

Development of Structural Energy Storage for Aeronautics Applications

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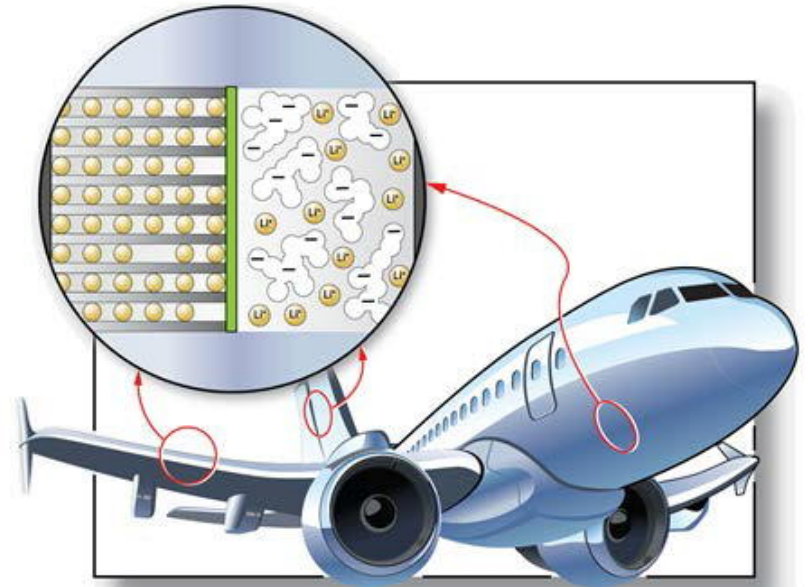
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Multifunctional Structures for High Energy Lightweight Load-bearing Storage (*M-SHELLS*)

Melding load-carrying aircraft structure with energy storage for hybrid electric aircraft

- Advanced materials for combined energy & power capability
- Electrochemical components capable of carrying structural load
- Innovative structural designs
- Atomistic modeling through flight systems analysis



Partners across Glenn, Langley and Ames Research Centers, outside collaborations with University of Cincinnati and Case Western Reserve University

M-SHELLS Ultimate Goal – demonstrate mass savings using multifunctional material on a UAV

Why Structural Hybrid Energy Storage for Aeronautics?

NASA ARMD Strategic Thrusts and Associated Outcomes Addressed:

Strategic Thrust 3: Ultra-Efficient Commercial Vehicles

Strategic Thrust 4: Transition to Alternative Propulsion and Energy

Future hybrid electric propulsion will maximize efficiency and minimize environmental impact for commercial aircraft

Long poles include weight, longevity, operations, and safety of energy storage system

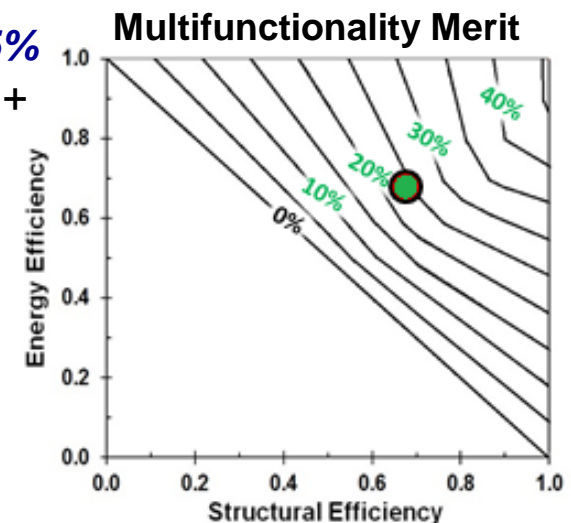
Structural Hybrid Energy Storage uniquely targets these challenges:

- ✓ *Weight is minimized*
- ✓ *Long life is provided*
- ✓ *Operations are enhanced*

Multifunctionality Merit

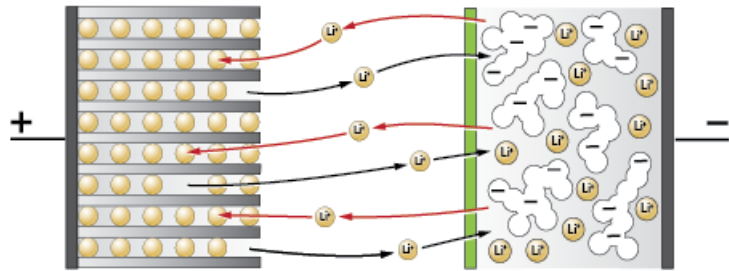
- Creates significant weight reduction for hybrid electric and all-electric aircraft
- Addresses high risk item: **energy storage**
- Leap-frogs the question “Will technology grow 5X within 15~20 years?” with our new construct (multifunctionality)
- An example demonstrates potential weight savings:

- single aisle hybrid electric propulsion
- replace SOA energy storage with just 67% energy and structurally efficient multifunctional material
- **weight savings of almost 25%** over separate energy storage + structure!



