# Development of Structural Energy Storage for Aeronautics Applications

*Dr. Diana Santiago**, Dr. Patricia Loyselle*, Brianne DeMattia and Dr. Brett Bednarcyk* / NASA Glenn Research Center

*Dr. Erik Olson**, Russell Smith and David Hare* / NASA Langley Research Center

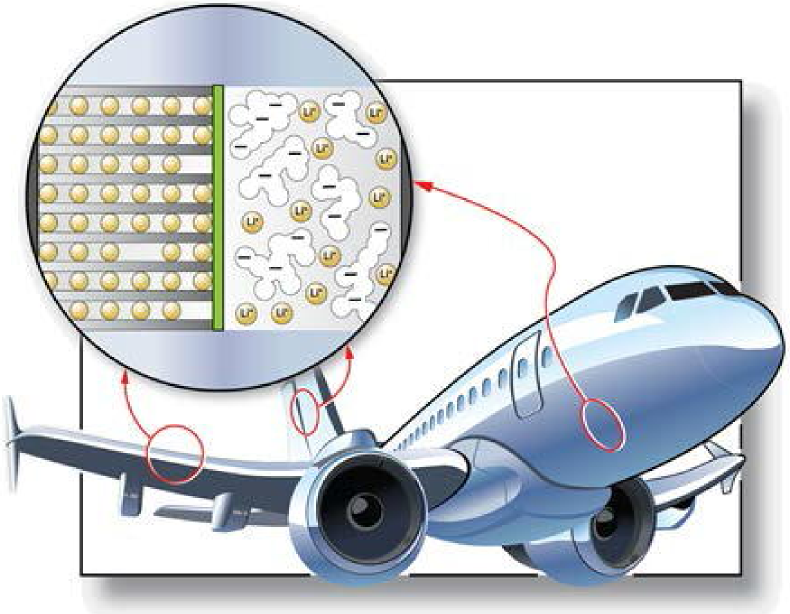
*Principal Investigator, **Co-Principal Investigator

**AIAA AVIATION 2017 · June 8, 2017**

# 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

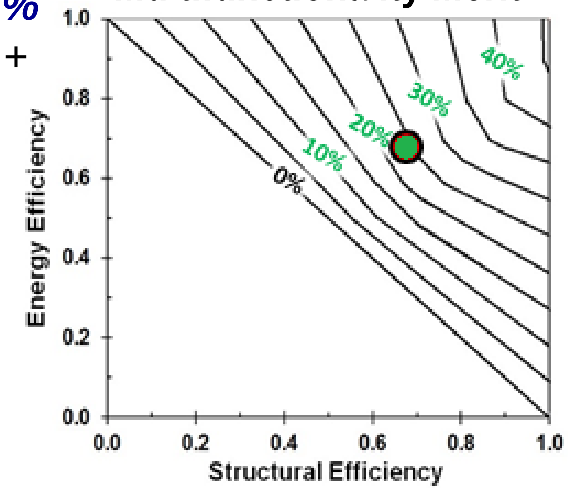
**Structural Hybrid Energy Storage uniquely targets these challenges:**

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

# Multifunctionality Merit

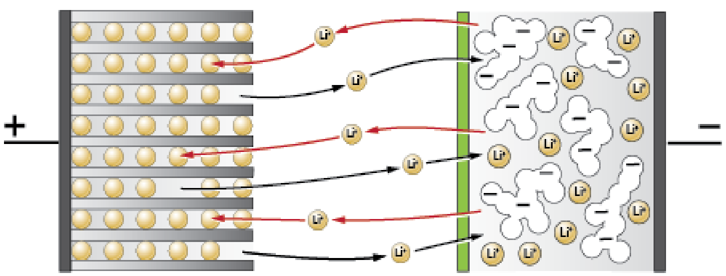
- Creates significant weight reduction for hybrid electric and all-electric aircraft
- Addresses high risk item: ***energy storage***
- Leap-frogs the question "Will technology grow 5X within 15~20 years?" with our new construct (multifunctionality)
- An example demonstrates potential weight savings:

