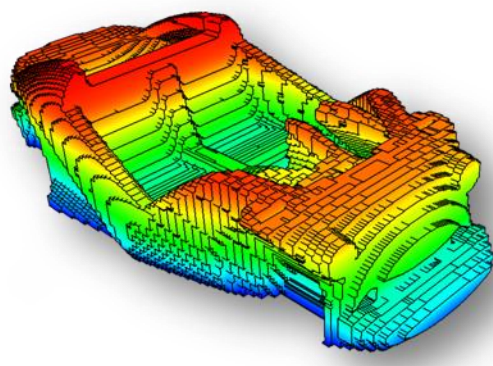
GENOA Tested and Verified.™

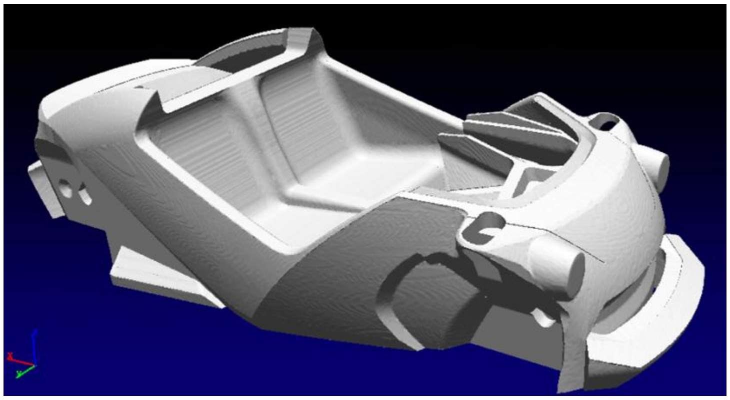
3-D Printing Simulation

AlphaSTAR Corporation (**ASC**) is collaborating with Oak Ridge National Laboratory (**ORNL**) to offer 3-D printing simulation using GENOA suite of software to accurately predict the deflection, residual stress, damage initiation, and crack growth formation observed by 3-D printing machines. Advanced Multi-Scale Progressive Failure Analysis (**MS-PFA**) methods are used to determine the entire 3-D printing process at two levels: **1) Material Characterization** using quick and accurate analysis without the use of FEM and **2) Structural MS-PFA** that simulates the entire 3-D printing process using FEM. With the ability to import directly from the printer STL file and simulate the printing process, GENOA offers a micro view of the crack and damage formation that may occur.

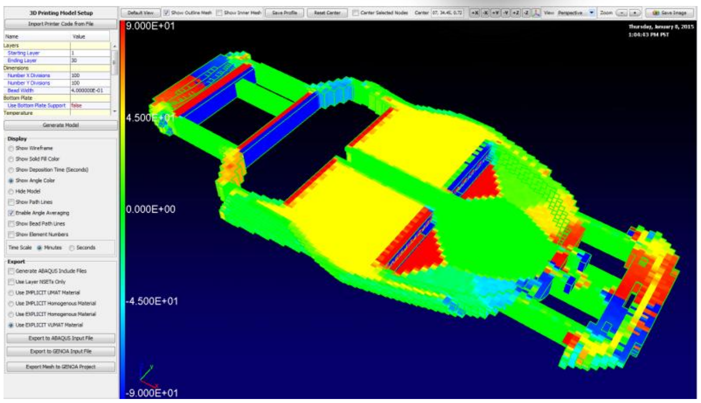
Automated FE Mesh Generator

- Import from G-Code Printer Code File (from STL source)
- Big Area Additive Manufacturing (**BAAM**) for fiber reinforced thermoplastics which can be extended to thermosets as well
- Re-simulate printing paths with bead width, angle and timing precision
- Define resolution of solid element model from low to high fidelity
- Preview or refine individual layers, with the option to mesh and include bottom plate for additional heat transfer variables
- Export either specific or all layers to ABAQUS input deck for analysis





Import from STL file to generate G-Code printer file that provides actual printer machine instructions

