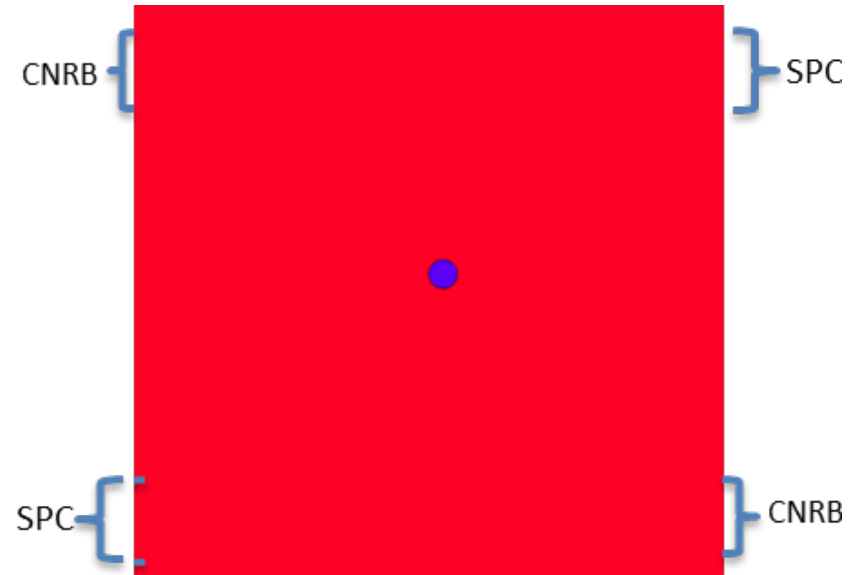
Ballistics two cell battery setup

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Test



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TEST & M&S model set up for pouch cell bullet impact shown above

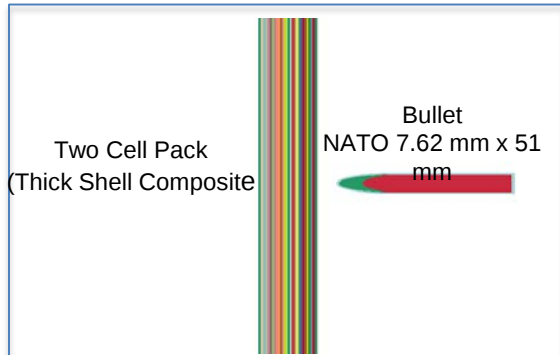
- ✓ CNRB (Constrained Nodal Rigid Bodies) represents two clips top left and bottom right which are free to move and or rotate depending upon the load
- ✓ SPC (Single Point Constraints) represents two clips bottom left and top right as fixed boundary conditions

Model set up of pouch cells bullet impact

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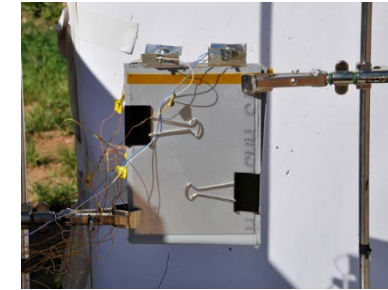
Ballistics two cell battery setup

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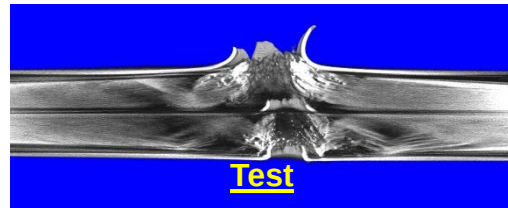
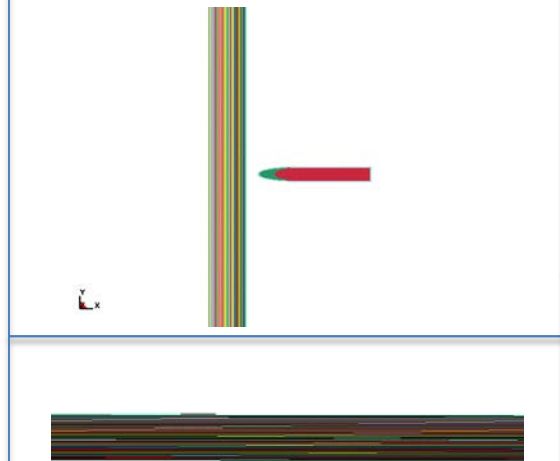
Bullet Specification

