MULTISCALE SYSTEMS

Projectile Motion

Achieving Long Distance Aerial Delivery

White Paper **MetaCORE™**

Market: Defense

Application: Future Aerial Delivery Systems

Solution: MetaCORE

Keywords: aerial delivery; cargo airdrop; impact protection; crashworthiness; lightweight; JPADS; isotropic; pro-isotropic; honeycomb alternative; anti-access; anti-access area denial; area denial; A2/AD

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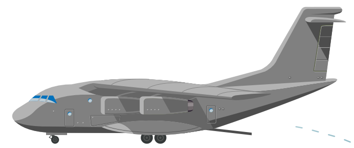
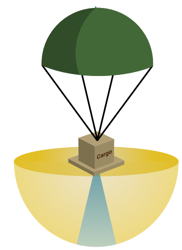
Executive Summary



Focus Area: Soldier Lethality and Survivability through Expeditionary Force Sustainment.

Technology Statement: We make lightweight high-performing energy absorbing materials to mitigate damage from unpredictable high-impact loads.

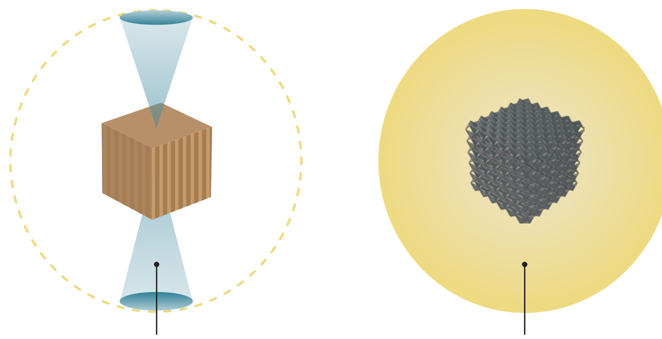
Impact Statement: “Every pound of payload successfully delivered is another pound of food, water, and equipment for the Soldier.”



Problem Statement: Air dropped payloads require impact-mitigating solutions to ensure cargo is delivered 100% mission capable. Current missions use cardboard honeycomb as an energy absorbing device to “soften” the landing. The operational envelope of cardboard directly constrains payload size, weight, drop times, horizontal glide distances, and speed. Future missions involving large horizontal glides are outside the operational envelope of cardboard honeycomb due to its poor shearing properties.

Solution: MetaCORE is an advanced material with isotropic energy absorbing properties that eliminates the 200% to 600% asymmetry in cardboard honeycomb’s material properties. It was developed by Multiscale Systems under a NASA SBIR Phase I/II contract as a lightweight low-cost material for non-defense aerospace and ground vehicle applications (est. ~$1Bn commercial market). With some modification to the existing manufacturing process, it would be an ideal energy absorber for vastly expanding airdrop operational envelopes. This is a dual-use technology with TRL 4 for aerial delivery applications.

Needs: Manufacturing MetaCORE from natural fibrous/pulp materials is required to be cost-competitive with current cardboard honeycomb and to achieve biodegradability/flammability for easy disposal. Low throughput manufacturing is currently feasible, but further development is required to scale up production.



Honeycomb’s operational envelope is a pair of cones covering 3.4% of a sphere.

MetaCORE’s operational envelope is a sphere offering 100% omni-directional coverage.

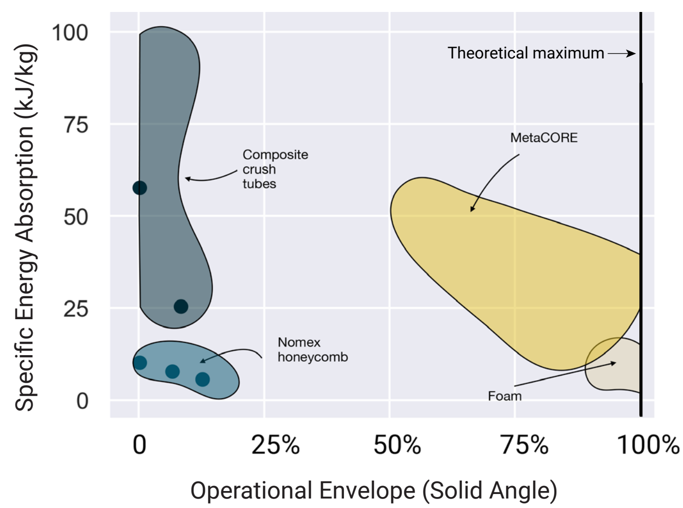


Figure 1: *MetaCORE is a lightweight energy-absorbing replacement for honeycomb that offers 30x improved performance without increasing weight, costs, or logistical challenges.*

Value Proposition:

- 30x increase in the operational envelope for impact mitigation compared to honeycomb (Fig. 1).
- Enabling longer glide distances and larger horizontal speeds necessary to overcome A2/AD threats.
- Manufacturable in a format compatible with existing rigging specifications and agnostic to cargo type.
- Lightweight material increases expeditionary value.
- Natural fiber/pulp-based fabrication adds no additional signature and requires no power source.
- Biodegradable polymer formulation enables heavier payloads while reducing total system mass and volume.

Fast Facts About the Technology and Team:

- Material design technology discovered and developed in the Physics Departments of Cornell University and University of Massachusetts, Amherst, as well as Harvard University's Wyss Institute.
- Multiscale Systems is a small, domestically owned business in the ASA(ALT) xTechSearch 4 and Innovation Combine cohort of "non-traditionals" with disruptive new technologies responsive to Army modernization priorities. We have experienced stable growth since forming in 2018 by developing advanced materials for dual-use applications.

Summary video: multiscalesystems.com/resources

Acquisition ROIs

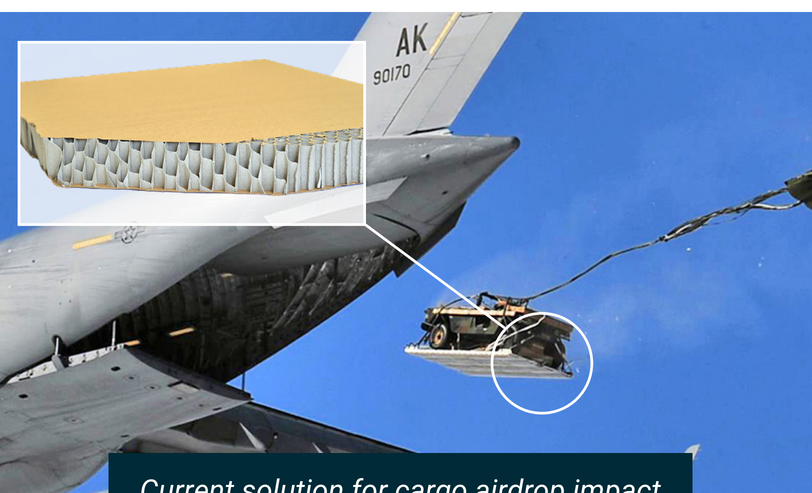
Performance
30x improved operational envelope