  - 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

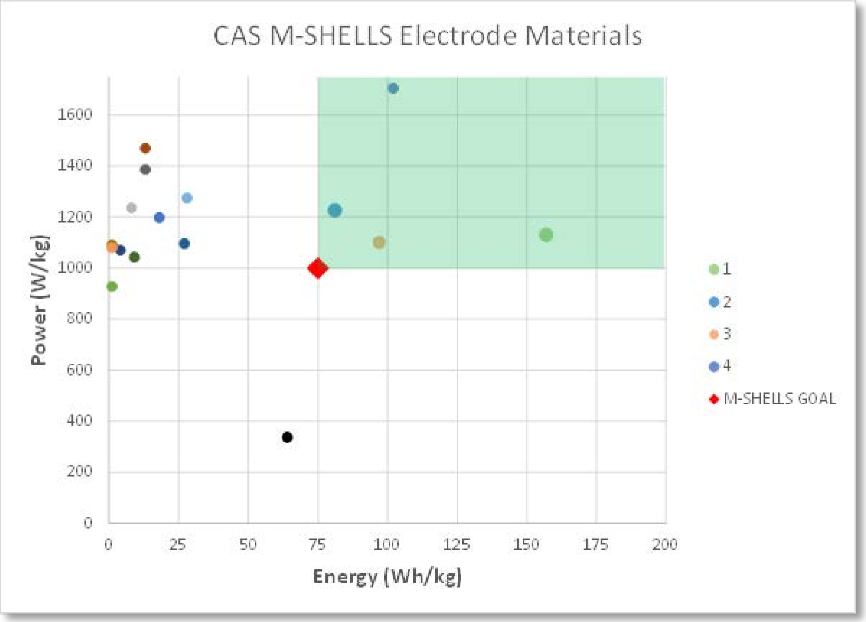
- Coin cell testing for quick turn-around
- Integration of multiple electrodes to determine compatibility
- Scale-up of electrodes & testing to pouch-cell size

- 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

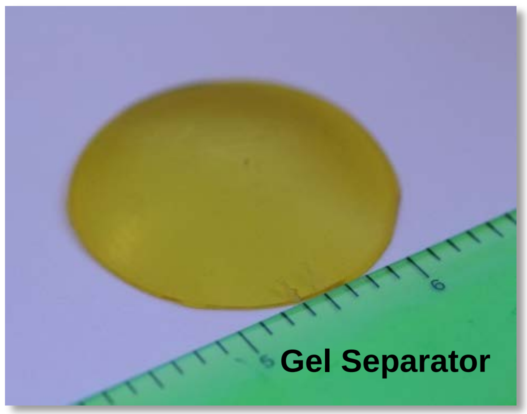
| Electrode Pairing | Power (W/kg) | Energy (Wh/kg) |
|---|---|---|
| 1 | 1131 | 157 |
| 2 | 1226 | 81 |
| 3 | 1102 | 97 |
| 4 | 1705 | 102 |