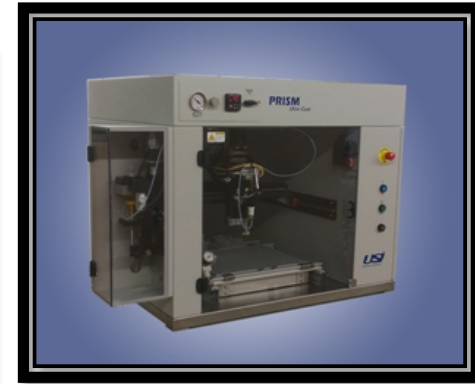
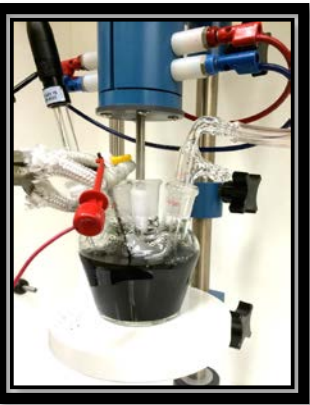
M-SHELLS Electrochemical Concept Description

- Combines properties of supercapacitor and battery for optimal electrochemical performance
- Uses materials and nano-enhancement to transfer stress among constituents and provide load carrying capability



Properties	Super-capacitor	Battery	Structural Hybrid Energy Storage
High Power Density	✓		✓
Long Cyclic Life	✓		✓
Rapid Recharge	✓		✓
No Ionic Swelling	✓		✓
No Runaway Thermal	✓		✓
High Energy Density		✓	✓
Load Bearing			✓

Electrochemistry Approach

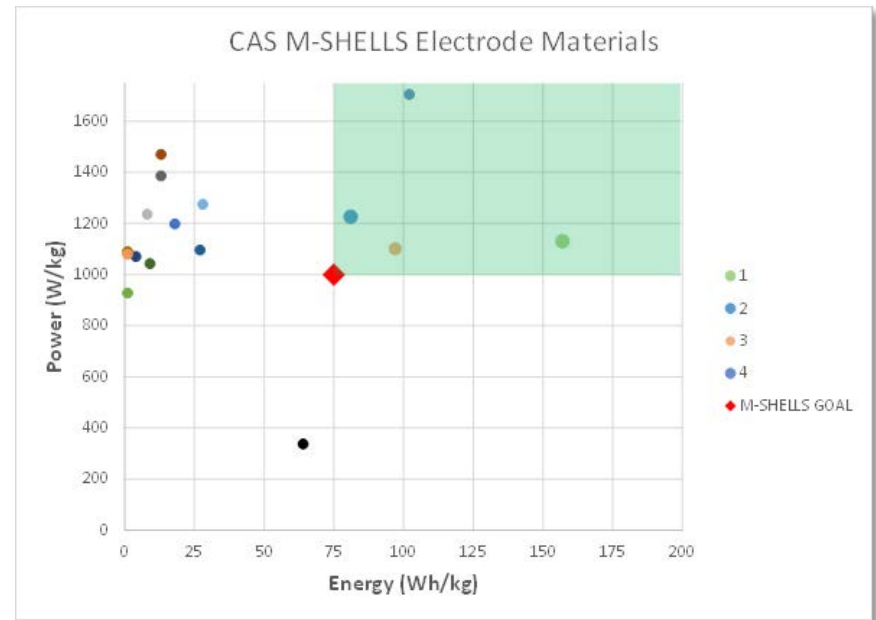


- In-house synthesis of materials with hybrid characteristics of both batteries and supercapacitors
- Processing techniques such as electrodeposition and plasma doping
- Composition optimization
- Optimize slurry composition for casting into electrodes
- Cast electrodes on new substrates, such as carbon fiber or foam
- Coin cell testing for quick turn-around
- Integration of multiple electrodes to determine compatibility
- Scale-up of electrodes & testing to pouch-cell size
- Scale-up electrode processing with new techniques amenable to structure

Power and Energy Storage Feasibility Objective

- ✓ Specific power: **1000 W/kg**
- ✓ Specific energy: **75 Wh/kg**
- ✓ 4 Electrochemical Combinations

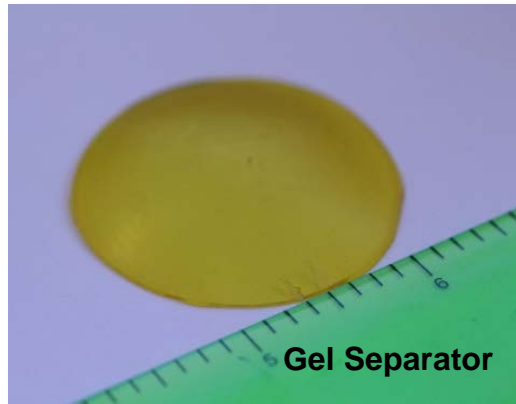
Electrode Pairing	Power (W/kg)	Energy (Wh/kg)
1	1131	157
2	1226	81
3	1102	97
4	1705	102



