DLR Institute of Engineering Thermodynamics

The E^2Flight Symposium

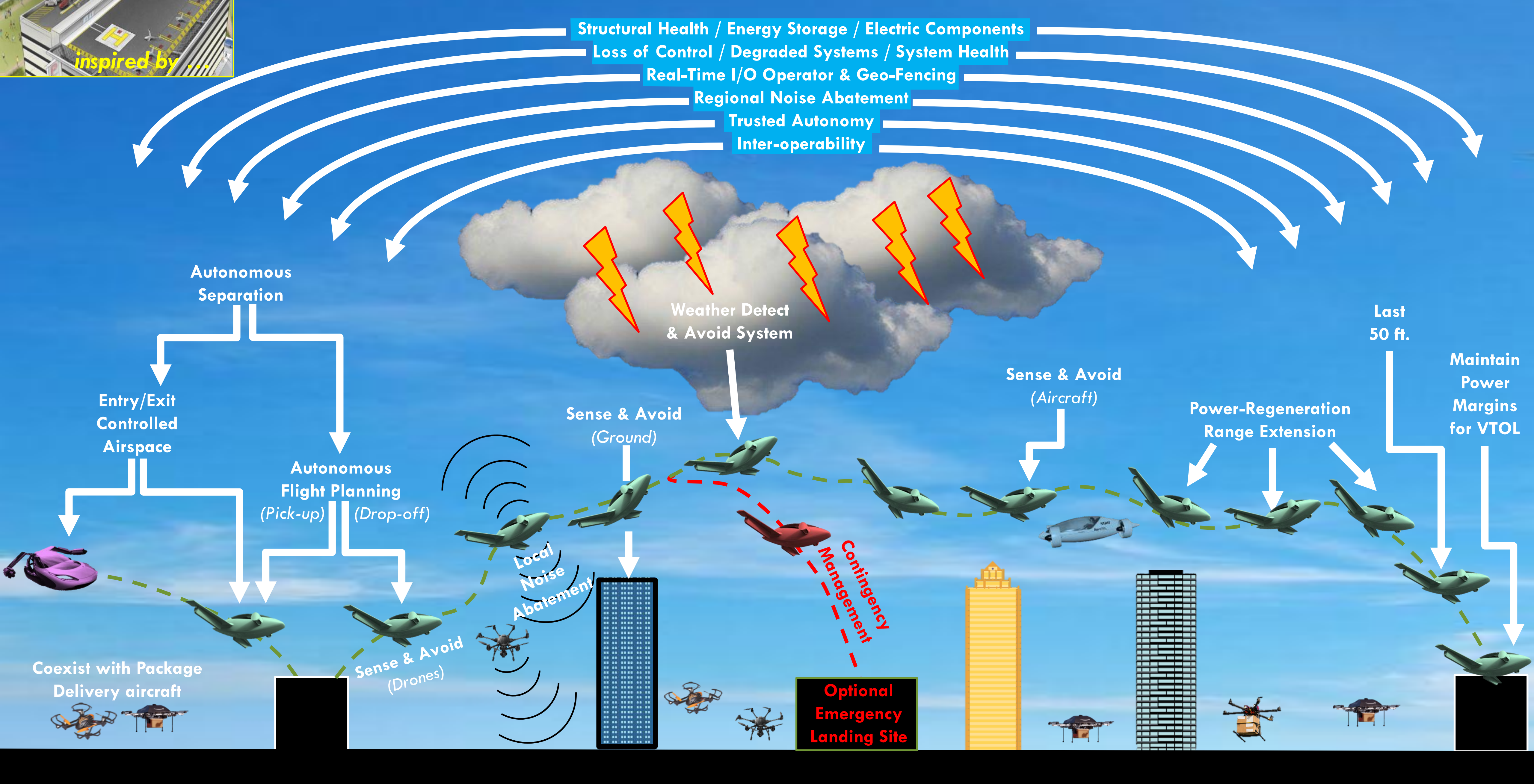
SPIRAL DEVELOPMENT OF ELECTRIFIED AIRCRAFT PROPULSION FROM GROUND TO FLIGHT

STARR GINN

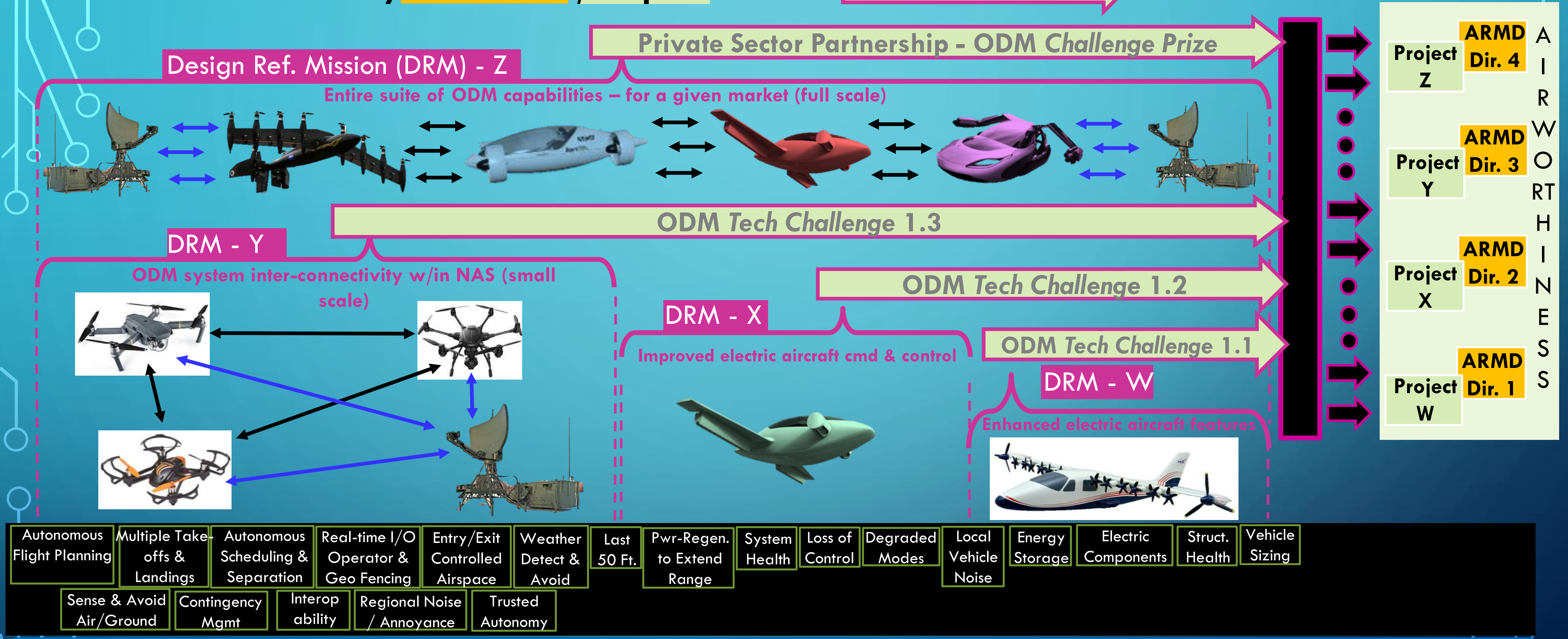
DEPUTY AERONAUTICS RESEARCH DIRECTOR

NASA ARMSTRONG FLIGHT RESEARCH CENTER

DRM: Integrated ODM 'Air-Taxi' Mission Features



Design Reference Missions (DRM's) enable integration of ODM Capabilities by ARMD Dir./Projects to meet ODM Milestones