# Structural Electrochemical Components Concept

Next-generation electrochemical components that will also provide strength

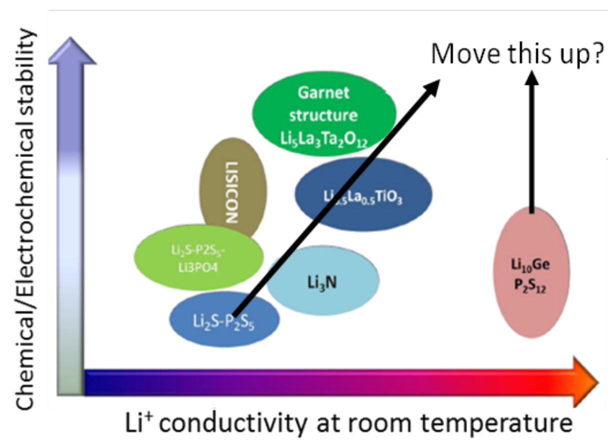
## Gel Electrolyte/Separator Concept



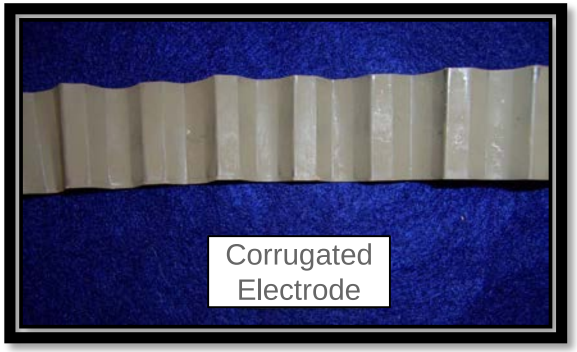

Preliminary experimentation suggests that gel electrolyte / separator could improve safety over SOA battery technology

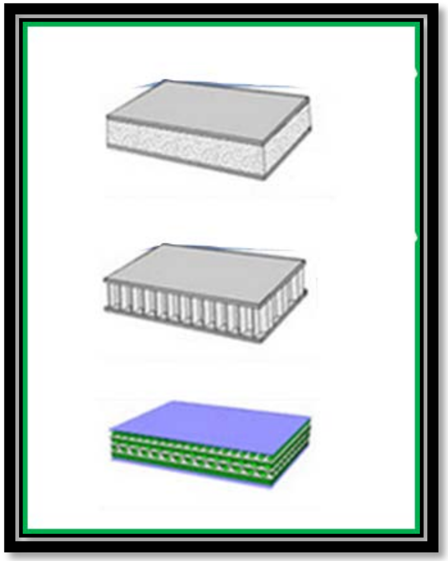
## Solid Electrolyte/Separator Concept

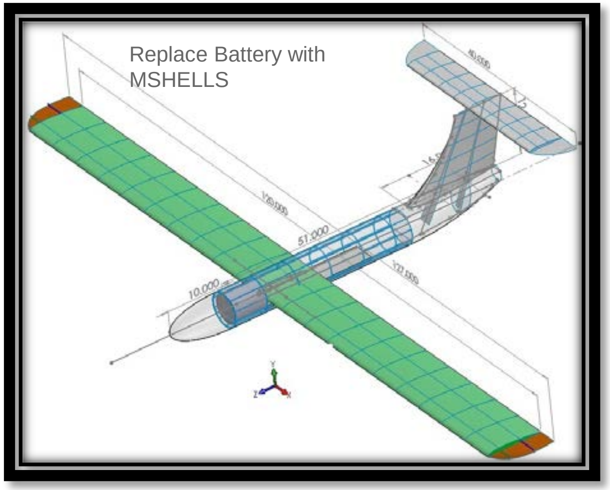
- Solid electrolyte replaces 2 components of SOA batteries – standard polymer separator and liquid electrolyte – while providing strength!
- Approach: Fabricate nano-sized solid electrolyte
- Resulting in a solid electrolyte-separator with high ionic conductivity, good mechanical properties and good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