Size, Weight, Power, Cost
Comparable to current solution

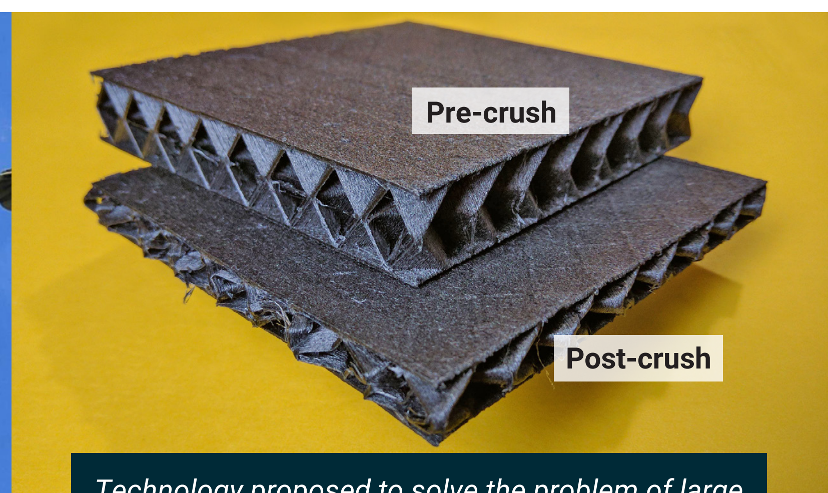
Schedule
Prototype ready for integration testing; 12-24 months to TRL 9

Risk
Comparable to a SBIR Phase II effort

Life Cycle (Obsolesce Risk)
Dual-use technology targeting 5:1 commercial:defense revenues



Current solution for cargo airdrop impact absorption: cardboard honeycomb.



Technology proposed to solve the problem of large horizontal impact velocities: MetaCORE.

Visual Abstract: In this white paper, we present quantitative data on MetaCORE demonstrating its ability to offer greater multi-directional energy absorption than current solutions. This pro-isotropic capability is comparable to cardboard honeycomb in terms of energy absorption, mass density, and cost, but provides greater predictability in variable landing conditions and high horizontal-velocity landings. MetaCORE is extremely lightweight (comparable to foams), increasing its expeditionary value.

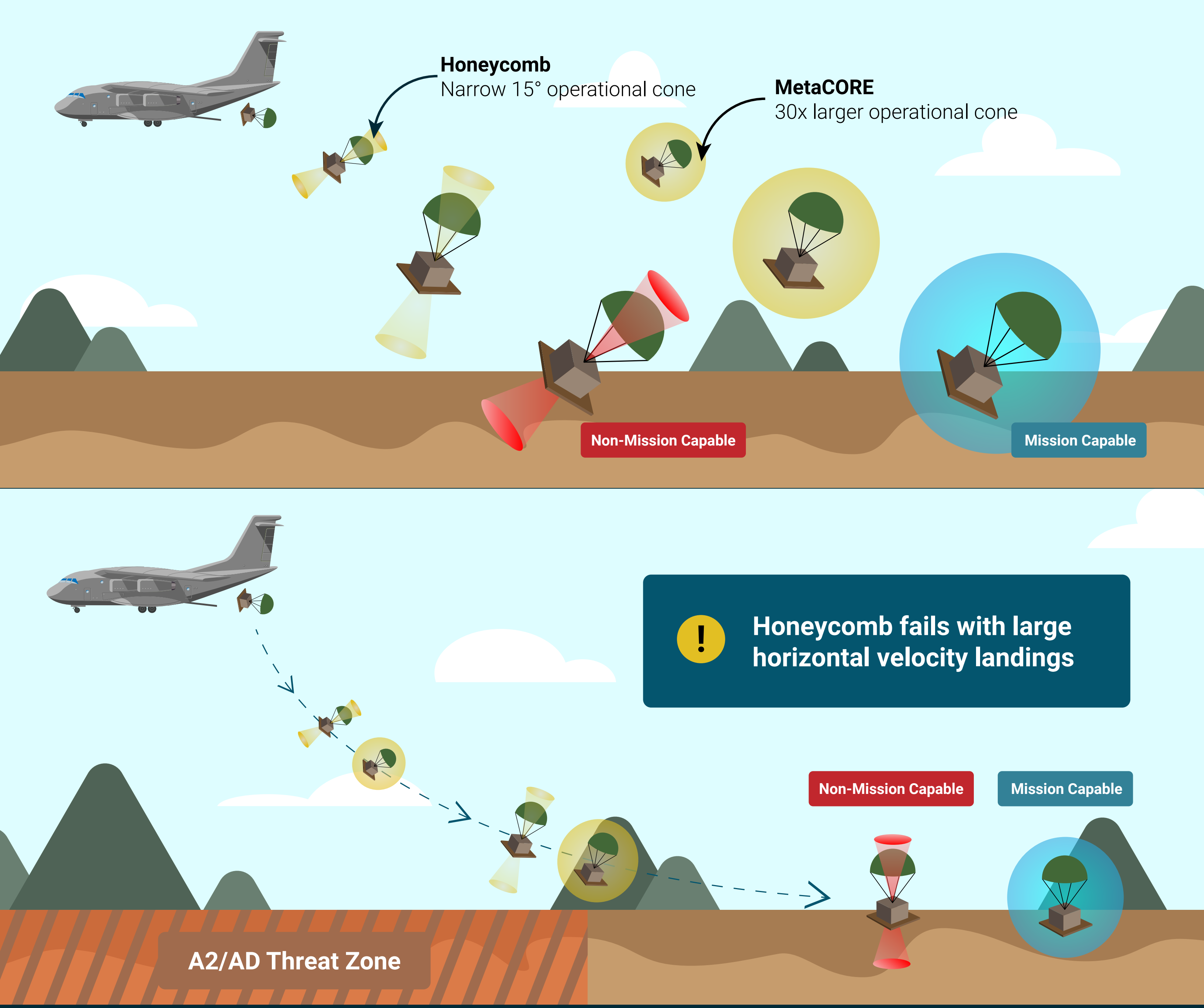


__Figure 2:__ Current airdrops require near-vertical landings to ensure 100% mission capable cargo delivery. Tomorrow's airdrops need to achieve much larger horizontal glide distances, which induce shearing forces beyond what today's solution can support. Because its energy absorbing properties are omni-directional, MetaCORE increases today's operational envelope and enables tomorrow's missions.

Aerial Delivery and Impact Absorption

Operational Challenges Motivate Technical Innovation

Countless words have been written arguing the significance and implications of Anti-Access (A2) and Area Denial (AD) for future defense operations. A2/AD has emerged as a framework for understanding the various challenges presented by entry into adversarial theaters, which are increasingly challenged by loss of overmatch capabilities in the post-Cold War era. U.S. strategists must de-risk missions, ensure Soldier survivability, and achieve the highest probability of operational success. However, hostile A2/AD capabilities introduce potential for insufficient on-ground supplies and require greater planning of air, sea, and ground force contingencies.