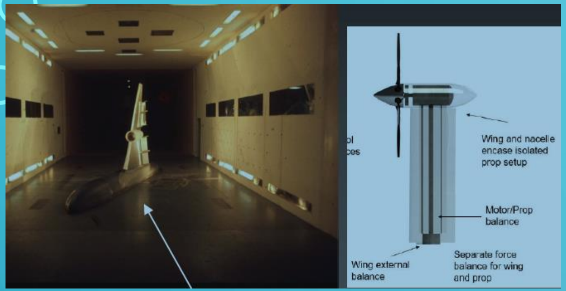


ODM Design Ref. Mission Technology Portfolio

LEARN BY DOING SPIRAL DEVELOPMENT

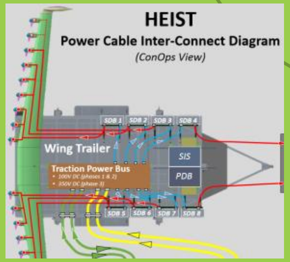
System of Systems Integration

Wind Tunnel Test – Aug.2019



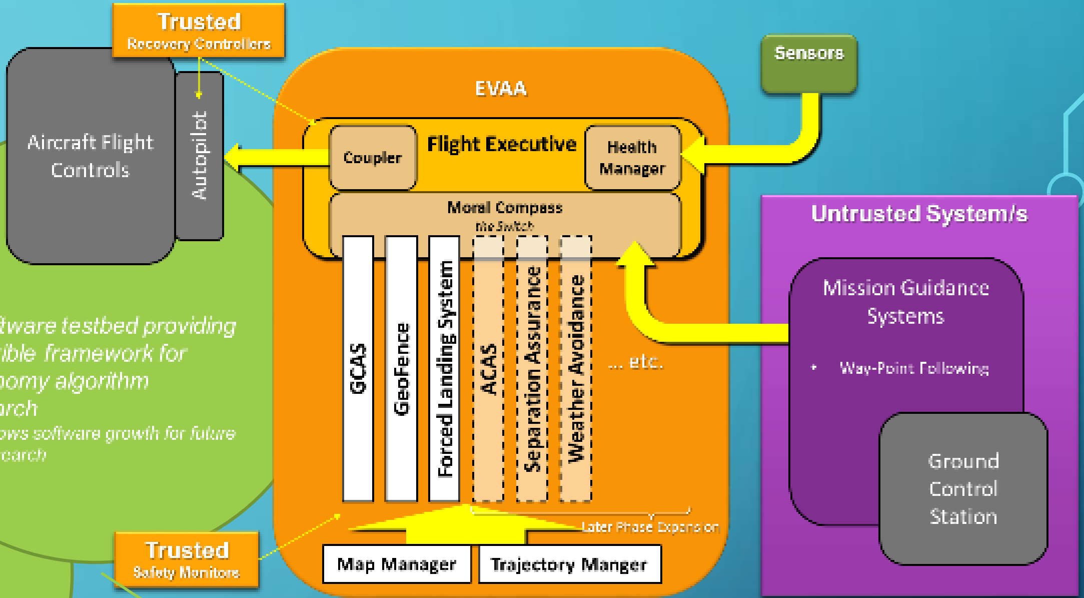
Peaking Seeking Performance for controllers and integrated power train

Adaptive Failure Recovery Mode



A software testbed providing a flexible framework for autonomy algorithm research

- *Allows software growth for future research*



Trusted Autonomy using Run-Time Assurance

Spiral Devlopment sUAS, lg-UAS, Air Taxi

Path to Safety and Certification

New Aircraft Performance Benefits with Distributed Electric Propulsion

Flight Controls Testbed for Closed-Loop command & control with Hybrid Power

Testbed for Enhanced electric aircraft features

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21

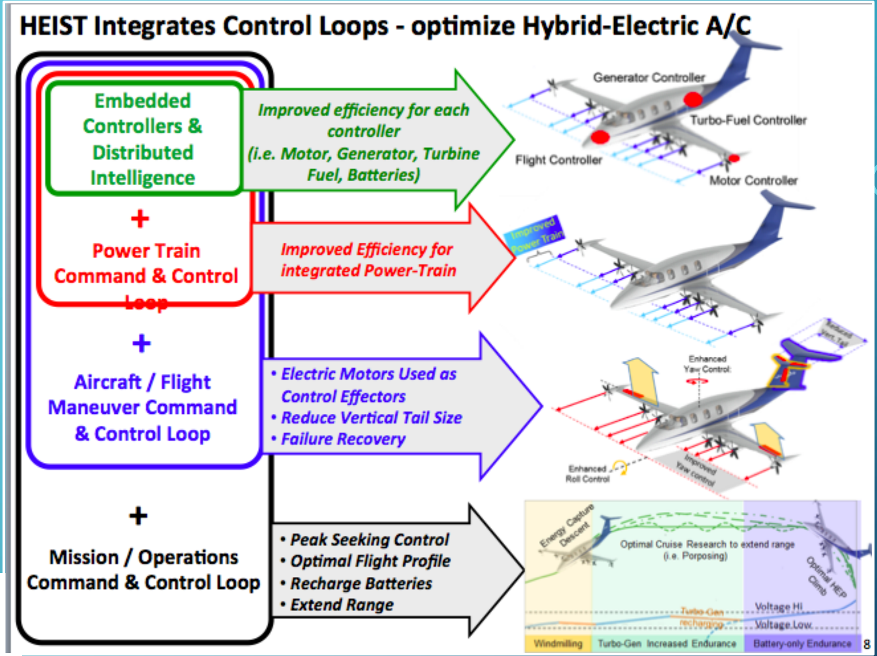
HYBRID ELECTRIC INTEGRATED SYSTEM TESTBED (HEIST)