- 308 Caliber Ammunition
 - 7.62mm x 51mm
 - Full Metal Jacket
 - 2500 FPS (762 m/s) Velocity



Test

Bullet impact

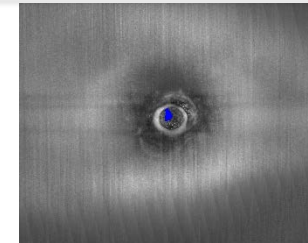


Test

- Aluminum cell separator penetrated into electrodes



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Test



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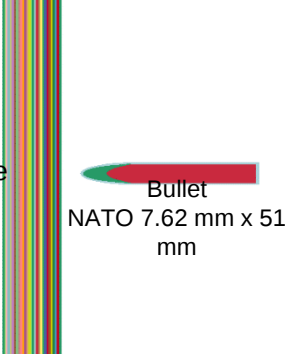
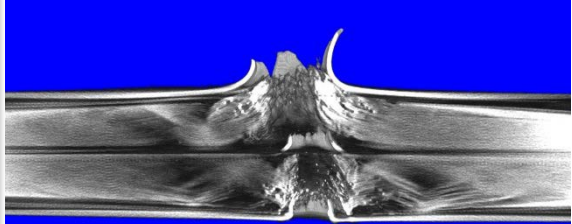
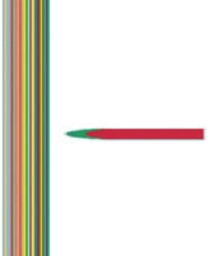
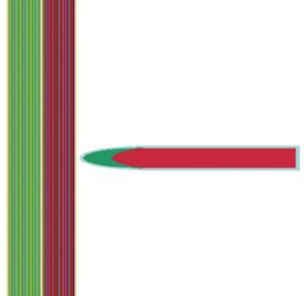
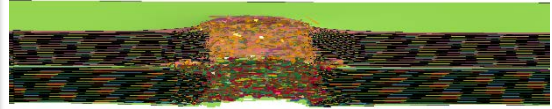
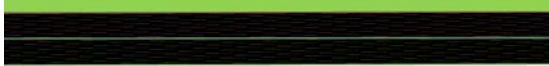
Model set up, animation and deformed cells

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Ballistics two cell battery setup

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Two Cell Pack (Thick Shell composite)  Bullet NATO 7.62 mm x 51 mm	➤ Both Thick Shell Composite and Thin Shell Layer models captures the ballistics impact ➤ Number of elements ✓ Thick Shell Composite = 2.5 million ✓ Thin Shell Layer = 12.5 million	 Test ▪ Aluminum cell separator penetrated into electrodes
<u>Bullet impact</u> (Thick Shell Composite) 	<u>Bullet impact</u> (Thin Shell Layers) 	 <u>M&S (Thin Shell Layers)</u>
		 <u>M&S (Thick Shell Composite)</u>

Model set up, animation and deformed cells

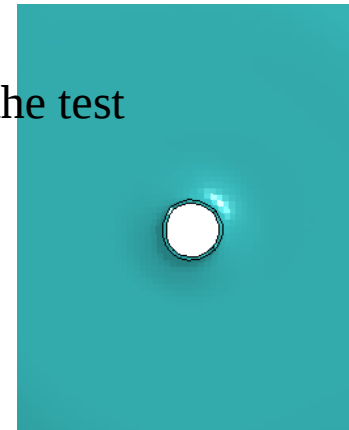
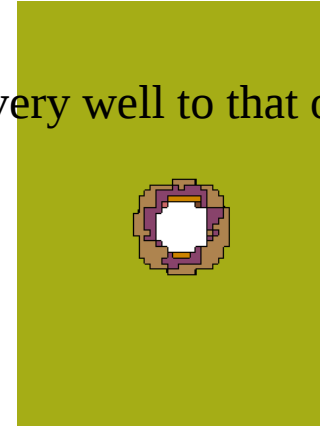
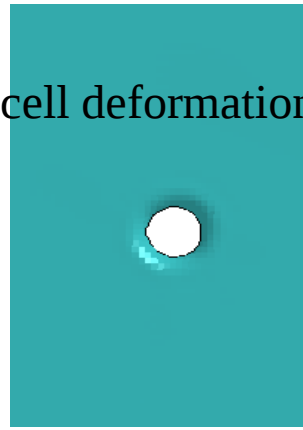
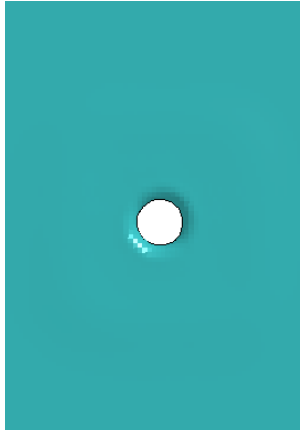
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Ballistics Cell Deformation