One tool for responding to A2/AD challenges is aerial delivery of combat equipment, ammunition, food, and water. When successful, aerial delivery facilitates faster ingress/egress, achieves greater signal reduction, and increases ground force capabilities. Given the range of materiels required to support an agile force, aerial delivery platforms including Joint Precision Aerial Delivery Systems (JPADS), High Altitude Low Opening (HALO), and Airdrop from Unmanned Aerial Systems (UAS) are available to respond to specific needs. Even though there is variety in the operational envelopes for these aerial delivery systems, they all fundamentally face the same technical challenge: ***hard impacts break stuff.***

Parachutes, airbags, and Energy Absorbing Devices (EADs) are various technical solutions to achieve softer landings and ensure mission-capable delivery of supplies. The new challenge introduced by A2/AD is an increase in the *horizontal travel distance between air drop and landing site* which is now necessary to respond to the emerging threat environment. These large horizontal offsets allow aerial delivery to operate outside the A2/AD threat, but increase the loss rate of deployed cargo, potentially resulting in non-mission capable delivery.

Increasing demand for multi-domain operations combined with the A2/AD threat put current aerial delivery solutions under pressure to continuously innovate and achieve high delivery success rates of *larger cargo* with *increased precision* from *greater distances*.

Technical Considerations for Successful Aerial Delivery

Airborne force projection and aerial delivery capabilities are dependent on the ability to mitigate damage from impact. This subject has an extensive history and various metrics for crash protection are already established. These metrics help to optimize and evaluate the effectiveness of EADs while remaining agnostic to the crash-protection technology. Characteristics of high-performing EADs include: (1) irreversible energy conversion from kinetic energy to inelastic energy through brittle fracture, plasticity, viscous losses, etc.; (2) low bare compressive strength (or “peak stress”) to minimize the deceleration at impact; (3) constant crush strength (or “crush stress”) to balance high energy absorption with low acceleration; (4) a long stroke distance to maximize the work done by the EAD; and (5) repeatable deformation characteristics across a wide range of loading conditions and orientations (see Fig. 3 for an example of a typical EAD load-compression curve along the axis of compression). From these five desirable EAD characteristics, the metrics an effective solution should optimize for include:

- **Specific Energy Absorption (SEA):** SEA is the amount of energy absorbed per unit mass for a material, device, or component. SEA is one of the most commonly reported metrics, and potentially the most informative for a single number. The upper limit for the SEA may be calculated by dividing the crush strength by the *effective EAD mass density*.
- **Crush Force Efficiency (CFE):** CFE is the ratio of the crush stress to the peak stress. This metric determines the uniformity of the crushing stress. If an EAD has a low CFE, it is likely to cause damage since the deceleration forces will be large. An ideal EAD has a CFE = 1, which means the impact decelerations are efficiently mitigated.

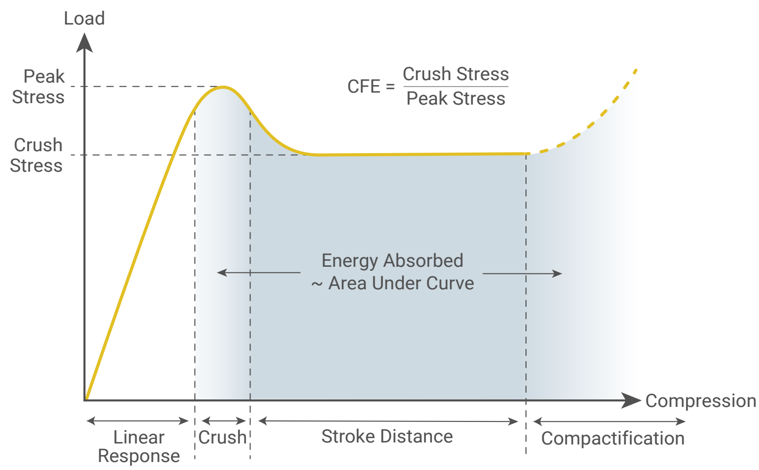


***Figure 3:** Typical load-compression curve for an energy absorbing device relating metrics of performance to desirable characteristcs. An ideal EAD load compression curve is shaped like a rectangle.*

These two quasi-static metrics of energy absorption and crush efficiency are useful since data showing impacts at speeds <20 meters/sec generally activate quasi-static failure response. Beyond a standard System, Weight, Power, and Cost (SWaP-C) analysis, SEA, CFE, and their directional dependence are key technical metrics. Potential solutions responsive to A2/AD threats that increase the airborne delivery operational envelope must therefore balance and optimize these (sometimes competing) performance characteristics.

Current Solutions for Aerial Delivery

Aerial delivery systems utilize multiple overlapping solutions to successfully protect cargo and achieve soft landings. To respond to the A2/AD threat and increase horizontal offset distances for advanced cargo infiltration we must first understand the operational envelope of these existing solutions and their ultimate limitations.

Cardboard Honeycomb

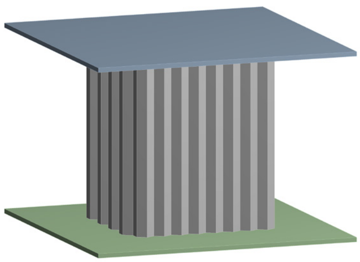
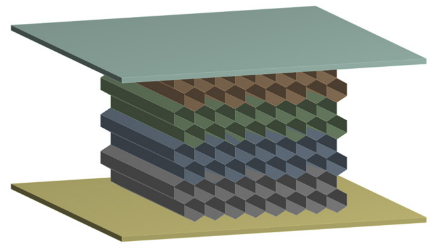
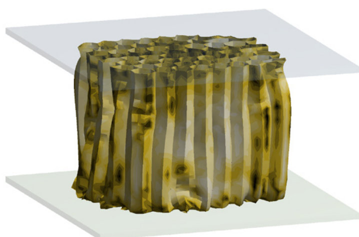
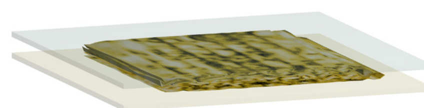
Honeycomb materials are widely used in aerospace, transportation, and construction industries and are available from numerous manufacturers in a variety of specifications. As their name implies, these structured materials consist of hexagonally shaped open-air cells that are frequently sandwiched between two panels, or machined to fill a 3D volume. Honeycomb manufactured from plastics, metals, and fibrous pulp are generally available and selected for based on the application, though chemical treatments can be used to provide additional fire, corrosion, or environmental resistance. Manufacturers working with honeycomb also have their choice of resins used to integrate the honeycomb with the mating interface. While lightweight, there are several drawbacks to honeycomb as an EAD material despite its wide prevalence. For example:

1. Honeycomb has unidirectional functionality and off-axis loading causes the material to collapse.
2. Honeycomb has a high peak stress, which means it transmits significant accelerations and risks payload damage due to its low CFE. Pre-crushed honeycomb is manufactured specifically to mitigate this problem but has limited availability and reduced load bearing capacity.
3. The costs of aerospace-grade honeycomb are quite high due to the materials, resins, and testing standards involved. Cardboard honeycomb for aerial delivery is less expensive to purchase, but there are significant shipping and storage costs due to the large volume of single-use material typically required. The operational expense of cardboard honeycomb is comparable to the cost of shipping or storing “boxes of air” due to its overall low mass density.
4. Because honeycomb is a well-established technology, key IP is already owned by large financially entrenched organizations doing little to innovate.
5. Honeycomb is an anticlastic material and does not conform well to shapes with positive Gaussian curvature such as an aerodynamic body or a curved, signature-reducing electromagnetic absorber.
6. Honeycomb is often damaged, crumpled, or torn when integrated into a product.