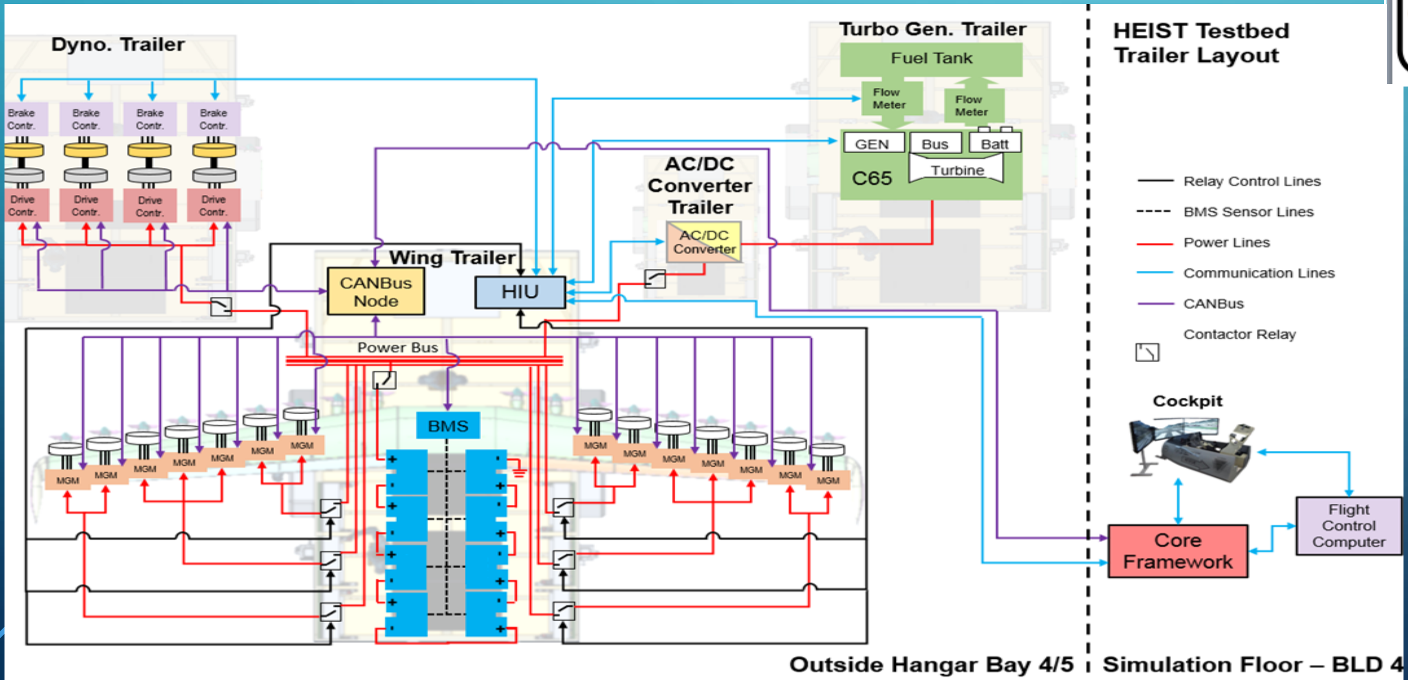
Hardware-in-the-loop (HIL)

In order for electrified aircraft propulsion to buy its' way on the airplane, intelligent systems are needed.

Objective

Automate the integration of power distribution, propulsion airframe integration, vehicle control, and mission management to optimize the energy used, provide simple pilot control, and extend the range





