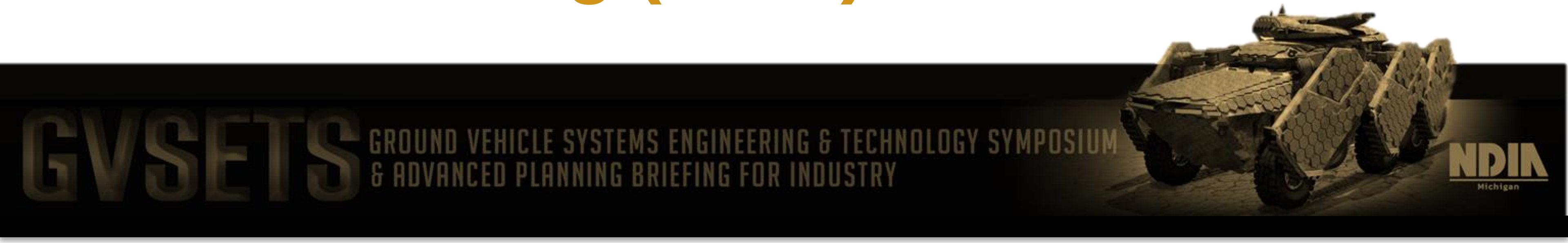
Advanced Materials & Manufacturing (AAM)



DESIGN OPTIMIZATION OF COMBAT VEHICLE DRIVER'S SEAT USING ADDITIVE MANUFACTURING AND COMPRESSION MOLDING

Robert J Hart[1], J. Scott Perkins[2], Brina Blinzler[2], Patrick Miller[2], Yang Shen[2], Ankit Deo[2]

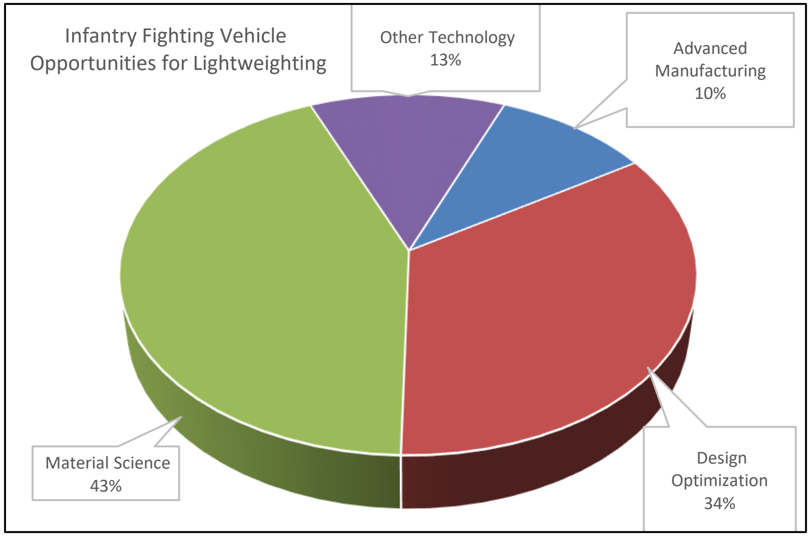
[1]US Army DEVCOM Ground Vehicle Systems Center, Warren, MI
[2]Arris Composites, Berkley, CA

Outline

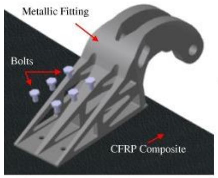
- Introduction
- Methods
- Results & Discussion
- Conclusions

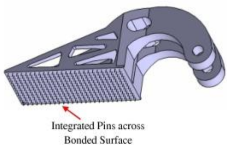
Advanced Materials & Manufacturing (AMM)

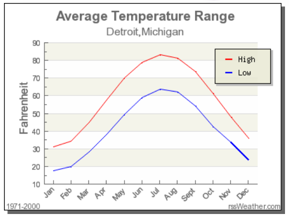
- *A Summary on the 2018 Update to Lightweight Combat Vehicle S and T Campaign*
  - Materials science combined with design optimization provides the greatest potential for weight savings in future combat vehicles.
  - Design Optimization, with advanced manufacturing as a recent enabler, continues to provide significant low-risk, high-reward opportunities for lightweighting ground vehicles.