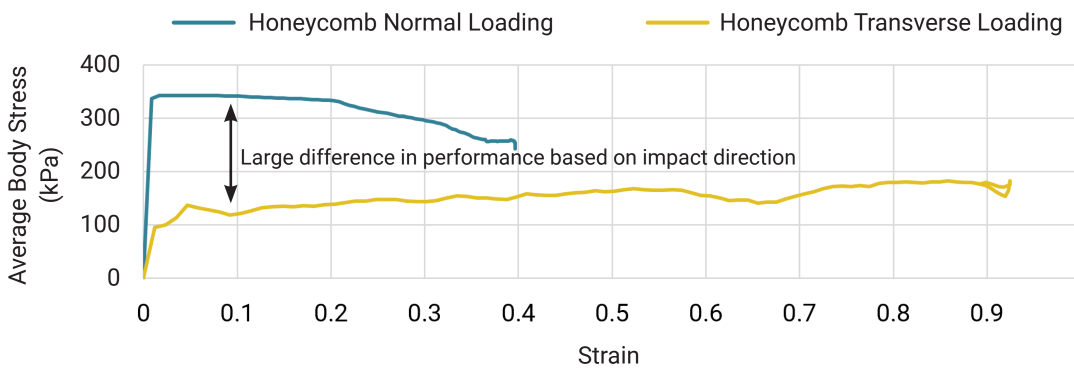
Since honeycomb cardboard is commonly used for aerial delivery, we conducted a Finite Element Analysis (FEA) simulation study to quantify the anisotropic properties of this material in greater detail (see Box 1 for summary of results). The setup is relatively straight forward and provides a simplified view of how a representative 17 x 14 x 20 cm^3 (~300 in^3) block of cardboard honeycomb EAD responds to impacts found during aerial delivery applications. We compared two honeycomb orientations – normal and transverse – and subjected them to the load of a steel plate moving at 8.5 m/s (~28 ft/s). The honeycomb itself was assigned a bilinear plastic hardening constitutive law to mimic real cardboard and the various inputs for moduli, strength, and density were cited from research literature [1]. The simulation was conducted in Ansys LS-DYNA, which is a specialized tool for computing highly nonlinear transient dynamic FEA with explicit integration.

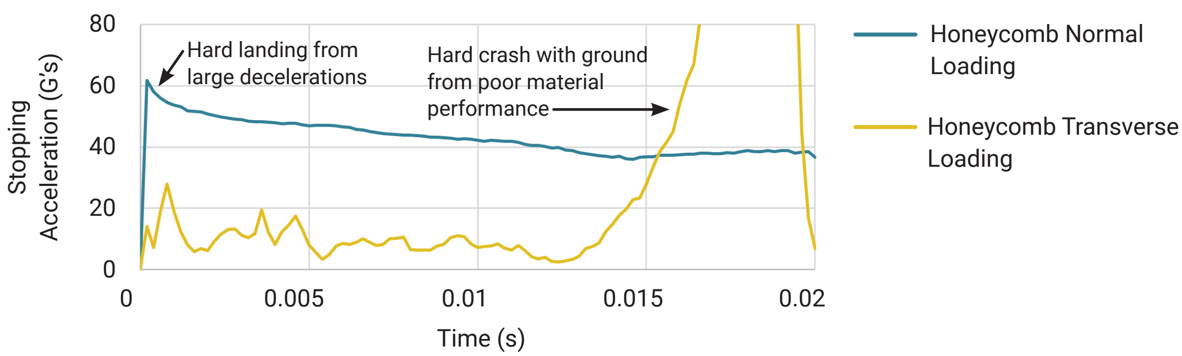
We analyzed the load-displacement data and stopping deceleration for both honeycomb orientations. The results show large (2x to 6x) performance differences depending on the load’s direction (Box 1). This simplified model provides useful insights for real aerial delivery applications, especially those with large horizontal glide distances and speeds involving a complex superposition of normal, transverse, and shearing loads. The highly anisotropic mechanical response of cardboard honeycomb suggests increasing risk of mission failure when confronted with increasingly off-axis loading and impacts. The specific scenario involving large horizontal velocities is likely to arise in aerial delivery missions with long glide distances seeking to counter A2/AD threats. Honeycomb’s predictability along the normal direction makes it an important tool for enabling current aerial delivery systems, but as the operational envelope is expanded beyond ±15°, limitations from this material’s anisotropic functionality become

***Box 1:** Analysis of cardboard honeycomb as an impact absorbing material subject to crush from a steel plate moving at 8.5 m/s (~28 ft/s).*

	Honeycomb Normal Loading	Honeycomb Transverse Loading
FEA Simulation Setup		
FEA Simulation End		

Simulation Data





more apparent (Fig. 1).

Foam Core

Foam core materials are widely used in heavy industries and are available from numerous manufacturers in a variety of specifications. Foam core, as their name implies, consist of a cured polymer precursor foamed and crosslinked into a random cellular packing. The mass density, rigidity, and size of the foam vary depending on the processing conditions, but like honeycomb, foam core is often integrated into impact-mitigating products. A critical disadvantage of foam core relative to honeycomb and other EADs is the low SEA (<10 kJ/kg). While appealing for its easy processing and manufacturability, the low performance generally makes it an inappropriate choice for this application (Fig. 4).

Crush Tubes

In contrast to material-based EADs, crush tubes are, as their name implies, tubular EADs that absorb impact energy along their axis of symmetry via irreversible deformations. Metallic crush tubes under impact conditions generally activate deformations such as the “concertina mode” and the “folding diamond failure mode” (Fig. 4). The stress focusing of these deformations leads to energy plastically absorbed by the material, but in a manner that depends on which mode is activated making crush tube performance as an EAD difficult to predict in real-world conditions. Composite crush tubes under impact conditions, unlike their metallic counterpart, activate brittle fracture and a tensile failure of the composite’s fiber bundles (Fig. 4). These failure modes absorb significantly more energy than the plastic deformation of metallic crush tubes but are very unpredictable since composites are typically hand-made and therefore highly variable in their manufacturing process. Like honeycomb, all crush tubes, regardless of their construction, become largely ineffective if the crash impact is off-axis by as little as 15°. Thus, the combination of high costs, variable performance, and unreliability in off-axis collisions make this EAD solution a poor candidate (despite the high SEA) in all but the most controlled circumstances.

Oleo-Pneumatic Struts, Landing Gear, and Other Energy Absorbing Devices

A number of purpose-built EADs implemented in modern rotorcraft design may be useful for future aerial delivery systems including: inversion tubes, oleo-struts, lightweight fixed skids, cruciform subflooring, and deployable EADs. Each system has a distinct CFE and SEA, but some have adverse effects on aerodynamics, while others are not useful for soft-ground landings. Furthermore, the more complex EAD designs are heavier, involve multiple moving parts, and require routine maintenance to be effective. When considering general-purpose impact protection for aerial delivery systems, we are seeking to reduce weight while maintaining cargo mission-capable delivery. Unfortunately, these independent purpose-built devices provide little flexibility for weight savings without sacrificing performance.