HEIST PHASE 1 CONTROLS RESEARCH

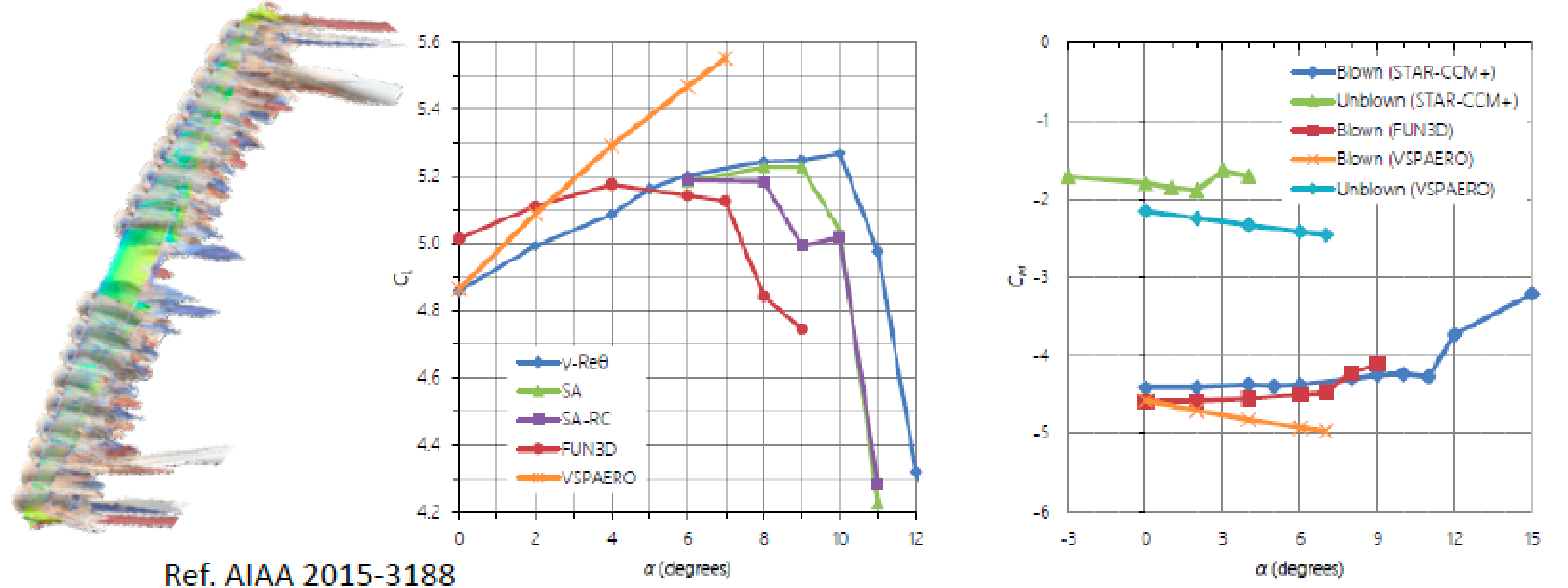
(CURTIS HANSON - NASA AFRC)

- Design & evaluate near-optimal DEP control allocation algorithm (w/ non-linear constraints)
  - Applicable to multiple DEP configurations, including…
    - Applicable hybrid-electric and all-battery
    - Fixed and variable vertical lift
    - Various mixes of electric motors and traditional control surfaces

- Non-linear constraints may be mission phase dependent and could include the following considerations:
  - Power-train
    - i.e. motor & propeller efficiency, motor temp, noise, response bandwidth & command resolution, & rpm/torque limitations
  - Battery
    - i.e. stored energy vs. mission requirements, discharge rate, battery temperature
  - Aero surface (i.e. drag penalties)
  - Frequency-dependent allocations for conditions such as turbulence
  - Failure modes
  - Component life & maintenance

- HEIST Phase 1 bench config. also used to develop models of some of these effects & their inter-dependencies, as well as provide a platform for evaluating the control allocation algorithm for certain conditions.