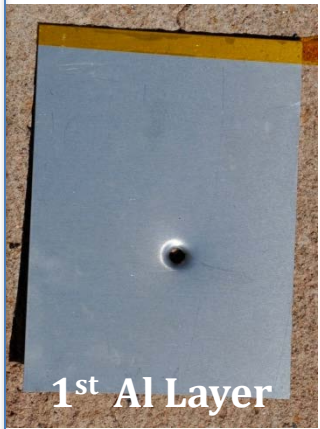
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☐ M&S captures the cell deformations very well to that of the test



M&S



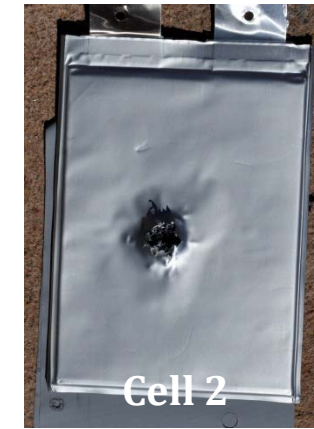
1st Al Layer



Cell 1



2nd Al Layer



Cell 2



3rd Al Layer

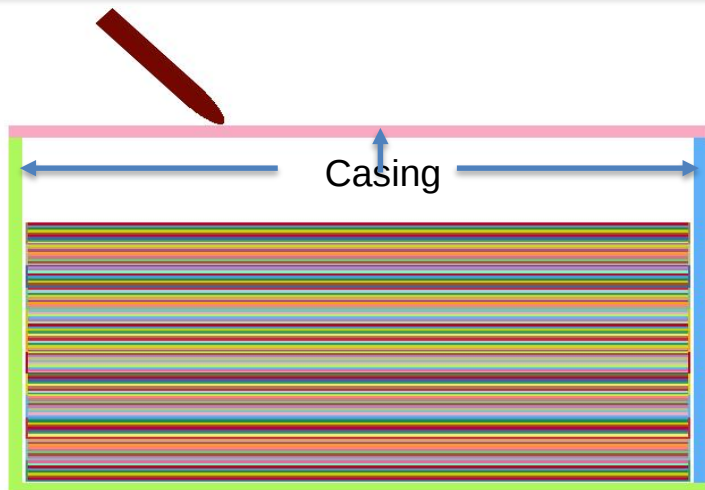
Test

Cell and layer deformations

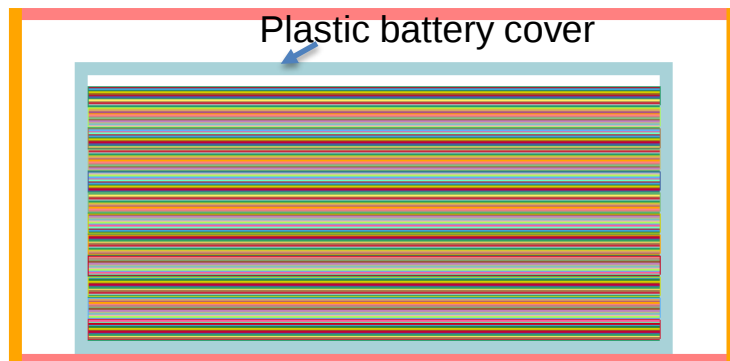
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Ballistics system level setup

