



# Design and Development of a 200-kW Turbo-electric Distributed Propulsion Testbed

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# NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21<sup>st</sup> Century



6 Strategic Thrusts



Safe, Efficient Growth in Global Operations



Innovation in Commercial Supersonic Aircraft



Ultra-Efficient Commercial Vehicles



Transition to Low-Carbon Propulsion



Real-Time System-Wide Safety Assurance



Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

# Strategic Thrusts 3 & 4

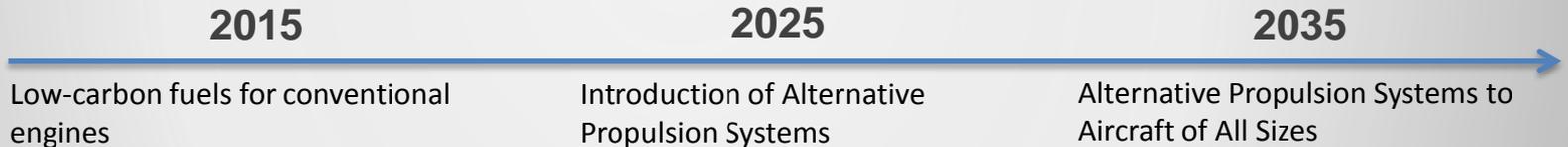
Hybrid Electric Propulsion Research Themes