Future Directions of Army Aerial Delivery Science and Technology

Many of the current operational solutions for aerial delivery are possible thanks to cardboard honeycomb and its ability to perform impact mitigation of vertically applied loads. Looking ahead with the help of Army Futures Command and the Army's Modernization Priorities reveal foreseeable challenges demanding new technical innovations. For example, the A2/AD threat and increased regularity of multi-domain operations are expected to demand larger horizontal offsets between payload deployment and landing sites. The shift toward a Continental United States (CONUS) based force with increasing mission responsibilities (including humanitarian missions), is expected to demand delivery of greater varieties of cargo from a greater variety of air vehicles. These factors are all pointing in the same direction: **the operational envelop for airdrops must widen**. Cardboard honeycomb may be the solution today, but it is also an obstacle to tomorrow's success.

Specific technical needs and stated areas of interest for aerial delivery innovation include:

1. **Increased aircraft/airborne force survivability** in threat environments by expanding the aerial delivery operational envelope.
2. **Improved reliability** while reducing ground impact velocity, oscillation, and exposure time to threats.
3. **Enhanced personnel airdrop capabilities** both for high altitude standoff and low-level operations by improving auxiliary system performance.

Source: Army CCDCSC BAA W911QY-20-R-0022

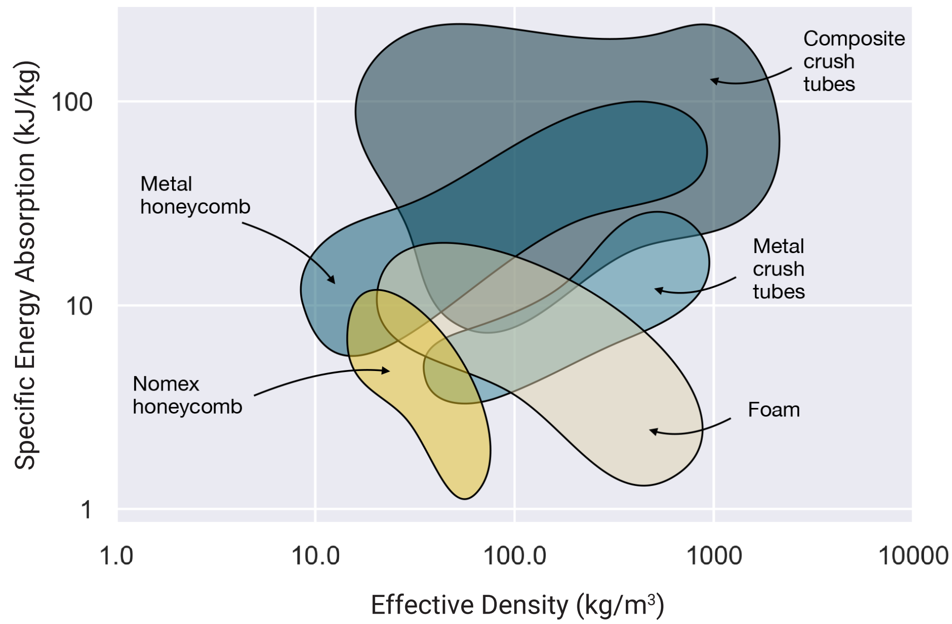
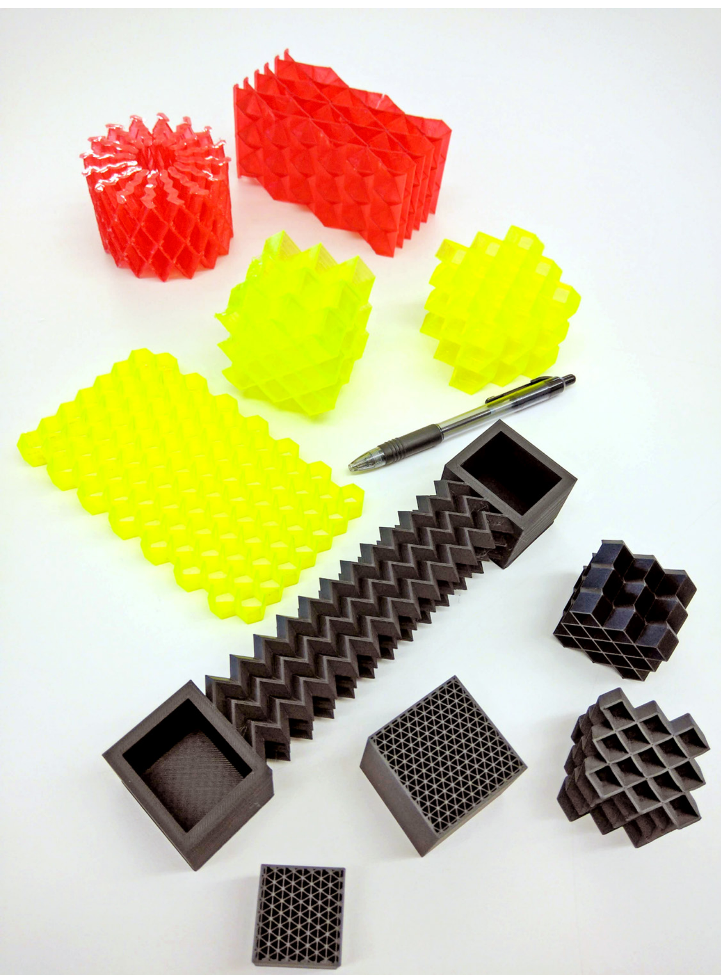


Figure 4: *Comparison of energy absorbing products for impact mitigation evaluated by two metrics vital for the success of a given aerial delivery system. Single-use composite crush tubes generally have large SEA for a given density, but they are also typically fabricated as hand layups, making the costs extremely high. Foams offer good omni-directional impact protection, but overall low SEA. Metal crush tubes are useful for mitigating impacts of large bodies (>5,000 lbs), especially in ground-based vehicles, but their applicability to aerial delivery is low. Metal and Nomex (paper) honeycomb balance SEA and density, but have functional properties in only one direction, making them poor choices for aerial delivery with large horizontal velocities as expected for responding to A2/AD threats.*

Moving Forward: New Solutions for Impact Mitigation

Mechanical Metamaterials in a Nutshell

Mechanical metamaterials are a class of structural materials designed with a wide range of exotic and high-value characteristics [2-11]. They are produced by embedding geometric patterns into a base material without making chemical or molecular modifications (Fig. 5). The base material is often, but not limited to, an elastomer, metal, fiber sheet, or composite. The geometric design is computationally generated and optimized for target characteristics using a three-prong approach of: kinematic analysis of mechanisms (inspired by the mathematics of origami); homogenization theory to develop a representative volume element; and full solid characterization. Once the metamaterial geometry is designed, it is embedded into the base material using additive (e.g., 3D printing, mold casting, etc.) subtractive (laser cutting, CNC milling), or pattern transfer (thermoforming, roll-to-roll production, etc.) manufacturing methods. Geometry is scale-free, meaning that the tessellated unit cell can be micro- or macroscopic. In all cases, the effective material properties are determined by the metamaterial's geometric pattern. This computational approach to material design allows us to conduct multi-objective optimization for metrics such as SEA, CFE, system size, system weight, and cost (Fig. 6).