Structural Electrochemical Components Concept

Next-generation electrochemical components that will also provide strength

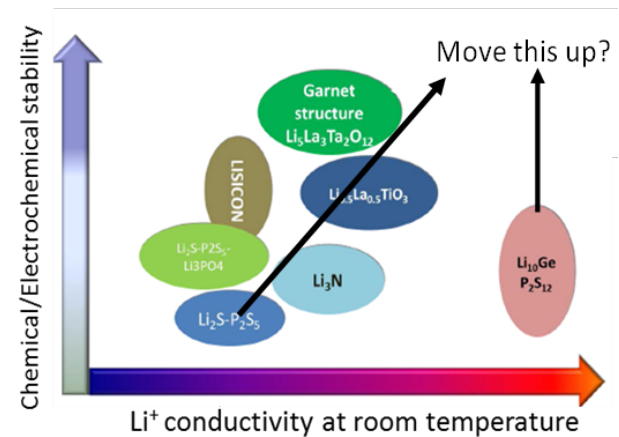
Gel Electrolyte/Separator Concept



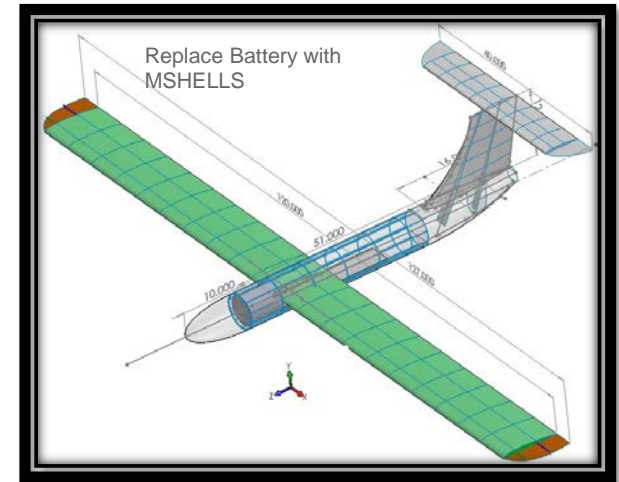
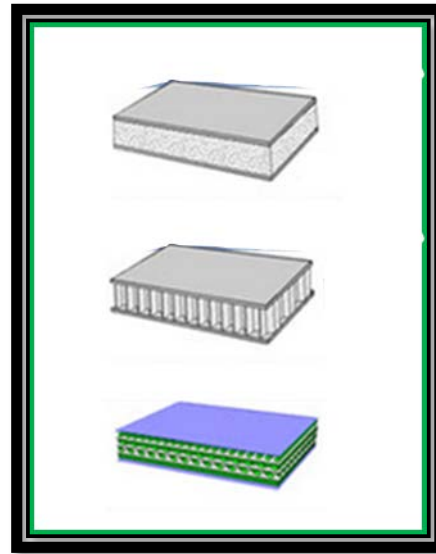
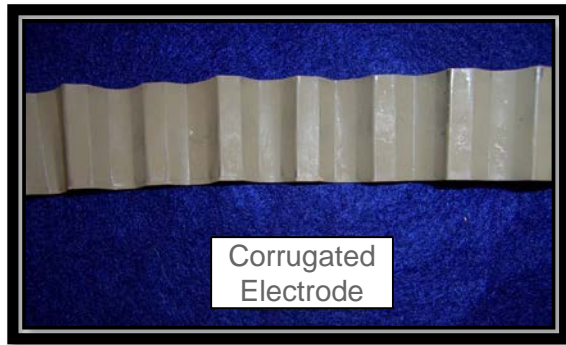
Preliminary experimentation suggests that gel electrolyte / separator could improve safety over SOA battery technology

Solid Electrolyte/Separator Concept

- Solid electrolyte replaces 2 components of SOA batteries – standard polymer separator and liquid electrolyte – while providing strength!
- Approach: Fabricate nano-sized solid electrolyte
- Resulting in a solid electrolyte-separator with high ionic conductivity, good mechanical properties and good stability