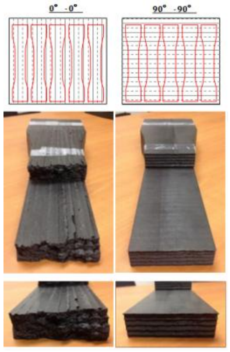


Visualize layer-by-layer the angle and time calculated in every element determined by paths printed

Material Characterization & Qualification - Chopped

MCQ Chopped Tested and Verified.™

- ✓ **Chopped Mechanics:**
  - Predict aligned, in-plane random and 3D random material properties
  - Reverse engineer effective constituent material properties
- ✓ **Orientation Distribution Determination/Orientation Tensor Determination:** Predict effective % orientation distribution of the fillers through-thickness
- ✓ **Chopped Characterization:** Graphically verify the variation in aligned layer properties with variation in constituent material properties and manufacturing variables
- ✓ **Material Nonlinearity:** Predict aligned layer, 2D random, 3D random and user defined layup stress-strain curve using matrix stress-strain curve as input.
- ✓ **Aligned Layer Nonlinearity:** Reverse engineer aligned layer stress-strain curve from flow or cross-flow direction test stress strain curve
- ✓ **Progressive Failure: Predict damage evolution, damage growth and final failure for chosen orientation (e.g., user defined, flow or cross-flow direction un-notched coupons)**
- ✓ **Design Failure Envelope:** Predict damage initiation and final failure of coupons subjected to biaxial loading
- ✓ **Parametric Carpet Plot:** Effective material property prediction for several different orientation % distribution of plies through-the-thickness
- ✓ **Material Uncertainty:** Predict average material properties (flow, cross-flow, user defined) directions considering material uncertainty, orientation, and thickness effect
- ✓ **Fatigue:** Predict effective S-N curve for the aligned layer, 2D random, 3D random and user defined orientation using matrix S-N curve as input



	MCQ	TEST	Ply-Layup
E (Msi)	1.09	1.19	0-0
E (Msi)	0.36	0.327	90-90
S (Ksi)	6.98	7.73	0-0
S (Ksi)	2.03	1.87	90-90

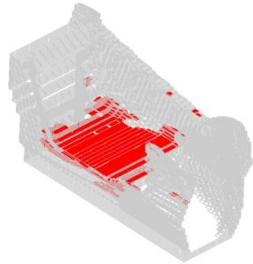
3-D Printing Simulation

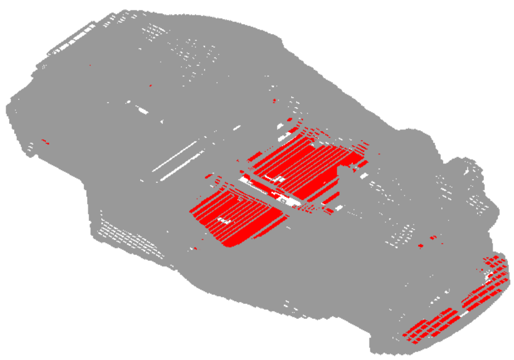
In addition to the prediction of damage initiation and crack growth formation observed by 3-D printing machines, AlphaSTAR Corporation's GENOA software can visualize damages in the printed structure. Damage types (fiber, matrix, several delamination types – transverse shear, fiber crushing, fiber microbuckling, relative rotation, out of plane stresses) can be visualized and highlighted (identified) separetely in the GENOA GUI. Damage can be traced directly to 3D printing variables (deposition speed, bead width, overall path, bottom plate temperature, convection conditions, and, if necessary, radiation to enclosures and within itself) as well as material variables (fiber, matrix, chopped - agglomeration, long fiber waviness). This allows manufacturers to produce robust designs with predictable strength and fatigue life in a timely manner.