- Historical Barriers to Integrating Composite Materials in Ground Combat Vehicles
  - Raw Material Cost
  - Design Methodologies / Modeling & Simulation (M&S)
  - Manufacturing / Tooling Cost
  - Flame / Smoke / Toxicity Characteristics
  - Long Term Environmental Exposure
  - Integration techniques







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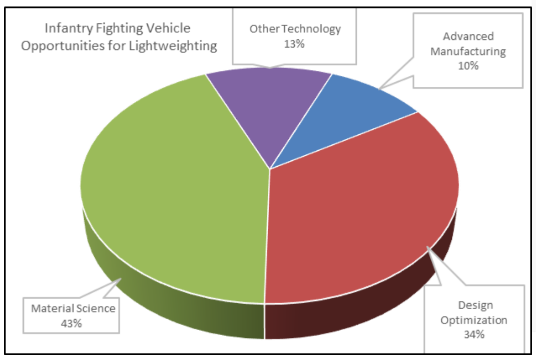
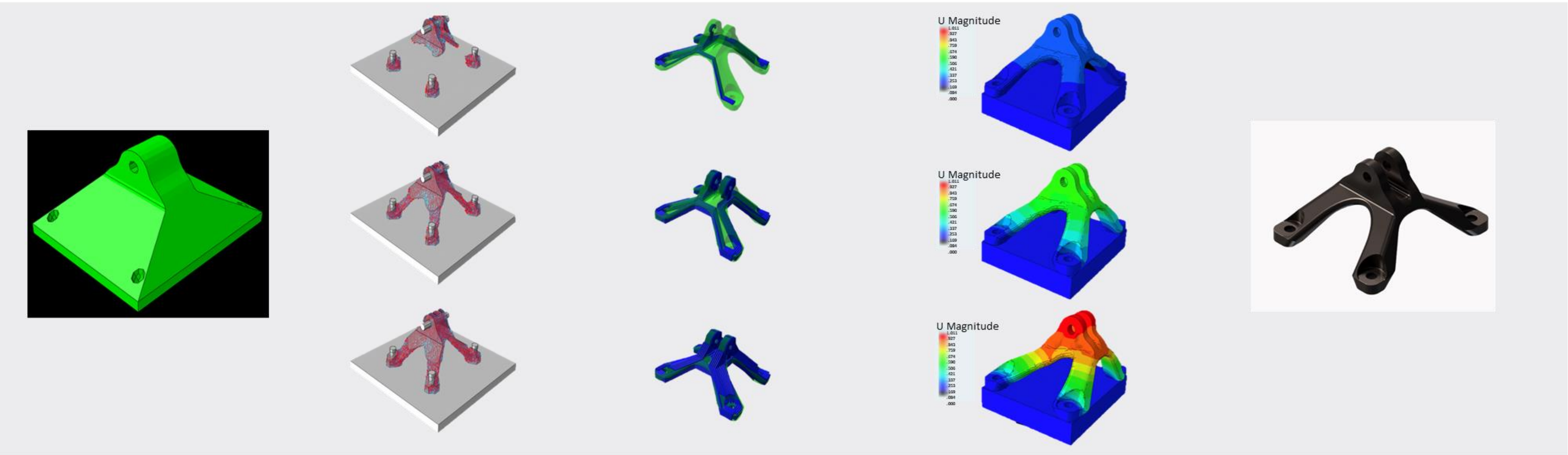


Manufacturing Capabilities & Economics:
Additive Molding™ Design Phase



1. Define Requirements

   Functional, Geometric, Etc.