Structural Approach

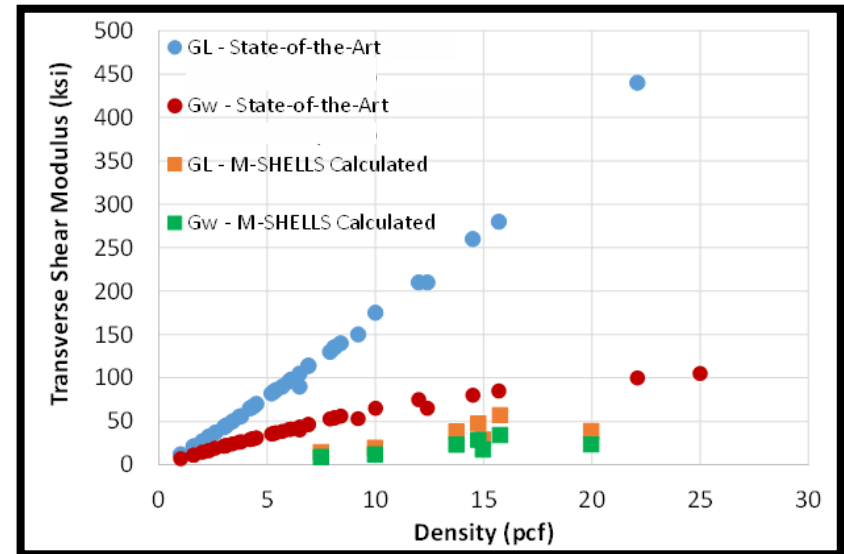
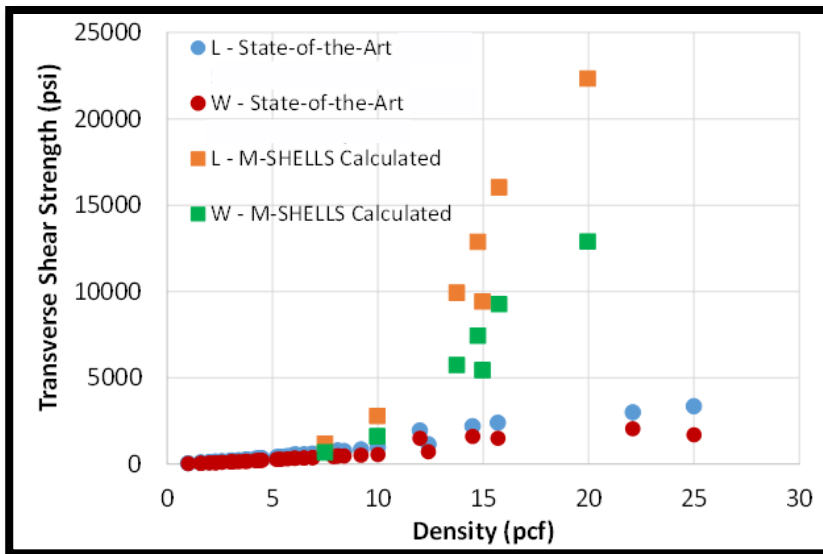
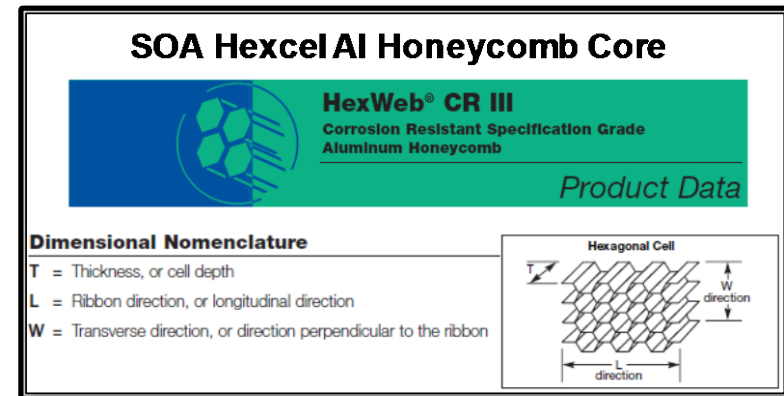


- Design & develop potential structural concepts
- Incorporate advanced materials into structural designs
- Structural concepts aim to combine energy storage components with load-bearing capability

- Experimenting with different fabrication methods
- Modeling/analysis of aircraft structural needs

Modeling of M-SHELLS Structural Concepts

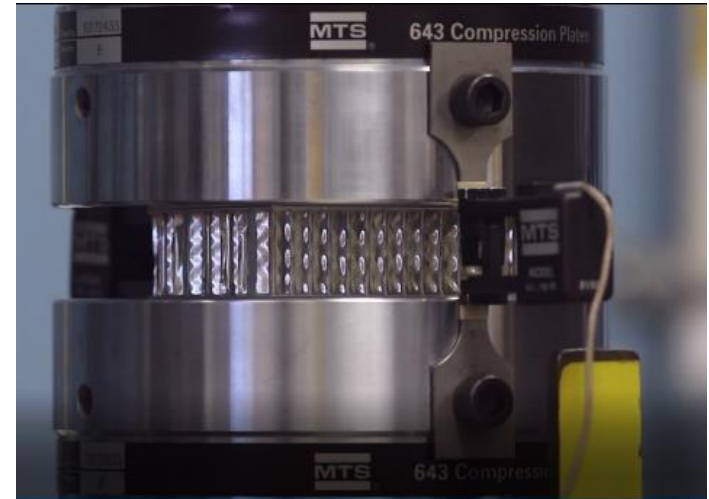
- Calculated properties of sandwich core from properties of constituents
- Calculations show higher strength than SOA sandwich core components, but lower stiffness (due to compliant electro-chemical components)