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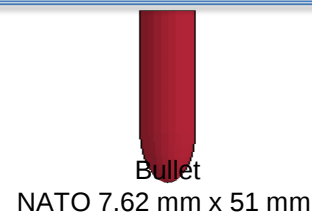


45 Degree oblique impact



0 Degree horizontal impact

- o Full battery module with 1762 layers was impacted with three different loading conditions
 - ✓ Vertical impact
 - ✓ Oblique impact @ 45 degrees
 - ✓ Horizontal impact
- o Casing represents generic vehicle structure.
- o Analysis was performed with two casings
 - ✓ Case1 – 1" RHA
 - ✓ Case2 – 1" Aluminum



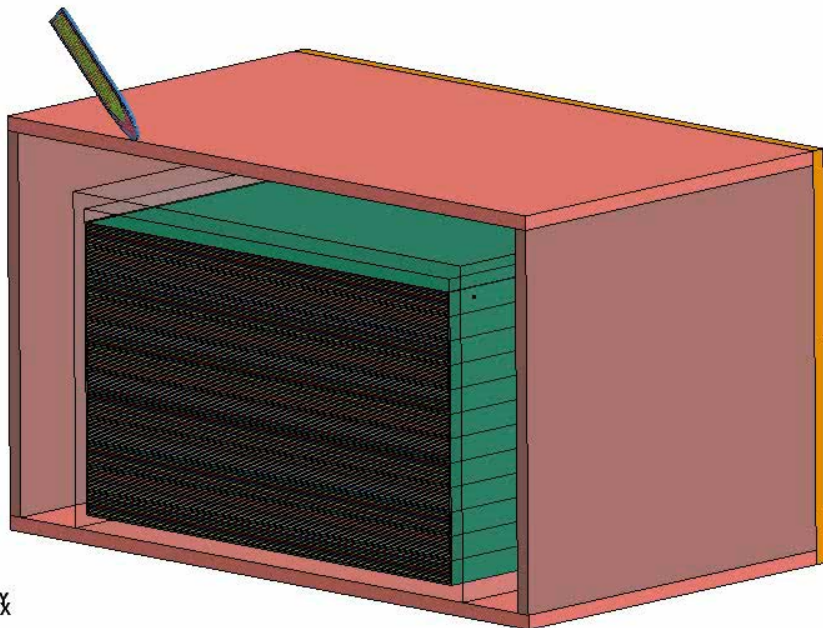
90 Degree vertical impact

BASIMLIB – Oblique impact animation

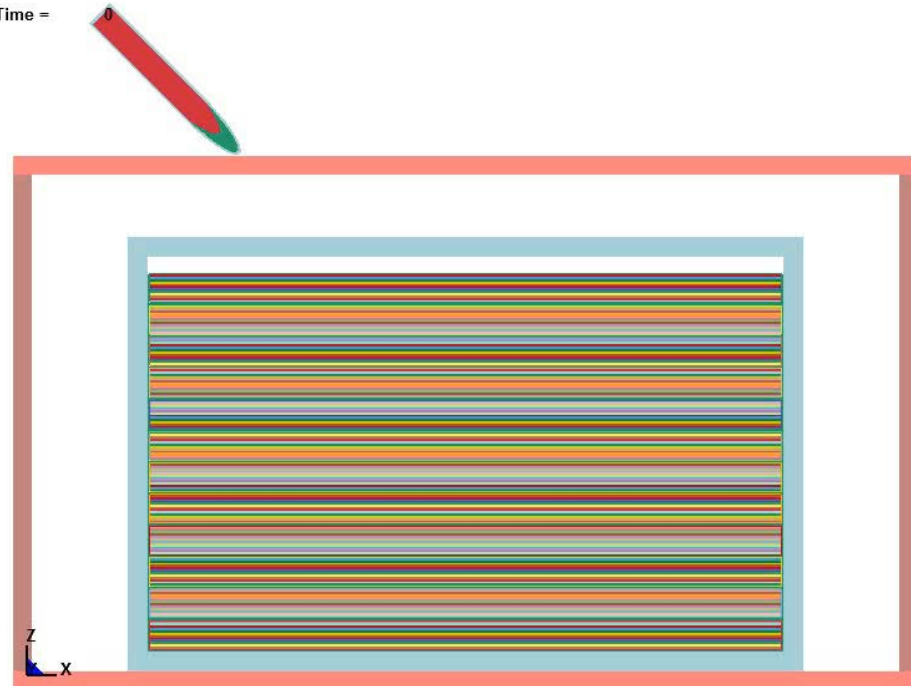
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Time = 0