CFD PREDICTIONS OF LEAPTECH DISTRIBUTED ELECTRIC PROPULSION EFFECTS WERE VARIED

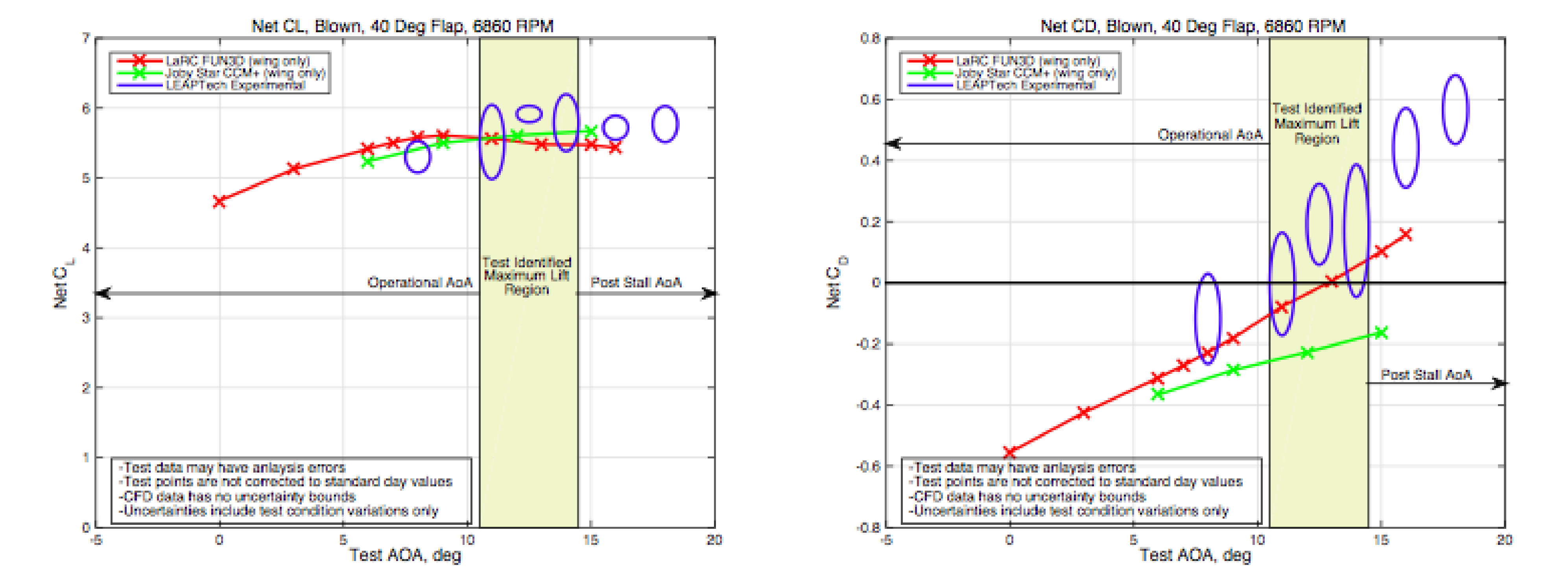


Ref. AIAA 2015-3188

LEAPTech was a feasibility experiment to quantify if a coefficient of lift of 5 was achievable

- experimental data was insufficient for tool validation

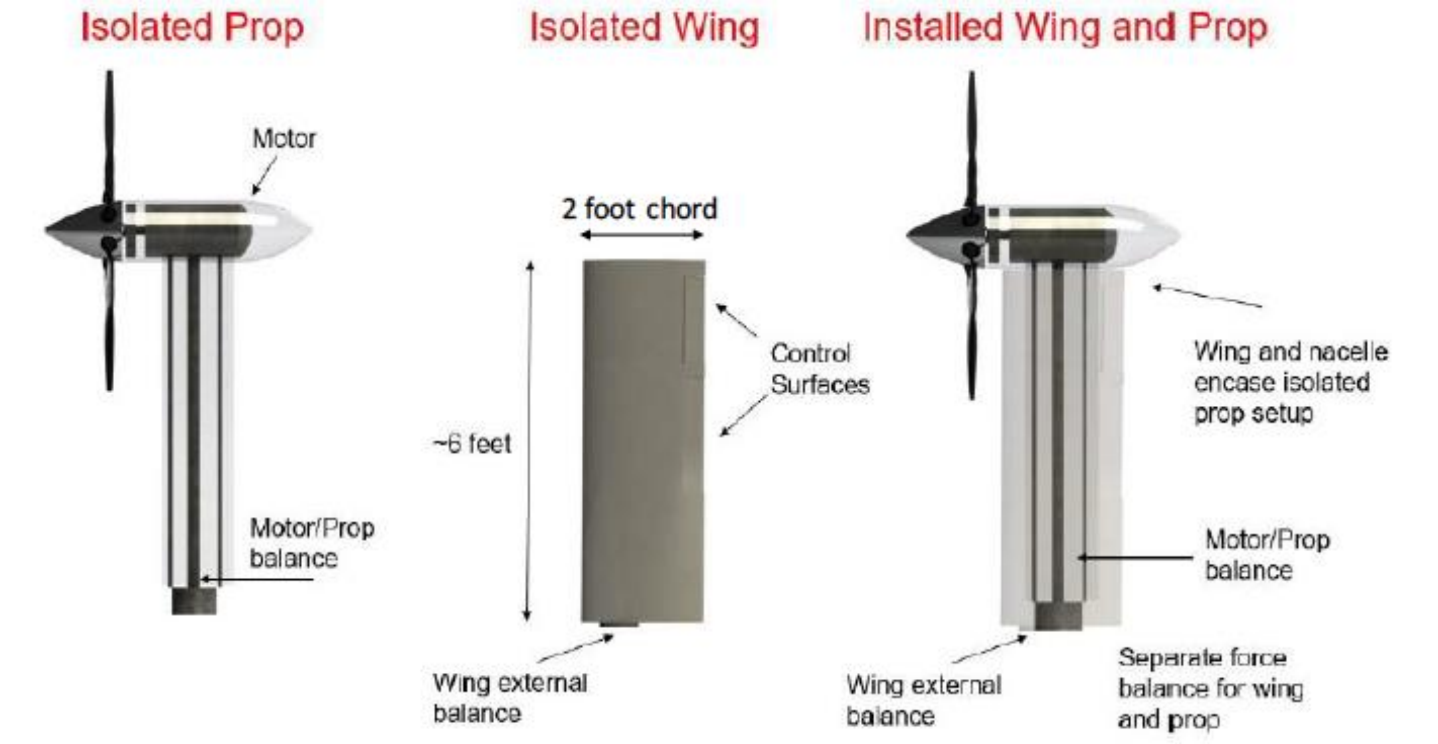
MEASUREMENT TECHNIQUES FOR PROPULSION AIRFRAME INTEGRATION STILL UNDER INVESTIGATION