# Structural Approach



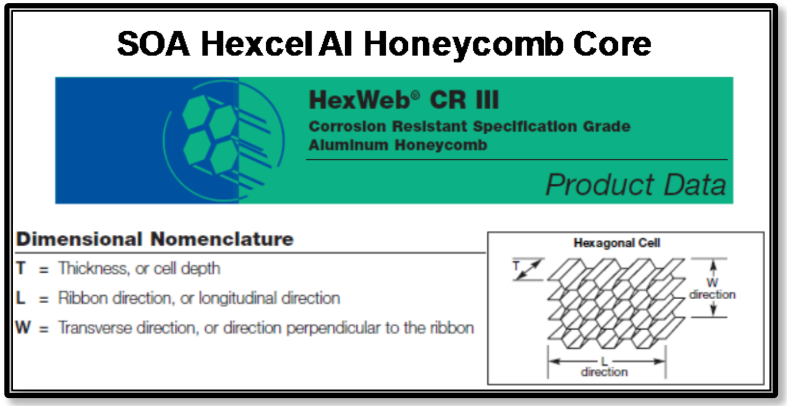


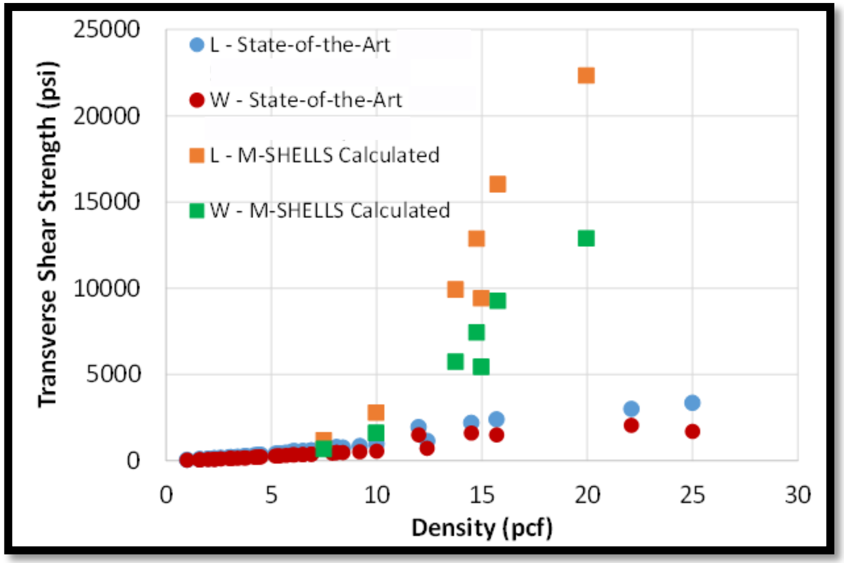

- Design & develop potential structural concepts
- Incorporate advanced materials into structural designs
- Structural concepts aim to combine energy storage components with load-bearing capability

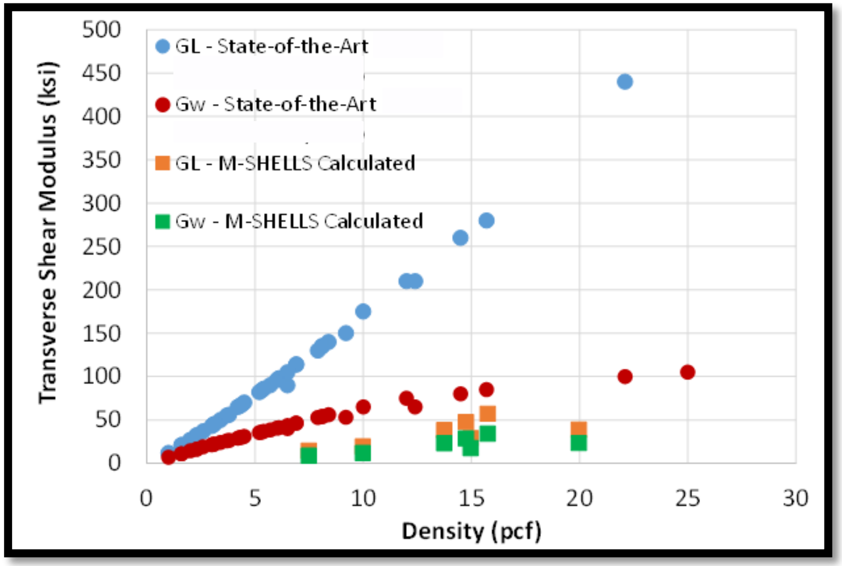
- Experimenting with different fabrication methods
- Modeling/analysis of aircraft structural needs