Time =



Animation of 45 deg oblique bullet impact with Aluminum Structural Enclosure

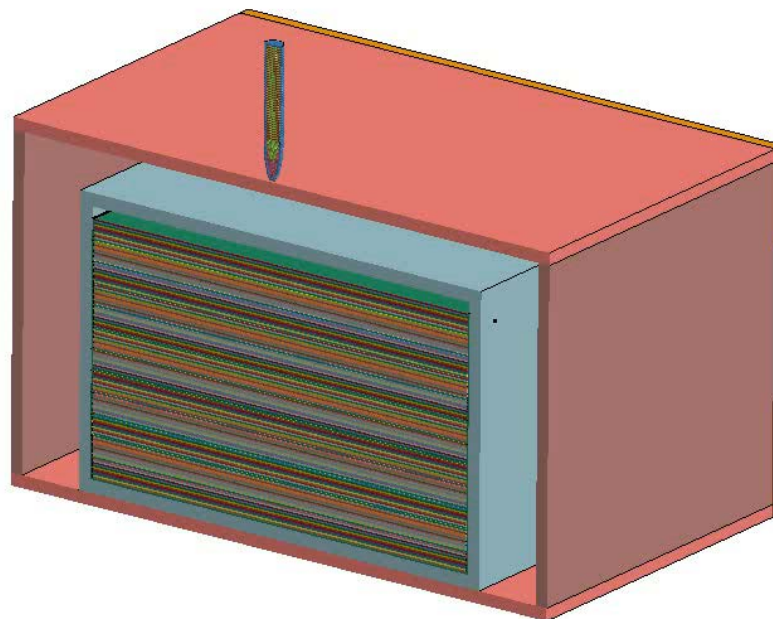
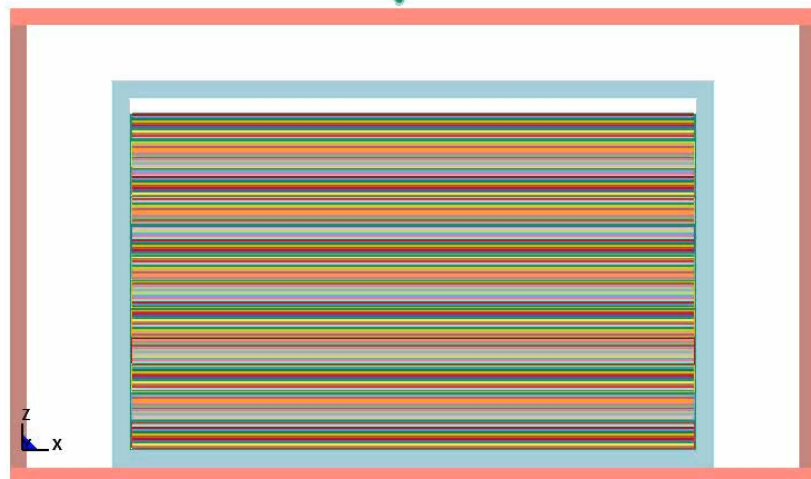
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90 Degree impact animation