2. Computer Aided Design (CAD)

   Topology & Fiber Alignment-Optimization

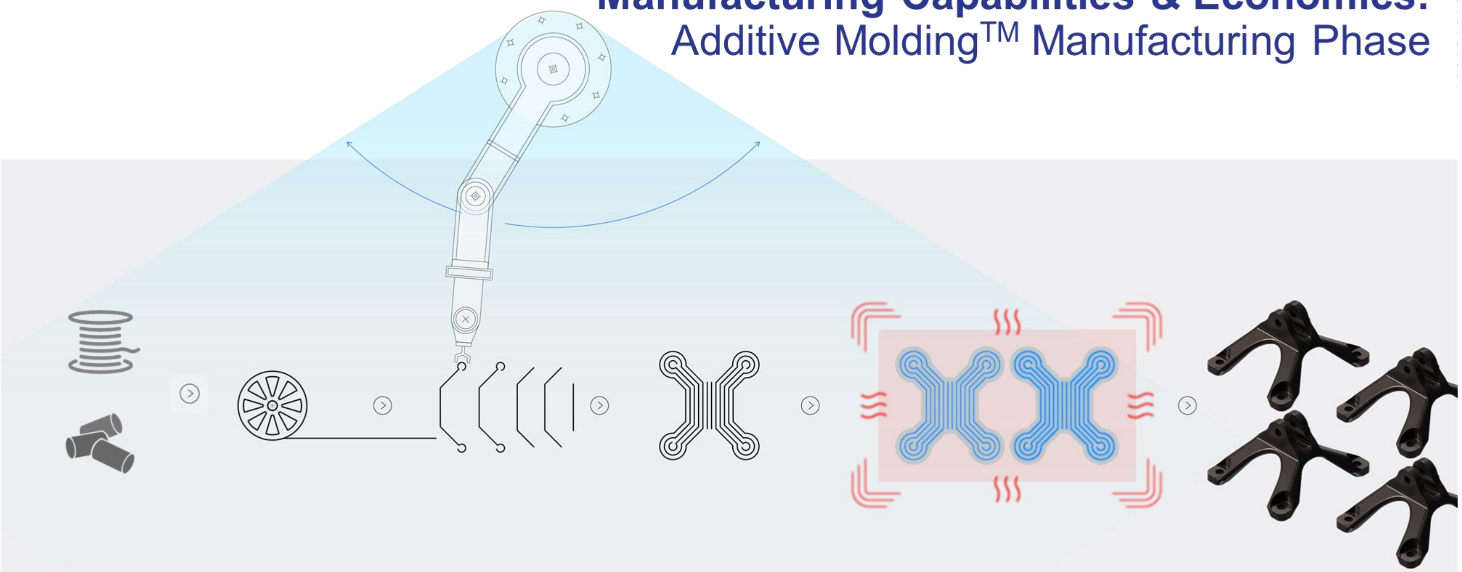
3. Computer Aided Manufacturing (CAM)

   Additive Molding System Manufacturing Instructions & Composite Preform Design

4. Computer Simulation of Part

5. Final CAD & CAM locked

Manufacturing Capabilities & Economics:
Additive Molding™ Manufacturing Phase



1 Raw Material

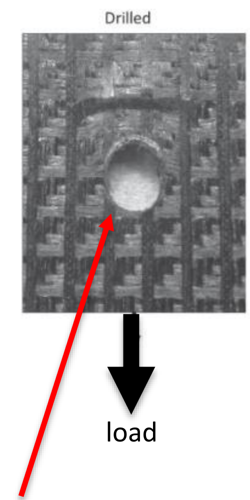
2 Impregnation Of Composite Material

3 Preformed Composite
4 Pieces Assembled Into Near-Net-Shape Composite Preform Assembly

5 Mold Processing Of Preformed Composite Material

6 Final Part + Testing

vs. traditional



Drilled holes lead to broken fibers/weak points

- The objective of this effort was to design a lightweight composite driver's seat for a ground combat vehicle (see Fig. 1) using fiber-reinforced thermoplastic composites and the Additive Molding™ manufacturing process.
- Due to the severe operating environment of a combat vehicle, the driver's seat would need to be tolerant of extreme dynamic mobility loads (see Fig. 2.), varying thermal loads (from arctic to desert climates), as well as resistance to flammability, smoke generation, and toxicity (FST).

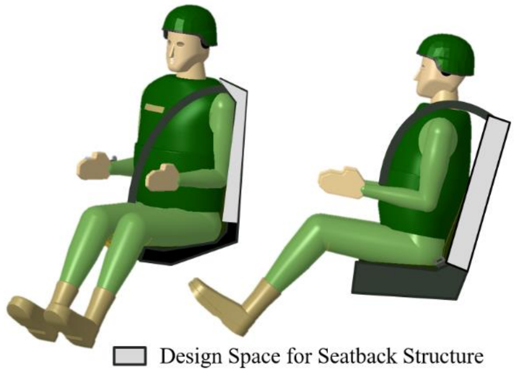


Figure 1: Representation of a 95th-percentile male soldier seated with the allowable design space for the optimized seatback structure defined.