# 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)

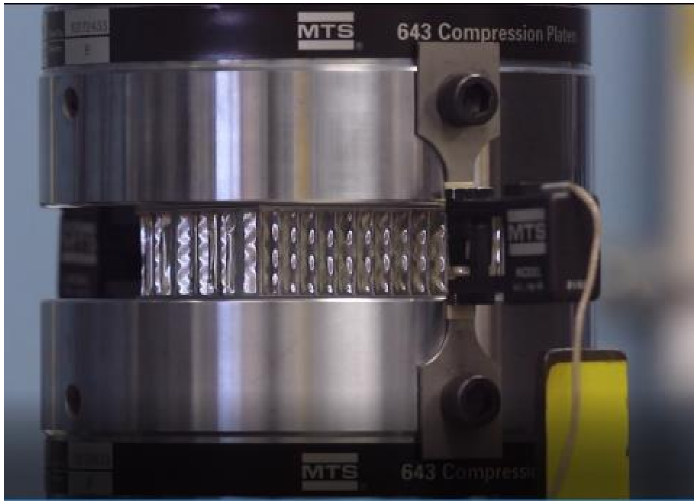


# M-SHELLS Structural Concepts Tests

- 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

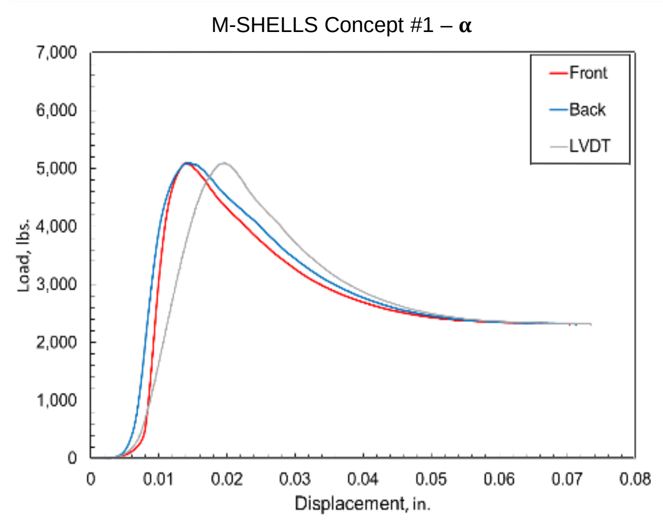


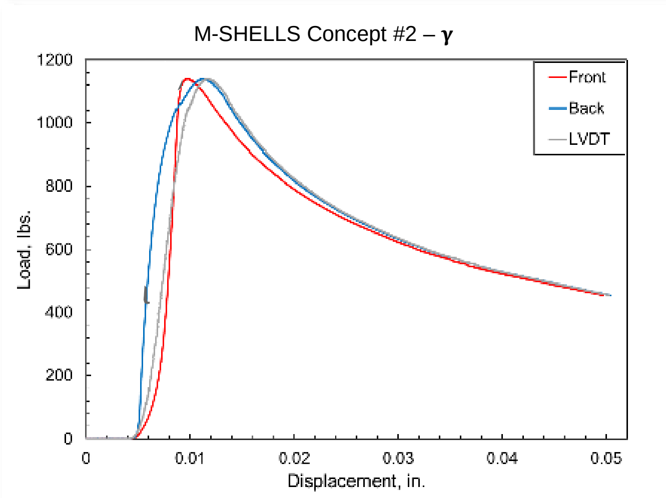

- ASTM C365 and AMS C-7436 as guidance.
- 20 Kip Load Frame
- 6 inch diameter flat platens (aligned to 0.0005” flat and parallel
- Front and Back Extensometers on platens
- Displacement rate 0.005in/min
- M-SHELLS coupons fabricated flat and parallel within 0.001in.