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Time = 0



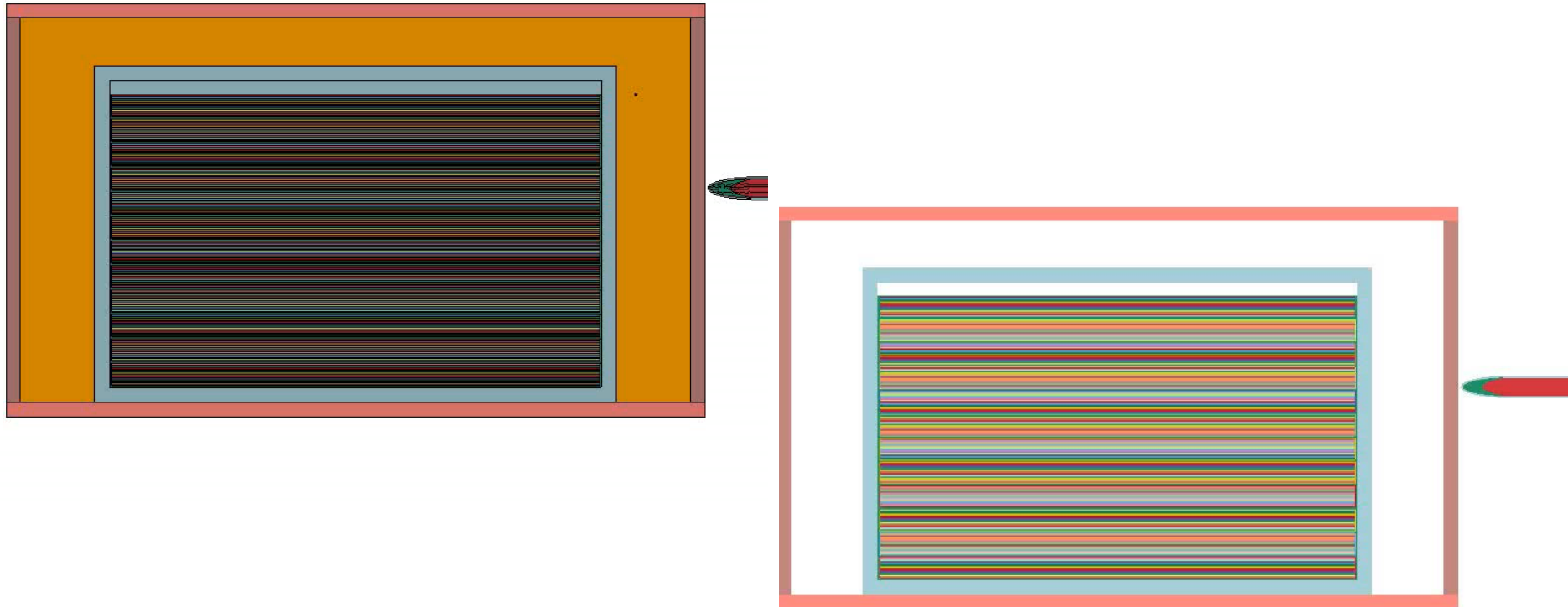
Animation of vertical bullet impact with Aluminum Structural Enclosure

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Zero degree lateral impact animation