Establish an open experimental dataset for predictive tool validation and new measurement techniques of a generic wing and powered tip-mounted propeller configuration

WINGTIP PAI WIND TUNNEL TEST

- USED TO DETERMINE BEST PRACTICES FOR MODELING PROPELLOR AIRFRAME INTEGRATION



Isolated Prop Data Used For:
- Thrust / Drag Bookkeeping
- Prop Wake Surveys for Act Disk CFD BC Development

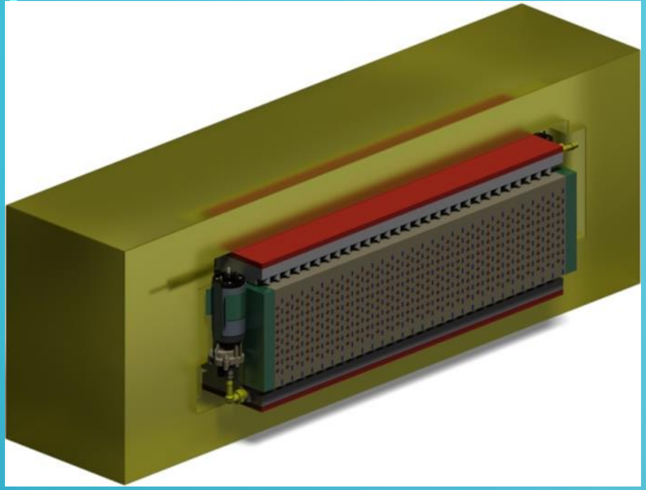
Unpowered Data Used For:
Establishes Unpowered Baseline Performance and Wing Pressures

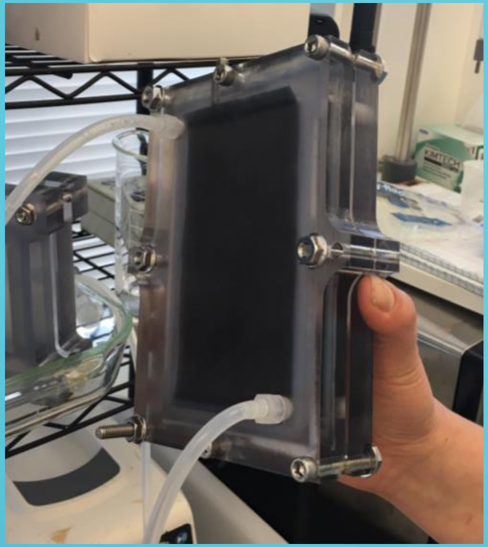
Integrated Powered Data Used For:
- Quantifies Impact of Prop on Performance and Pressure Taps
- 2 Balances (Wing & Prop)

Animation of the X-57 Transformation through risk reduction

CURRENT BARRIERS

- Explosive Energy Storage
- Fast Charging
- Decoupling Energy and Power
- Internal Volume limitations in High Aspect Ratio Wings
- Electromagnetic Interference