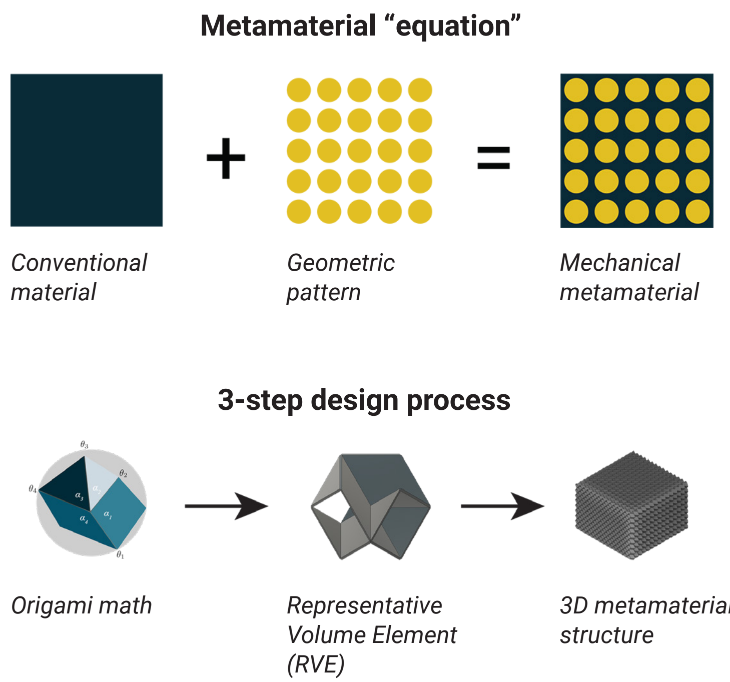


Figure 5: *Instead of creating new materials through chemical or molecular engineering, we design geometric structures to enhance performance of conventional materials. Our approach is summarized by the symbolic equation and design process above, and the photo shows several example prototypes developed by our team.*

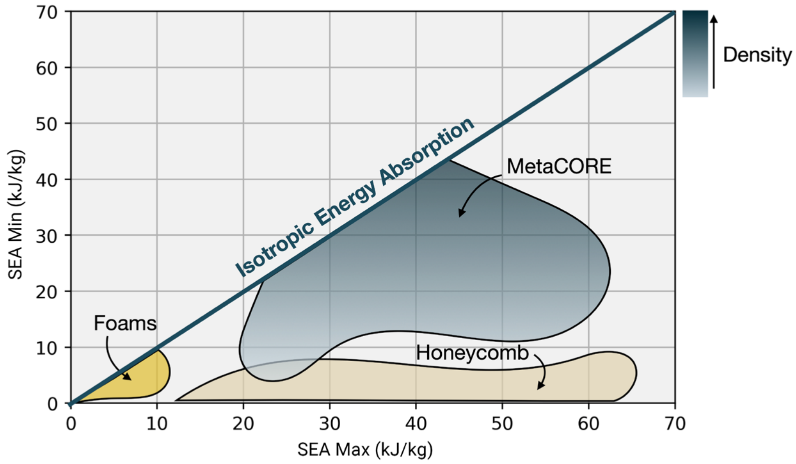
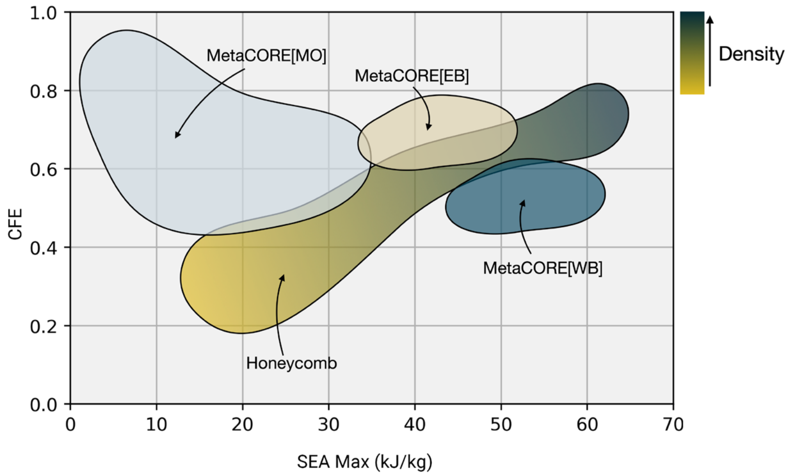


Figure 6: *Technical data for SEA min vs SEA max shows how conventional energy absorbing materials (honeycomb, foam) have either a poor relative performance, or at best, performance in only one direction.*



CFE vs SEA Max shows how increasing performance of honeycomb's one functional direction increases the material's density and subsequently the system's weight.

Parametric Design Allows Metamaterials to be Optimized for Better Performance Characteristics

A central ingredient for the success of mechanical metamaterials as an advanced materials technology is that their structure is represented by a geometric pattern quantified in terms of lengths and angles. As a result, one can generally pick a set of variables characterizing the geometric structure, calculate the effective material properties arising from the geometry, and then utilize software to modify the underlying geometric parameters for optimal performance. At Multiscale Systems, we focused this capability to develop lightweight impact-absorbing metamaterials with the support of NASA and the National Science Foundation. These metamaterials are optimized to **reduce density**, **maximize CFE**, and **increase SEA**. Our approach to designing advanced materials is better than conventional alternatives since it is faster and has more accurate predictions for bulk material performance. Unlike novel molecular structures, we have fewer restrictions (cost, time, complexity, certifications, environmental impacts, etc.) when it comes to fielding new metamaterial products since we fabricate these advanced materials by combining existing conventional materials with a novel geometric pattern. In cases where manufacturing methods are critical constraints or cost drivers, we restrict our design space to geometries that can be fabricated by a given method. For example, MetaCORE blocks can be fabricated from bonded fiber sheets in a process similar to that used to manufacture cardboard honeycomb.

MetaCORE: A Lightweight Pro-Isotropic Energy Absorber

Anisotropic properties of honeycomb present outstanding challenges to expanding the operational envelope of aerial delivery capabilities. We propose using mechanical metamaterials as a new approach that addresses the technical problem of off-axis impact mitigation. Our flagship product, MetaCORE, was specifically engineered to be a lightweight solution whose geometry promotes isotropic (pro-isotropic) energy absorption. Data plotting the maximum and minimum SEA values for various EAD materials (Fig. 6, top) highlight the unidirectional nature of honeycomb and the low range of performance for foams. The blue diagonal line is a fully isotropic material and the region below it occupied by MetaCORE is the pro-isotropic range. These data show how MetaCORE is able to absorb a large amount of energy regardless of the impact direction, making it a responsive choice to replace cardboard honeycomb. Data plotting the CFE vs maximum SEA (Fig. 6, bottom) shows how various MetaCORE geometries ([MO], [EB], and [WB]) provide distinct ranges of performance. While honeycomb's CFE and maximum SEA are roughly proportional, we also see the increased performance lead to larger densities and increased disparities between the minimum and maximum SEA. MetaCORE [MO] prototypes (Fig. 7) subjected to crushing loads at various orientations demonstrate the pro-isotropic characteristics of this mechanical metamaterial. This particular geometry was optimized to have the stress-strain curve necessary for an ideal SEA and CFE (Fig. 3 and Box 2). The resulting data can be summarized as having the isotropy and large CFE like a foam, but with SEA comparable to honeycomb.