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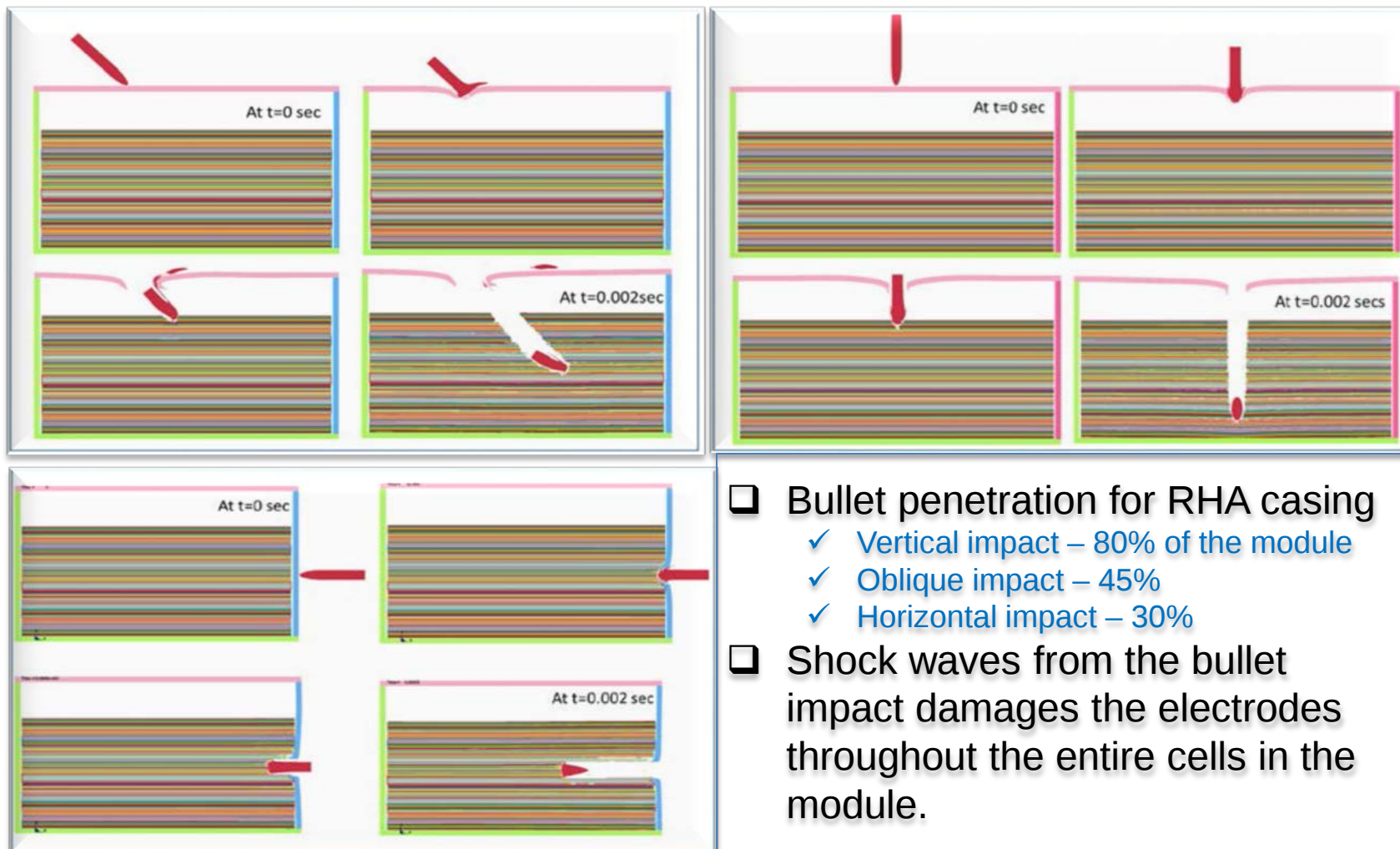
Animation of horizontal bullet impact with Aluminum Structural Enclosure

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Deformed Cell Layers with RHA Casing

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BASIMLIB – Summary & Conclusion

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- Lithium Ion Phosphate (LiFePO_4) battery cell, module and pack was modeled in LS-DYNA using both Thin Shell Layer (TSL) and Thick Shell Composite (TSC) methodology. This approach can be applied to other Lithium based battery chemistry
- Three bullet loading conditions were considered, 90 degree vertical, 45 degree oblique and zero degree horizontal
- Both TSL and TSC battery methods are correlated to a two cell ballistic test successfully for mechanical failures. Thermal runaway and short due to electric shock was not considered in this simulation
 - ✓ Thickness of Li-Ion batteries layers were modeled at micro scale.
 - ✓ NREL provided Anode, Cathode, Separator and electrode properties were used in this model
 - ✓ Vehicle enclosure is modeled with RHA steel with Johnson-Cook strength and failure material model.
 - ✓ Battery module is enclosed in a plastic casing.

BASIMLIB – Summary & Conclusion

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- Strong anisotropic deformation behavior of battery cells are captured in all the loading cases are shown in slides 3, 4, 5
- Shock waves from bullet impact damages the electrodes throughout the entire cells in the battery module in all the three loading conditions.
 - ✓ This may result in high temperature and thermal runaway.
- Thick Shell Composite model has 2.5 million elements compared to 12.5 million elements for Thin Shell Layer model per pouch cell.
 - ✓ One battery module was represented with 12 pouch cells with 1,768 layers consisting of positive & negative current collectors, anodes, cathodes (LiFePo₄), separators and electrolytes) using TSC



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Thank You