M-SHELLS Structural Concepts Tests

- Four structural concepts were selected to be tested
- Concepts can be implemented in aircraft flooring, fuselage, etc....
- Highly efficient bending type structures
- Testing was conducted to determine effective compressive core strength, stiffness and moduli of the M-SHELLS conceptual designs

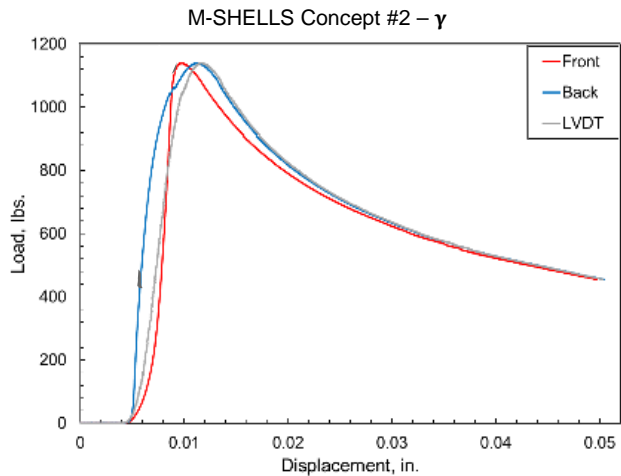
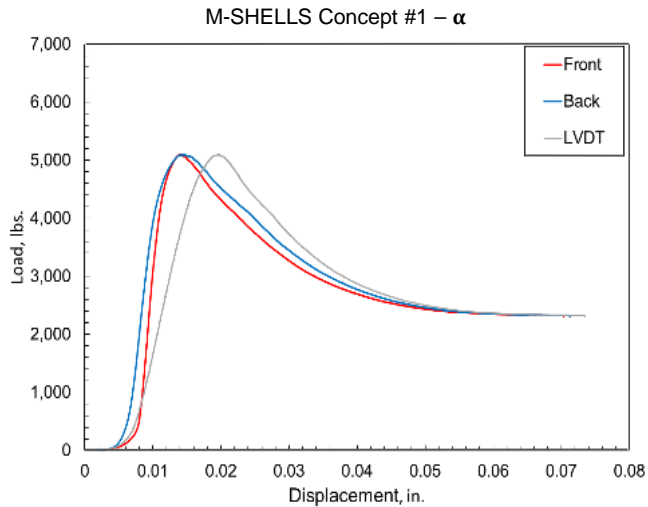
- ASTM C365 and AMS C-7436 as guidance.
- 20 Kip Load Frame
- 6 inch diameter flat platens (aligned to 0.0005" flat and parallel)
- Front and Back Extensometers on platens
- Displacement rate 0.005in/min
- M-SHELLS coupons fabricated flat and parallel within 0.001in.



Calibration test setup using baseline specimens:

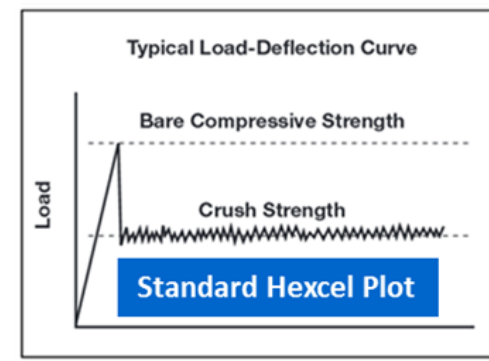
- Aluminum 5052 ¼-0.002 Honeycomb Core
- Specimen sizes 3" X 3"
- Al5052 0.032" face sheets bonded