**Calibration test setup using baseline specimens:**

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

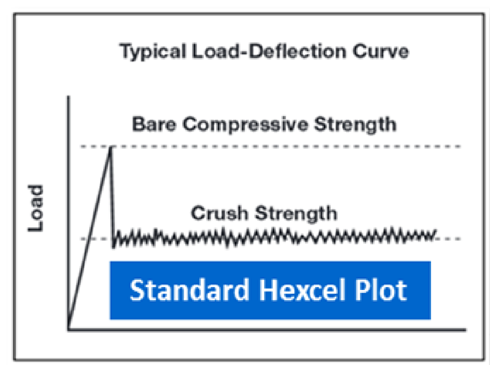
# Mechanical Test Results




- 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

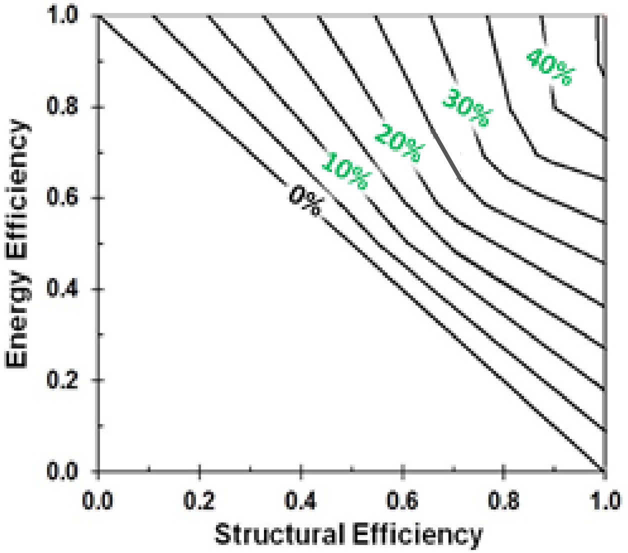
| M-SHELLS Flatwise Compression Testing | | |
|---|---|---|
| Concept Identification | Effective Compressive Module | Compressive Strength |
| | Ksi | Psi |
| **Concept #1 - α** | **100** | **462** |
| **Concept #2 - β** | **150** | **573** |
| **Concept #1 - δ** | 7 | 40 |
| **Concept #2 - γ** | 22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



# M-SHELLS Multifunctionality Demonstration

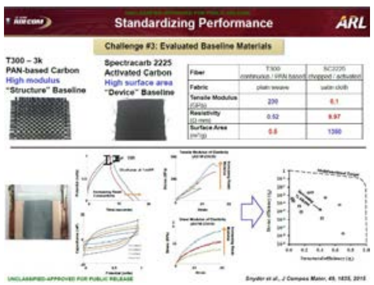
- Comparing total system mass for same structural & electrochemical functionality & volume, M-SHELLS materials has shown **positive multifunctionality**!
  - **Mass of M-SHELLS is lower than standard structure + standard battery**
- Structural properties of M-SHELLS are comparable to Hexcel standard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

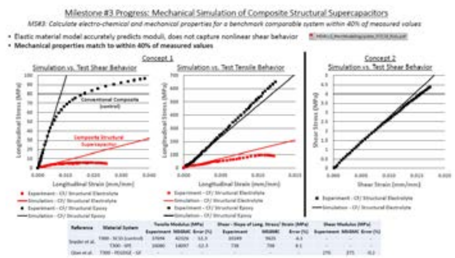
**Multifunctionality Merit**

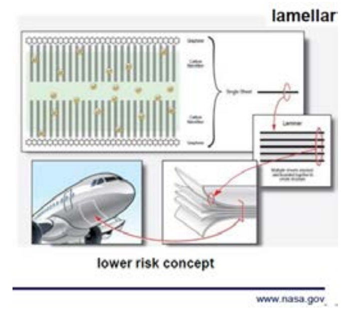


# Flight & Systems Analysis Roadmap

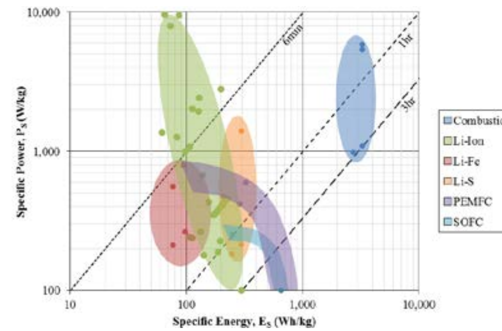
Advanced Electro Chemistry & Composite Material Properties