Temperature Changes, Damage Initiation, and Delamination Prediction

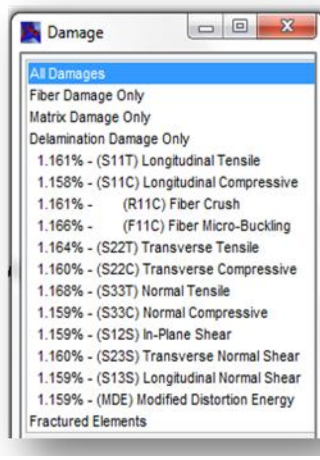
- Fully coupled structural and thermal/heat transfer model performed
- Damage types (fiber, matrix, several significant delamination types)
- Change printing and material variables to meet design requirements
- Post manufacturing strength/life predicted with any FE solver

Delamination Identified in Seat Region

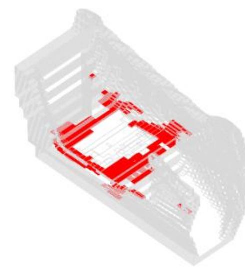




Full car model (420,000 elements, 4M dof), coupled structural/thermal/heat transfer simulated in 15 hours with 48 cpus on linux server (motherboard)

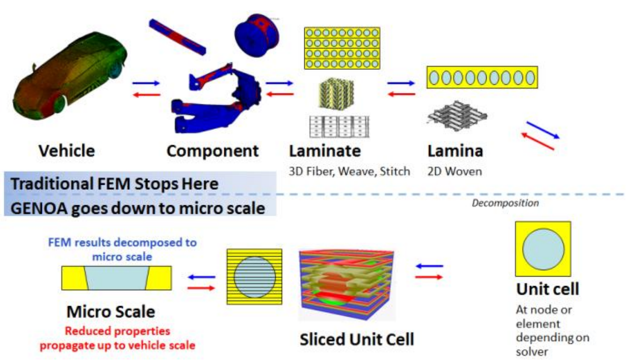


Delamination Reduced by Decreasing the Layer Deposition Time



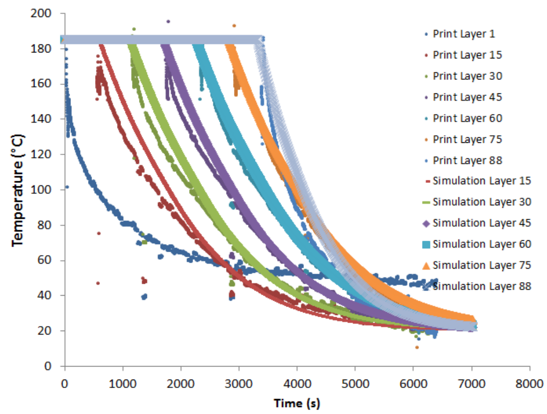
Identify root cause damage as either 3D printing variables (deposition speed, convection, bead width, etc…) or material (fiber, matrix cracking, or delamination)

Proven Multi Scale Technology

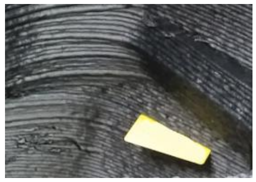


Test Verified Heat Transfer Simulation

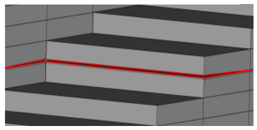
Convection, radiation, conductivity, with thermal gaps at every element and every layer.



Cracks From Printed Items Also Seen In Simulation



Cracks From Simulation Highlighted



References

1. Abumeri, G. H., Lee, M., (2006). *A Computational Simulation System for Predicting Performance of Chopped Fibers Reinforced Polymer Composites*. ERMR-2006-Elastomer-Reno.

2. Kunc, Vlastimil, Scott W. Case, Hector J. Santos-Villalobos, and Srdjan Simunovic. *The Stiffness Tensor for Composites with Curved Discontinuous Fibers*. Composites Part A: Applied Science and Manufacturing (2014).

3. Tekinalp, Halil L., Vlastimil Kunc, Gregorio M. Velez-Garcia, Chad E. Duty, Lonnie J. Love, Amit K. Naskar, Craig A. Blue, and Soydan Ozcan. "Highly oriented carbon fiber–polymer composites via additive manufacturing." Composites Science and Technology 105 (2014): 144-150.

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