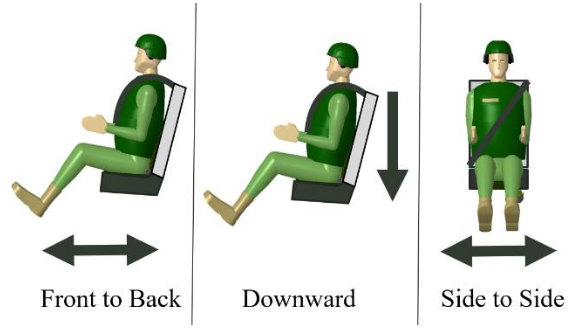


Figure 2: Mobility load cases used for optimizing the design of the driver's seatback structure.

Methods

- The challenge of light-weighting a load bearing structure made with continuous carbon fiber composite can be formulated as a multi-objective minimization problem.

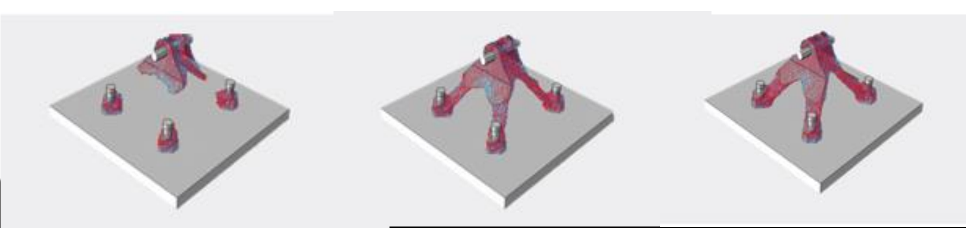
$$\min_{x,u}(U(x), r(u))$$

$$\textit{subject} \quad \frac{V}{V_0} \le \eta$$

$$0 \le x \le 1$$

  - Where **U** denotes the strain energy and measures global stiffness, **r** denotes a vector of failure indices, one per each finite element, and measures local strength.
  - The light-weighting criteria is formulated as a constraint to achieve a target volume fraction, η. Finally, the densities are bounded to values between 0 and 1

- A traditional approach to solving this problem is to sequentially design the topology using a proxy isotropic material and thereafter optimize the fiber orientation for the previously optimized shape, which does not account for the anisotropy of the reinforcement during the shape definition stage, resulting in not leveraging the full design latitude of design for functional requirements.
- Taking advantage of the anisotropy of the reinforcement requires solving the topology and fiber orientation simultaneously.
  - The solution to this problem must use computer resources efficiently to scale up many parameters.
  - Requires a manufacturing process capable of aligning the fibers along the complex shapes that may result thereof. Arris Composites, Inc., patented Additive Molding ™ provides a solution to this problem.

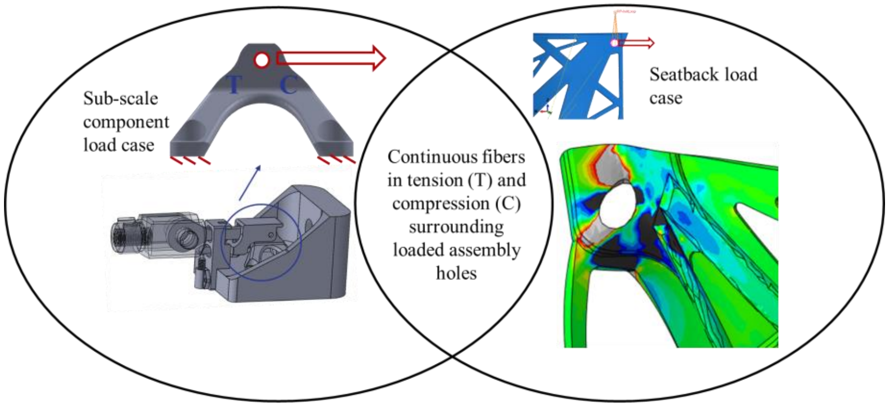


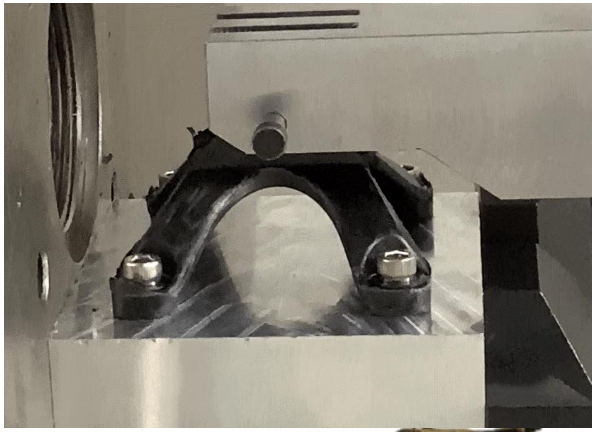
Computer Aided Design (CAD)