Mechanical Test Results



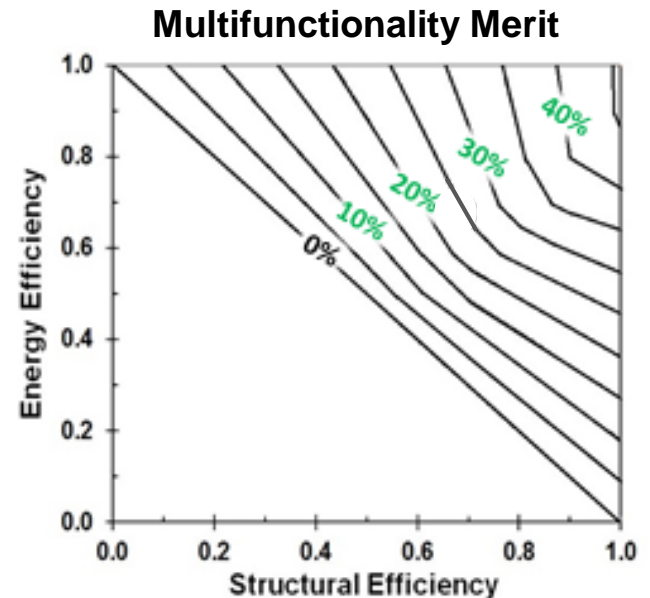
- Loading would have to be confined to the linear response region to avoid possible leaking/loss of electrical function via material yielding or failure
- Four point bend testing underway

M-SHELLS Flatwise Compression Testing		
Concept Identification	Effective Compressive Module	Compressive Strength
	Ksi	Psi
Concept #1 - α	100	462
Concept #2 - β	150	573
Concept #1 - δ	7	40
Concept #2 - γ	22	127



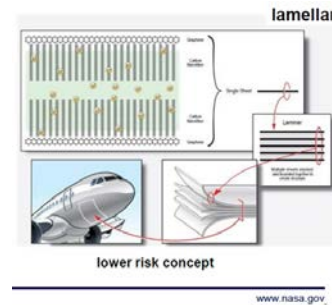
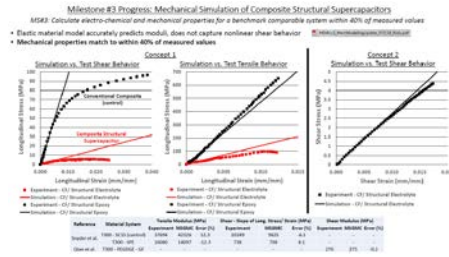
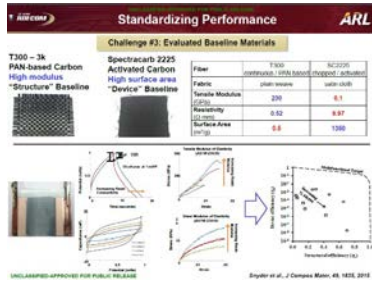
M-SHELLS Multifunctionality Demonstration

- Comparing total system mass for same structural & electrochemical functionality & volume, M-SHELLS materials has shown **positive multifunctionality!**
 - **Mass of M-SHELLS is lower than standard structure + standard battery**
- Structural properties of M-SHELLS are comparable to Hexcel standard (though heavier)
- Early testing has proven power & energy storage capability of cell building block; building block size is scalable