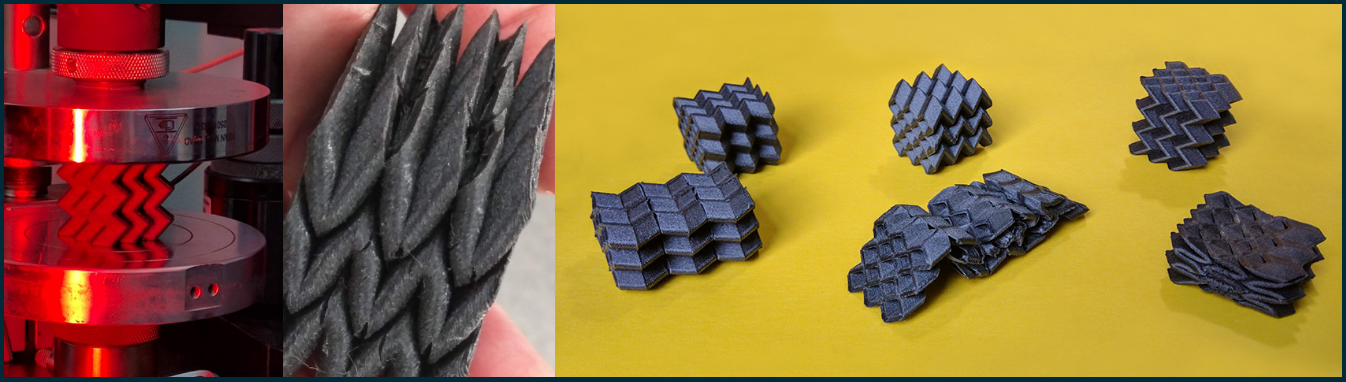


Figure 7: *Prototype MetaCORE [MO] samples were fabricated from carbon fiber reinforced nylon and compressed with a universal tester to empirically validate the computationally optimized design. Left photograph shows a sample loaded between 6"-diameter platens. Second photograph shows post-compression deformation and tearing at points of localized tension (tension arises from metamaterial geometry despite bulk compression being applied). Right photograph shows three uncompressed MetaCORE [MO] samples in three distinct orientations and the post-compression deformed states. These photos demonstrate how real-world samples respond to loads. This geometry can also be fabricated in fibrous pulp to offer metamaterial advantages in cardboard-like materials.*

An Aerial Delivery Simulation: MetaCORE vs Honeycomb

Setting up a Comparative

We already examined how cardboard honeycomb responds to on- and off-axis loading using a simulation mockup of an airdrop impact (Box 1). Those results highlighted honeycomb's anisotropic properties and suggested the challenges aerial delivery science and technology must overcome as missions evolve to meet future operational requirements. As a concept of operation (CONOP), this FEA simulation for honeycomb offers a useful comparative framework to demonstrate the technical advantage of MetaCORE.

We therefore take the same CONOP as before, but replace the cardboard honeycomb with a cardboard MetaCORE [MO]. Considering its high degree of in-plane symmetry, honeycomb generally has **two** relevant directions: normal (on-axis) and transverse (off-axis).

In contrast, MetaCORE [MO] has **three** distinct patterns in each orientation and therefore requires simulations performed in each direction. Again, using Ansys LS-DYNA, we subjected MetaCORE to impact from a high-velocity steel plate and measured its response (Box 2). The results are striking.

Technical Results

Our data reveal distinct differences between the anisotropic properties of honeycomb and the pro-isotropic properties of MetaCORE [MO] under identical CONOPS.

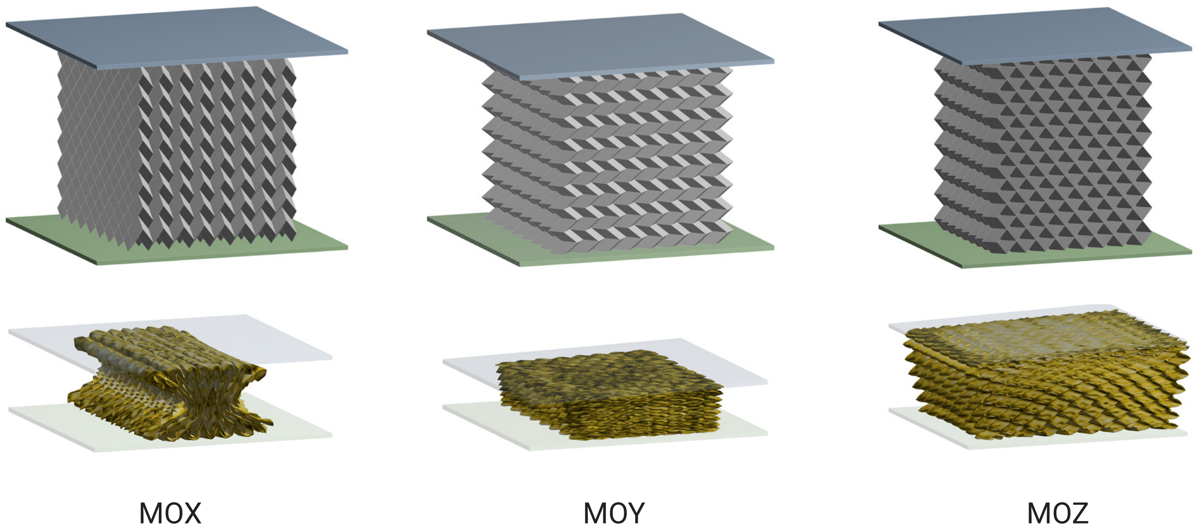
The following table highlights key performance metrics that summarize the findings and demonstrates capabilities outside the ±15° operational cone of honeycomb:

Loading Orientation	SEA (J/kg)		CFE		Specific Modulus (MPa)		Crush Strength (kPa)		% of Initial Energy Retained by Payload	
	[HC]	[MO]	[HC]	[MO]	[HC]	[MO]	[HC]	[MO]	[HC]	[MO]
Normal / X	1,070	940	0.8	0.92	25	7.8	270	220	0%	30%
Transverse / Y	460	740	0.0	0.87	5.2	7	150	160	68%	54%
- / Z	-	800	-	0.86	-	16	-	180	-	52%

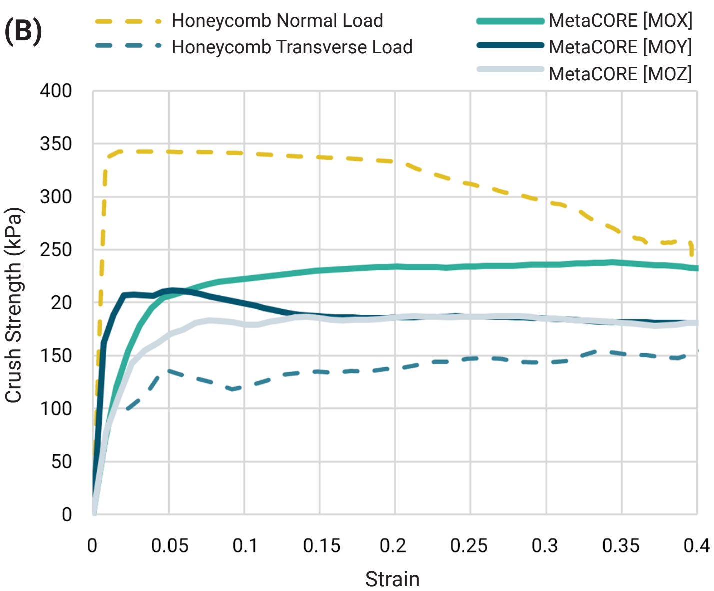
Table 1: *Summary of comparative simulation quantifying the functional properties of cardboard honeycomb and cardboard MetaCORE [MO] subjected to loading from various conditions. Data highlights the pro-isotropic properties of MetaCORE [MO] suggesting its potential to increase the operational envelope of future aerial delivery missions. Key: [HC] = Honeycomb; [MO] = MetaCORE [MO].*