Influit Energy, LLC

Nanotechnology Based Liquids for Energy Storage

ILLINOIS INSTITUTE OF TECHNOLOGY

I-Corps™ Energy and Transportation in partnership with Michigan I-Corps™

arpa·e

TEDxIIT x = independently organized TED event

NEXTENERGY

NSF SBIR/STTR SMALL BUSINESS INNOVATION RESEARCH SMALL BUSINESS TECHNOLOGY TRANSFER

Argonne NATIONAL LABORATORY

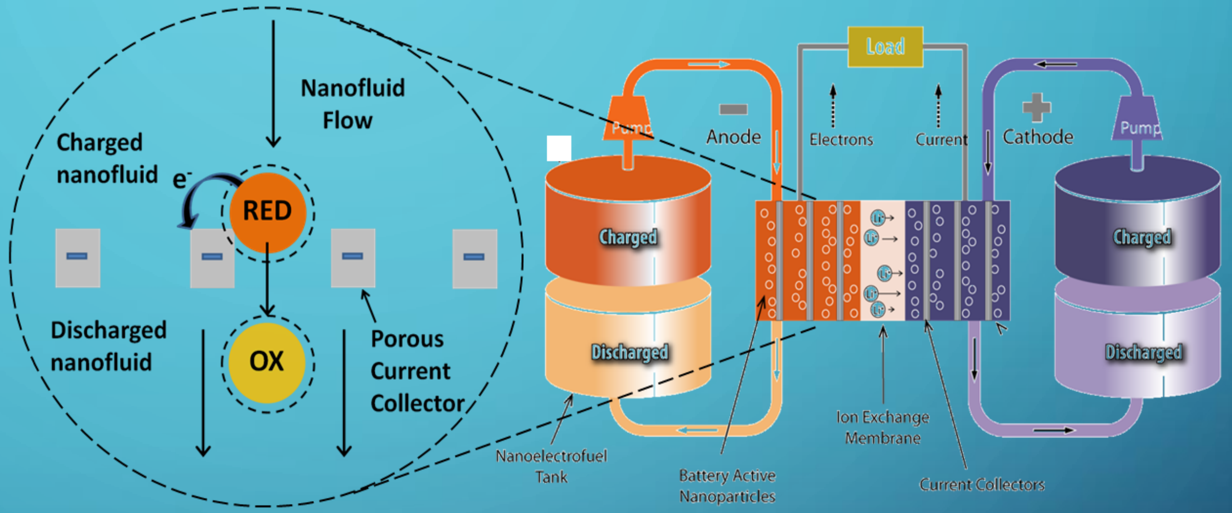
John Katsoudas, CEO
john@influitenergy.com

Nanoelectrofuel (NEF) BATTERY

1.4 times higher pack energy density than Li-ion (350Wh/L) at ½ cost ($130/kWh)

How achieved:

Solid battery cathode/anode materials turned into stabilized low viscosity nanosuspensions in aqueous electrolytes



Features include: rapid re-fueling; decouples power from energy storage – flexibility of designs; conformable low viscosity liquid; thermal management by active electrolyte; easy manufacturing, reduced packing (<40 wt% of the pack).

NEF flow battery approach enables a path to >700 Wh/kg pack density with all flow battery benefits.

John Katsoudas, CEO
john@influitenergy.com

Contributors

- **Empirical Systems Aerospace Inc. (ESAero – Prime Contractor)**
  - Prime Contractor managing all subcontractors and providing support to design, analyze, build, test, operate, and maintain the X-57 aircraft.
- **Scaled Composites**
  - Integration of flight subsystems into X-57 Mod II aircraft
- **Joby Aviation**
  - Development of the flight cruise motors and cruise motor controllers
- **Xperimental**
  - Fabrication of the Mod III Wing, Integration of the Traction system and instrumentation into the Wing, and Modification to Fuselage structure required attachment the wing.
- **Electric Power Systems (EPS)**
  - Development of the flight Traction Battery system
- **West Virginia High Tech Consortium**
  - Software validation and verification
- **Electricore**
- **Sean Clarke, NASA AFRC**
- **John Saltzman, NASA AFRC**
- **Curtis Hanson, NASA AFRC**
- **Kurt Papathakis, NASA AFRC**
- **Kurt Kloesel, NASA AFRC**
- **Brent Cobleigh, NASA AFRC**

NASA Partners

- **Armstrong Flight Research Center**
  - Project and mission management
  - Airworthiness and design reviews
  - Piloted simulations
  - Ground and flight testing
  - Power system design specification
- **Langley Research Center**
  - Wing design requirements and structural analysis
  - Vehicle design and analysis
  - Flight Simulink simulation
  - Wind tunnel testing
  - Propulsor sizing
- **Glenn Research Center**
  - Thermal Management analysis
  - Battery Expertise
- **Johnson Space Center**
  - Battery cell destructive and abuse testing
  - Battery Expertise
- **Ames Research Center**
  - CFD to improve Mod III aerodynamic database for the X-57 piloted simulation