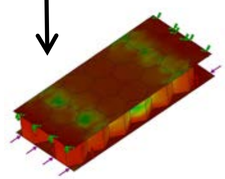



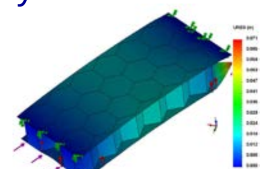



Energy and Power density

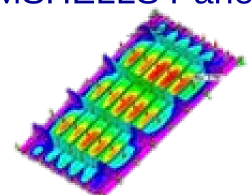



Coupon Analysis

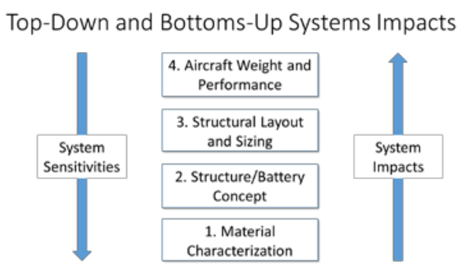


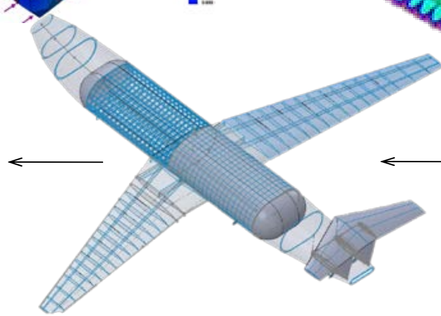


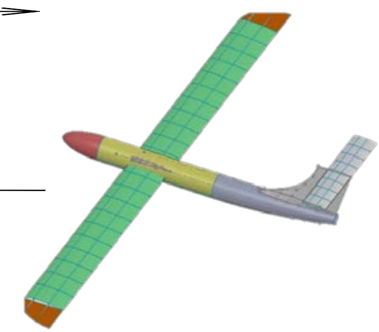
MSHELLS Panel Test



Ground & flight Tests





Sceptor X-57

UAV TEMPEST FEM

Aircraft Systems Analysis

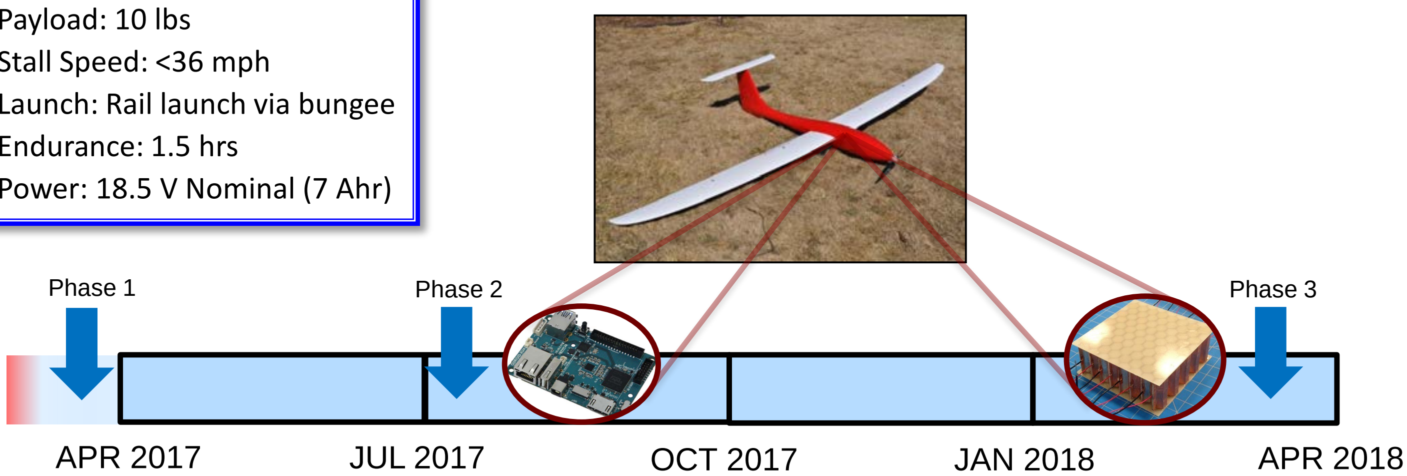
ND8 and Sugar-Volt

# 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

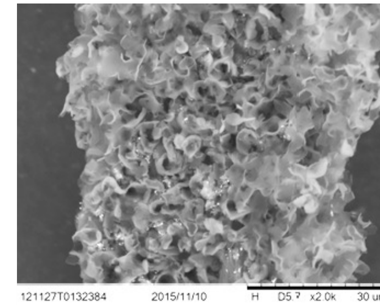
**Tempest Specifications:**
- Wingspan: 127 in (10.7 ft)
- Base weight: 10 lbs
- Payload: 10 lbs
- Stall Speed: <36 mph
- Launch: Rail launch via bungee
- Endurance: 1.5 hrs
- Power: 18.5 V Nominal (7 Ahr)