Box 2: *Comparative results of cardboard MetaCORE [MO] vs cardboard honeycomb.*

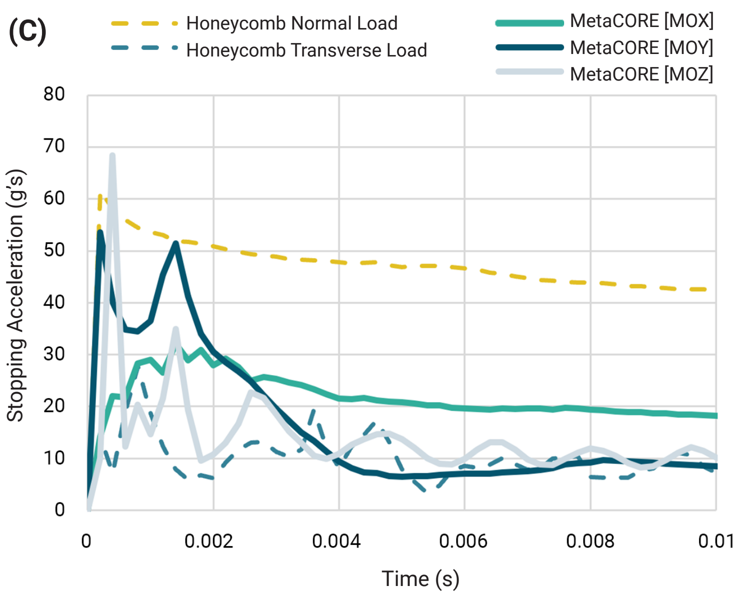
(A)



(B)



(C)



(A) *MetaCORE is a class of cellular materials that dissipates energy as they are crushed. Gray 3D renders of the specific MetaCORE [MO] design show its nominal structure, while colorful renders below show the fully compressed state from our FEA simulations. We typically fabricate samples like the one shown where each unit cell is 0.5 - 1 cm for in-house testing.* ***(B)*** *Comparative FEA simulation data from LS-DYNA show the stress versus strain for honeycomb (dashed lines) and MetaCORE [MO] (solid lines) when the impact comes from various directions. Notice how honeycomb has a large performance difference depending on whether the impact is normal or transverse to the honeycomb flute. In contrast, MetaCORE [MO] has a nearly isotropic performance. Also note the shape of the MetaCORE stress-strain curve, which has been optimized for a near-ideal CFE and maximum SEA.* ***(C)*** *The same simulation data as panel (B) but looking at the stopping decelerations (expressed as g-force) immediately after the collision event, which occurs at time = 0 s. Honeycomb has large differences in performance depending on orientation, whereas MetaCORE [MO] is far more consistent regardless of orientation.*

Payoffs of MetaCORE EADs in Aerial Delivery Systems

At Multiscale Systems, we believe evidence-based methods should be used to *show* rather than *tell*. While the simulation data (Box 2 and Table 1) speaks for itself, we want to highlight the critical payoffs for Soldiers and Airmen using MetaCORE-based EADs in future aerial delivery systems.

For the Soldier and Air Crew

Features	Payoffs
MetaCORE has a ~30x increase in the operational envelope for impact mitigation compared to honeycomb.	100% mission-capable delivery of food, water, and equipment outside the current aerial delivery operational envelope.
Large EAD functionality in horizontal direction allows airdrop off-set distances to be maximized for longer glides and advanced cargo infiltration that reduce exposure to A2/AD threats.	
Increased tolerance to landing orientation and velocity reduces risk of cargo tipping over.	

For the Loadmaster

Features	Payoffs
MetaCORE is agnostic to cargo type.	Frictionless transition from current solution means no new training.

For Certifications and Requirements

Features	Payoffs
MetaCORE is computationally designed and undergoes extensive empirical testing.	Easy integration for testing with existing modeling software.

For Acquisitions

Features	Payoffs
MetaCORE is manufacturable from the same fiber pulp as cardboard using similar manufacturing methods.	No significant cost increase; no significant increase in weight; no additional signature; flammable and biodegradable material offers single-use, environmentally-friendly operation.

What Next?

The future carries inherent uncertainty. Nevertheless, we plan today to be better prepared for tomorrow.

The A2/AD challenge is foreseeable and suggests airdropped cargos will experience operational conditions more difficult than those experienced today. Large sudden changes in motion from low altitude automatic derigging systems may defeat A2/AD threats, but they also decrease the rate of payload survivability. Long glide distances between payload release and landing may reduce risk to airmen, but they also push delivery systems outside the operational envelope. And CONUS-based humanitarian missions responding to natural disasters will demand heavier payloads containing water, food, and fuel.

Advanced materials technology has the potential to offer step-change improvements across all heavy industries. Aerial delivery systems are no exception. Airdrop EADs stand to directly benefit from Multiscale Systems' dual-use metamaterial technologies in aerospace, transportation, and geothermal energy development.

By working together, we will expand the operational envelope and create a foundation to increase aerial delivery success.

Appendix and Supplemental Materials

Multimedia and Links

White paper summary video
multiscalesystems.com/resources

MetaCORE datasheet (PDF)
multiscalesystems.com/assets/metacore-datasheet.pdf

DefenseMatters.org explainer video - What is Anti Access Area Denial?
youtube.com/watch?v=JMU8W2oHxiM

Acronyms

A2/AD	Anti-Access/Area Denial (or “Denied”)
CFE	Crush Force Efficiency
CONOP	Concept of Operation
CONUS	Continental United States
EAD	Energy Absorbing Device
FEA	Finite Element Analysis
HALO	High Altitude Low Opening
JPADS	Joint Precision Aerial Delivery Systems
SEA	Specific Energy Absorption
SWaP-C	System, Weight, Power, and Cost (the “a” and “-“ are historical and relate to the origins of this term as a “SWaP” analysis, which eventually grew to consider Cost)
UAS	Unmanned Aerial System

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About Multiscale Systems

Multiscale Systems is an advanced materials and manufacturing firm developing commercial applications of mechanical metamaterial technology. Instead of creating new materials through costly chemical or molecular engineering, their approach is based on embedding 3D geometric patterns into conventional materials to create new functionality. Their geometrically enhanced metamaterials are lighter, stronger, and more multifunctional than conventional materials.

Founded in 2018 and located in Worcester, MA, Multiscale Systems employs an energetic team and utilizes cutting edge scientific and engineering tools. We serve our customers by producing bespoke metamaterial products and integrating ourselves into their supply chain.

Visit us on our website (multiscalesystems.com) to learn more information about working with us and how we can develop better materials together.