Topology & Fiber Alignment-Optimization

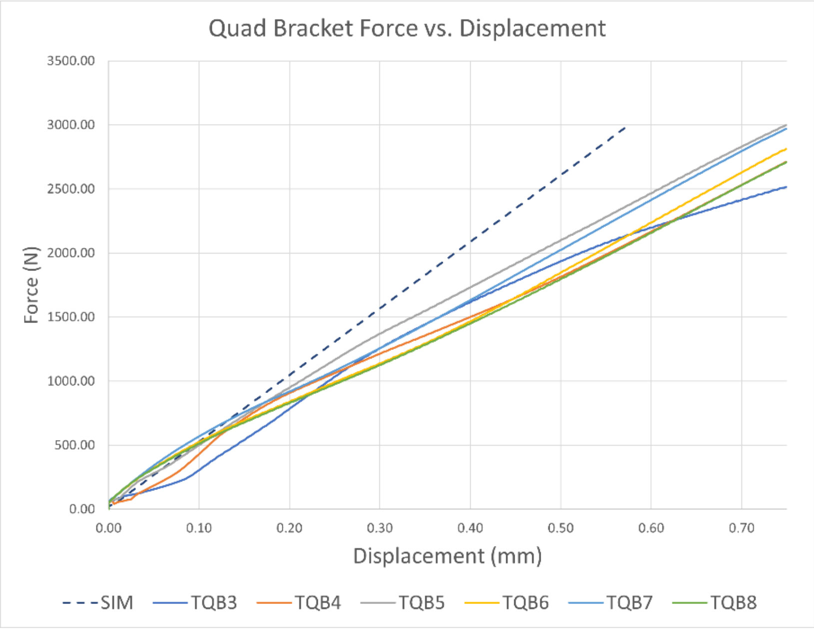
Methods – Subscale Manufacturing & Testing

- Due to scope constraints, proxy part would be delivered and tested in lieu of a full or partial seatback geometry. The chosen proxy part is a 4-prong bracket (aka quad bracket), developed internally by Arris previously, which is loaded analogously to the seatbelt attachment hole on the seatback component (see Fig. 3). Quad bracket performance was assessed both in simulation and empirically.
- The comparison between the simulated and actual performance of the quad bracket informs the simulation accuracy in a representative manner, thereby providing proxy verification of the seatback simulation results.
- The same simulation method is used for both parts, so accuracy of results is independent of geometry and size.
- This verification by proxy is NOT intended to substitute empirical testing of the actual seatback component, but rather to feasibly provide as relevant data as possible to inform simulation accuracy.





- The primary assessment criteria for testing of the quad bracket part was consistency across samples (i.e. precision), while comparison between empirical and simulated results (i.e. accuracy) was secondary.
  - Precision being the primary criteria evaluates the capability to consistently product complex parts having continuous fiber alignment, while accuracy being the secondary criteria informs factor of safety specification. Without precision, factor of safety accuracy would thus be inconsistent.
- For the tested sample set, the average measured stiffness was 4094.84 N/mm, with a standard deviation of 366.73 N/mm and coefficient of variation (CV) of 8.96%. The simulation predicted stiffness was 5820.17 N/mm.



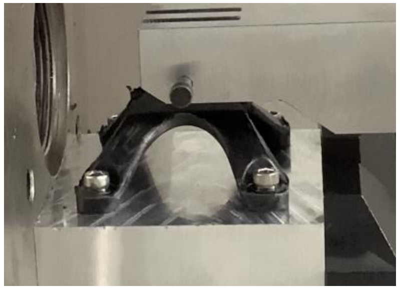
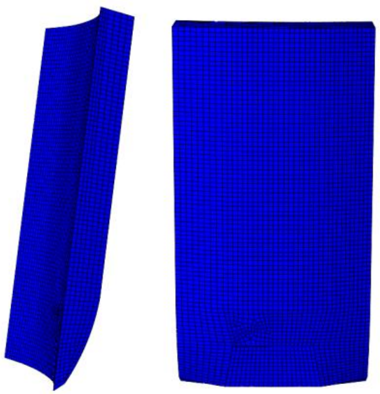
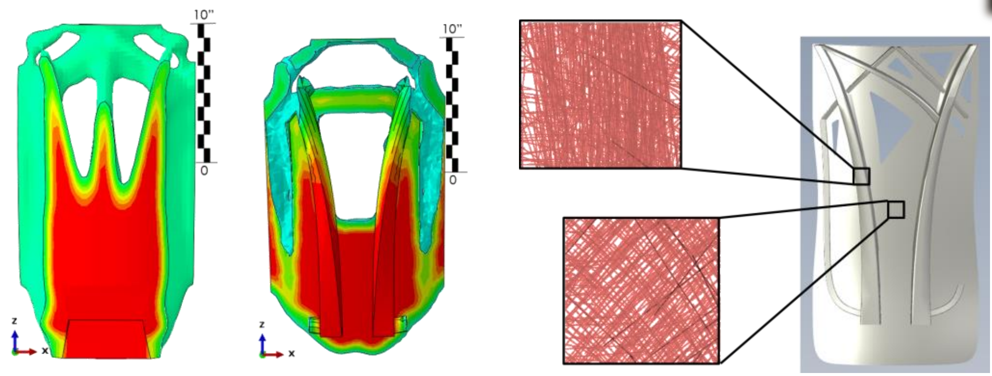