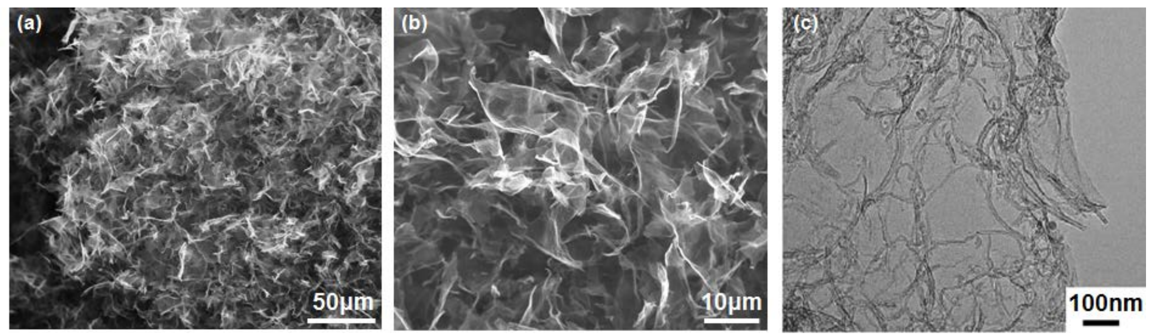
- Phase 1: Baseline Check Flights on COTS UAS
  – Verify COTS UAS power/energy flight profiles
- Phase 2: Instrument Check Flights
  – Install and evaluate data, sensor, & power switching systems in support of Phase 3 M-SHELLS research flights
- Phase 3: Research Flights with M-SHELLS
  – Install and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



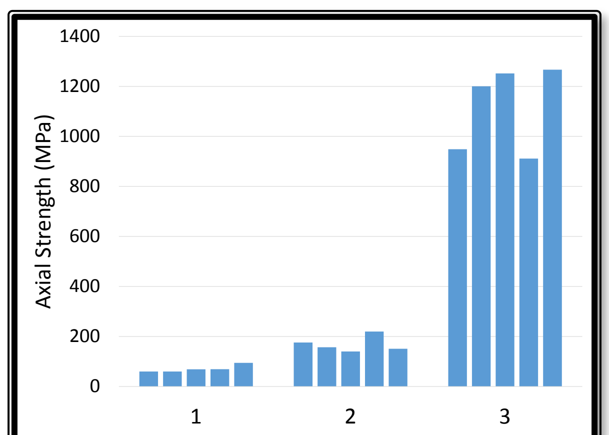
# Collaboration with Partners

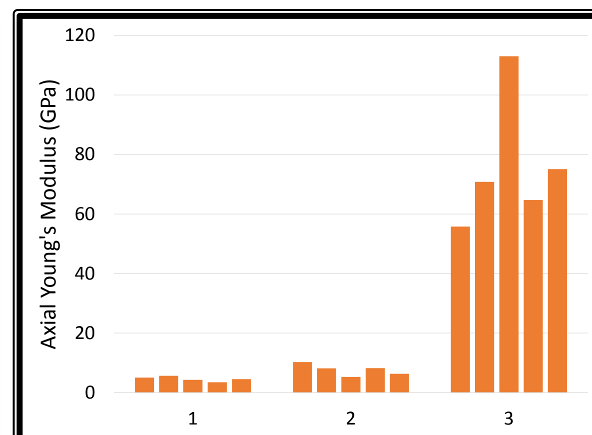
- Next generation of nanomaterials
- Developing new chemistries to improve energy density
- Fiber energy storage development for composite application






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