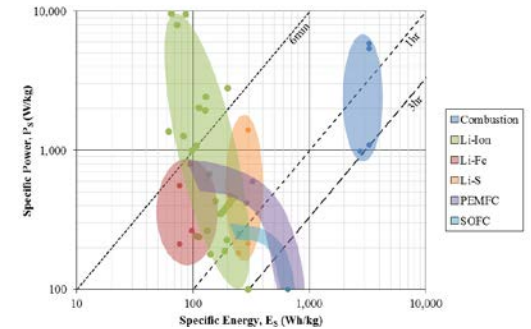


Flight & Systems Analysis Roadmap

Advanced Electro Chemistry & Composite Material Properties



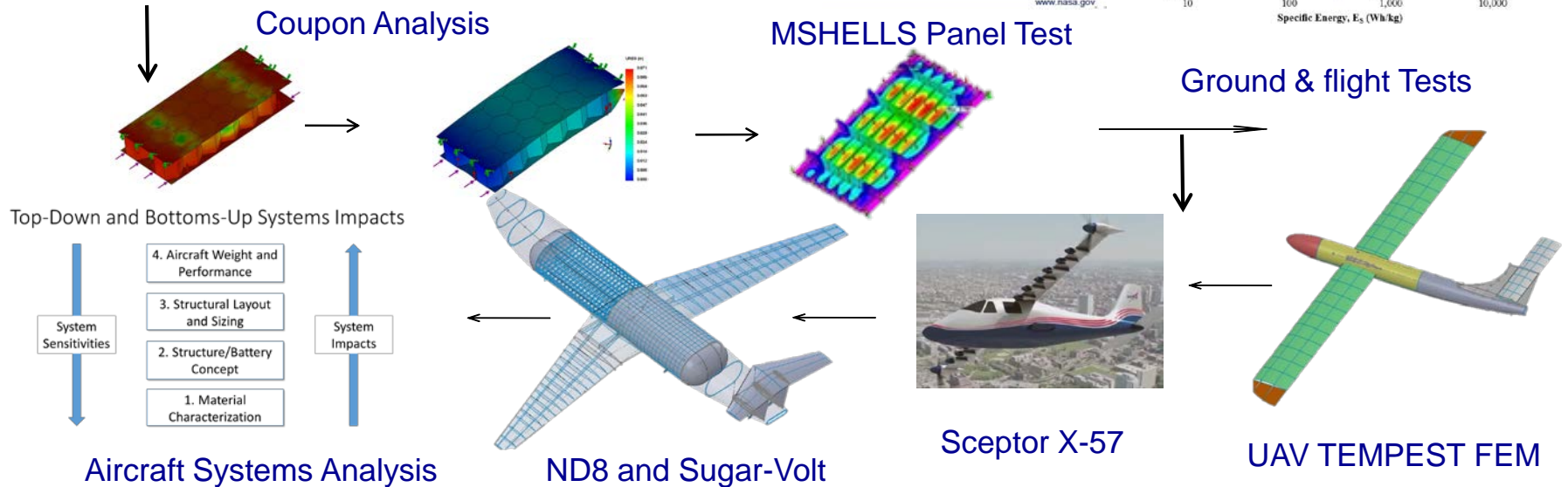
Energy and Power density



Coupon Analysis

MSHELLS Panel Test

Ground & flight Tests



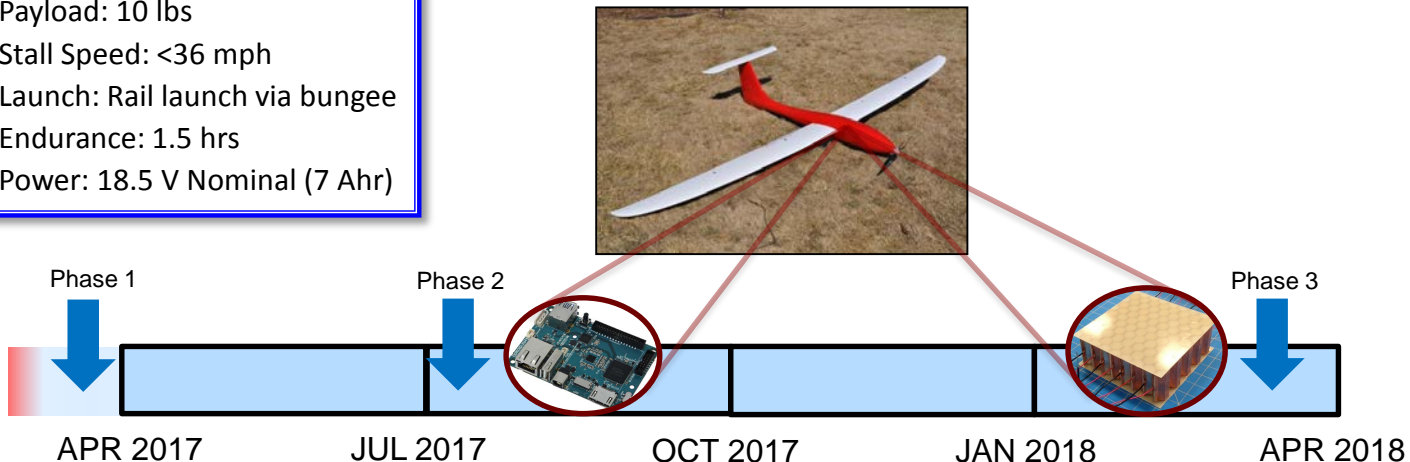
M-SHELLS Flight Demonstration

- Trade Study including over 25 vehicles
- Selected UAS “Tempest” for Flight Demonstration based on:
 - Low energy consumption
 - High payload capability
 - Ease of Operation
 - Existing Operational Experience

- Phase 1: Baseline Check Flights on COTS UAS
 - Verify COTS UAS power/energy flight profiles
- Phase 2: Instrument Check Flights
 - Install and evaluate data, sensor, & power switching systems in support of Phase 3 M-SHELLS research flights
- Phase 3: Research Flights with M-SHELLS
 - Install and perform fully instrumented UAS Research flights with M-SHELLS material