Figure 4: Graph showing the quad bracket force vs. displacement trend predicted by simulation (SIM, dashed line), as well as the measured force vs. displacement trends of the six samples (TQB3-8, solid lines).

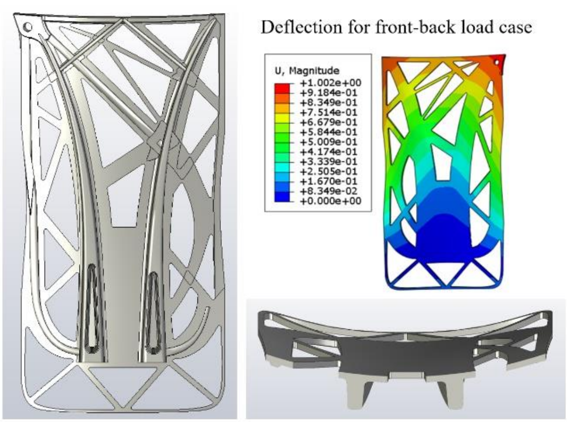


1. Initial Design Envelope



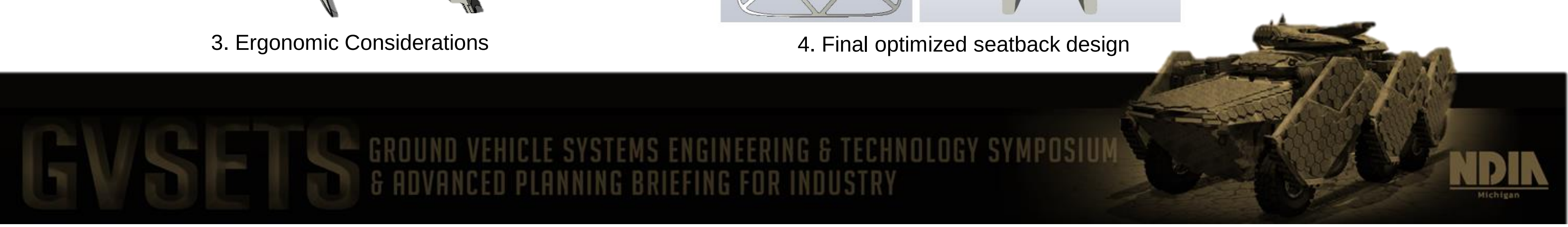
2. Topology Optimization simultaneous with tailored fiber orientations

3. Ergonomic Considerations



4. Final optimized seatback design

18 lbs to 3.6 lbs. 80% weight savings.



Conclusions

- This paper focused on the application of a novel Additive Molding™ process in the design optimization of a combat vehicle driver's seat structure. The design was optimized to account for mobility loads and a 95-percentile male soldier, and the result was a reduction in weight from 18 to 3.6 pounds, which was an 80% weight savings. One critical design feature identified in the seatback was the location where the seatbelt loop attached to the seat structure. This novel manufacturing process enabled the optimized design to utilized fibers oriented around the attachment points, which is not possible in traditional composites manufacturing.
- A subscale bracket was manufactured and experimentally tested to simulate the performance of the carbon fiber / polycarbonate material in the location of the seatbelt loop, and the results showed that the tailored fibers wrapped around the bolt location successfully reinforced the hole and effectively carried the simulated seatbelt loop load.