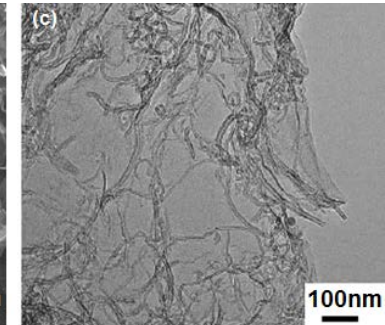
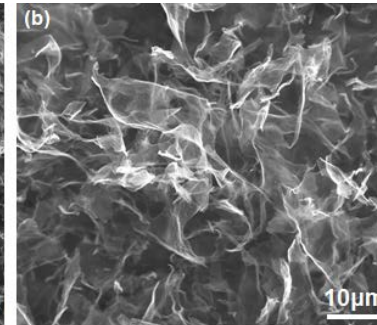
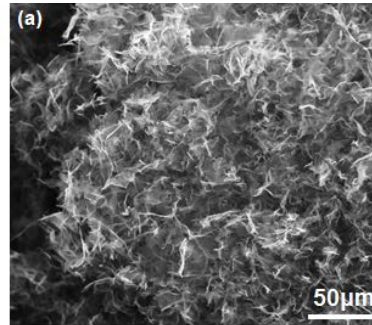
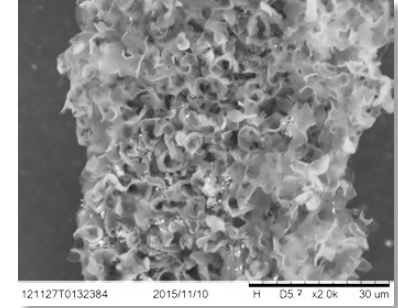
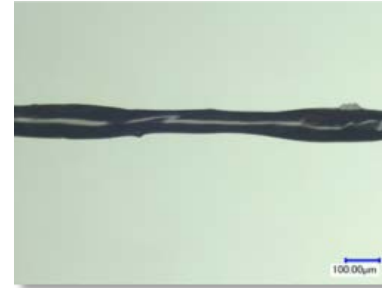
Tempest Specifications:

- Wingspan: 127 in (10.7 ft)
- Base weight: 10 lbs
- Payload: 10 lbs
- Stall Speed: <36 mph
- Launch: Rail launch via bungee
- Endurance: 1.5 hrs
- Power: 18.5 V Nominal (7 Ahr)

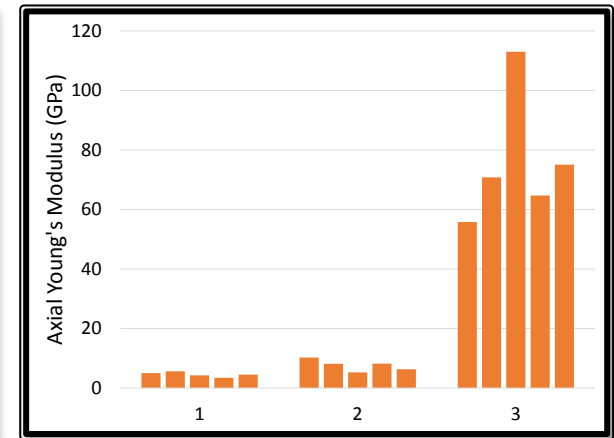
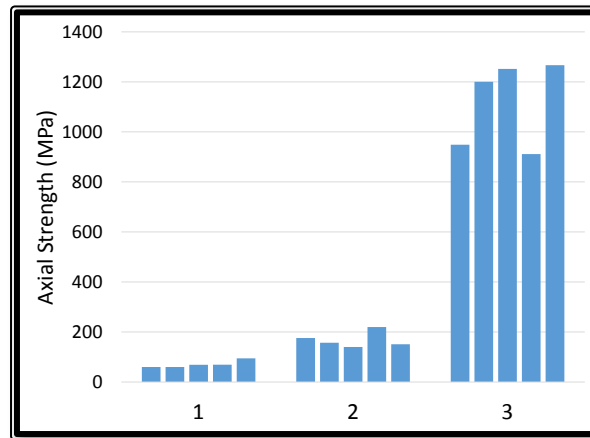


Collaboration with Partners

- Next generation of nanomaterials
- Developing new chemistries to improve energy density
- Fiber energy storage development for composite application



Fibers sizes: (1) 50µm, (2) 35µm, and (3) 16-18µm



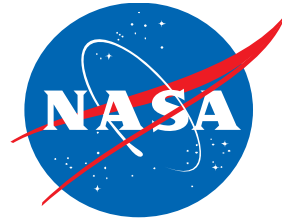
Summary

- Energy storage performance has the potential to be improved with next generation of high energy density materials.
- Structural electrochemical concepts were tested. Gel electrolyte / separator could potentially improved safety on energy storage devices.
- Four M-SHELLS Structural Concepts were tested in coordination with numerous ASTM standards. Testing demonstrated a feasible concept for the Structural Function of M-SHELLS;
- Calculated **positive multifunctionality** for both M-SHELLS concept and from a partner University of Cincinnati fiber concept

What's Next?

- Moving towards optimization and scale-up
- Continuation of fabrication and testing of building block, finding a balance to maintain electrochemical performance and allow for successful building block assembly
- Systems analysis/modeling to determine best location to integrate structure onto Tempest vehicle
- Integration of advanced components to create the hybrid multifunctional system
- M-SHELLS will demonstrate multifunctional mass savings of a hybrid energy storage system with structural capability on a UAV flight demo

Questions?



Thanks to
Convergent Aeronautics Solution