## Strategic Thrust 3: Ultra Efficient Commercial Vehicles



## Strategic Thrust 4: Transition to Low Carbon Propulsion

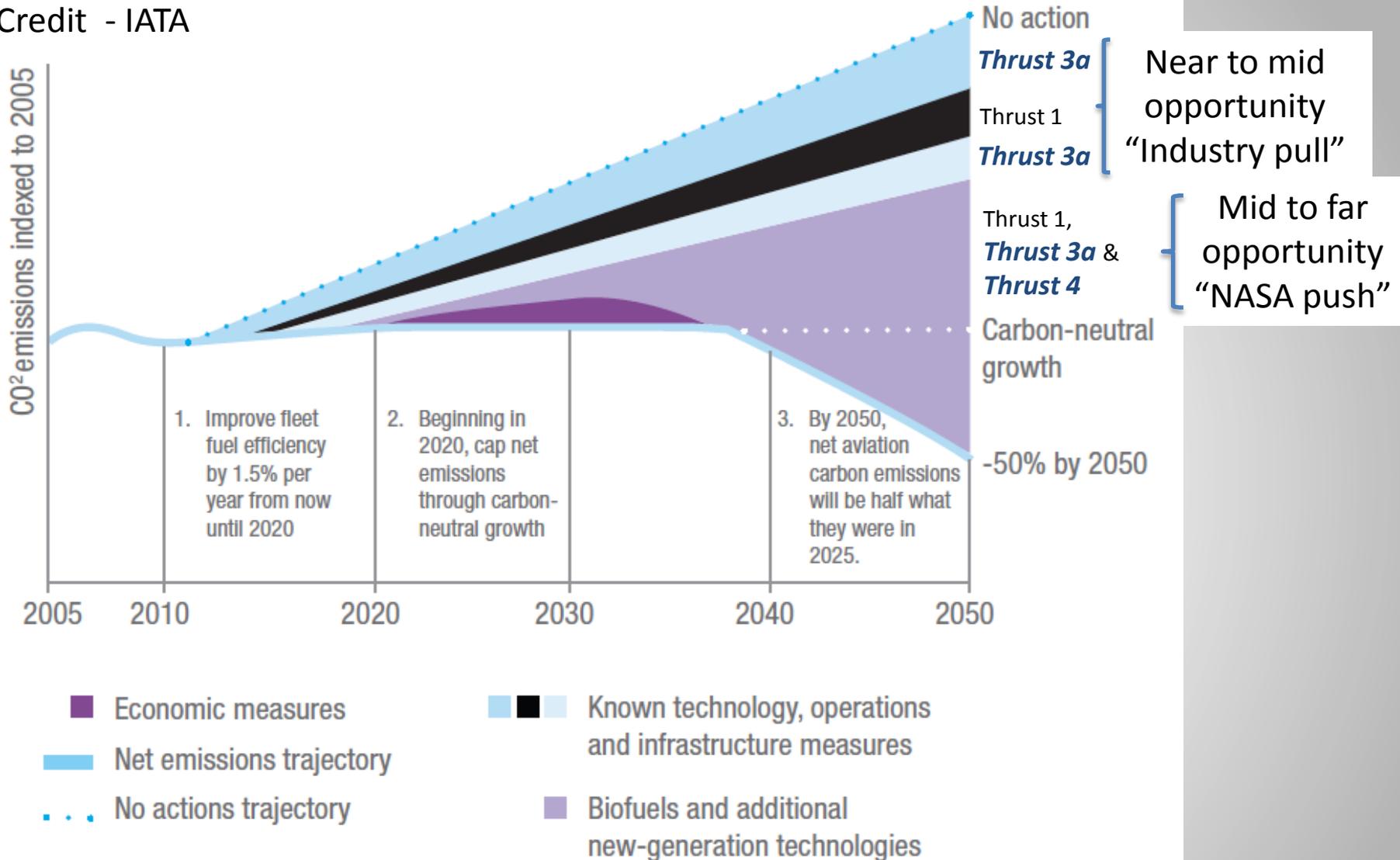


- **Integrated Technology Concepts (Vehicle / Synergy)**
- **Power and Propulsion Architectures**
- **HEP Components / Enablers**
- **Modeling, Simulation, and Test Capability**

# CO<sub>2</sub> Emissions Forecast through 2050



Credit - IATA





## A Vision for Electrified Aircraft

National Aeronautics and Space Administration



Can ALL-ELECTRIC and Aircraft Fundamentally

HYBRID-ELECTRIC Improve Mobility?

What TECHNOLOGIES and

KNOWLEDGE BASES are Required?

Can HYBRID and TURBO Propulsion Enable Carbon Use and

ELECTRIC Significant Reductions in Emissions?



### Thin-Haul-Distributed Electric Propulsion

- Maximize aerodynamic, propulsion, and flight-deck efficiencies for commuter aircraft
- Provide concept platform to infuse new technologies, develop certification standards, and provide subscale demonstration for <100 PAX



### SCEPTOR Flight Demonstration

- Scalable convergent electric propulsion technology operations research

### Leading Edge Asynchronous Propeller Technology (LEAPTech)

- All electric aero-propulsive integrated testing



### Hybrid-Electric Vertical Lift Concepts

- Demonstrate robust transition between hover and forward flight
- Achieve 4x the cruise efficiency (lift to drag ratio) compared to conventional helicopters

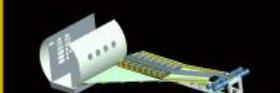
### Risk Reduction Ground Testing

- Explore distributed propulsion vehicle architectures through build, test, and fly cycles
- Validate transformational electric propulsion integration capabilities



### Modeling Tools and Analyses

- High-fidelity, multidisciplinary simulations
- Power and energy management
- Controls and diagnostics



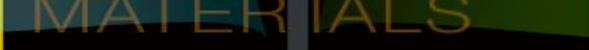
### NASA Electric Aircraft Testbed (NEAT)

- Scalable, reconfigurable flightweight power systems
- Multi-MW architectures
- Performance, thermal management, and electromagnetic interference (EMI) testing



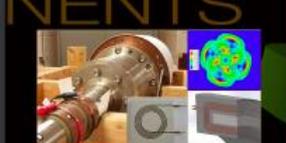
### Enabling Materials for

- Motors and generators
- Power electronics
- Conductors and insulators



### Hybrid Electric Integrated System Testbed (HEIST)

- Hardware-in-the-loop
- Subsystem characterization
- Ironbird system testing
- Piloted flight simulations



### High Specific Power, High-Efficiency Electric Machines

- Superconducting and nonsuperconducting configurations
- Advanced machine topologies
- Flightweight thermal management systems



### Parallel Hybrid-Electric Geared Turbofan Architecture

NASA, United Technologies Research Center, UTC-Aerospac, and Pratt & Whitney



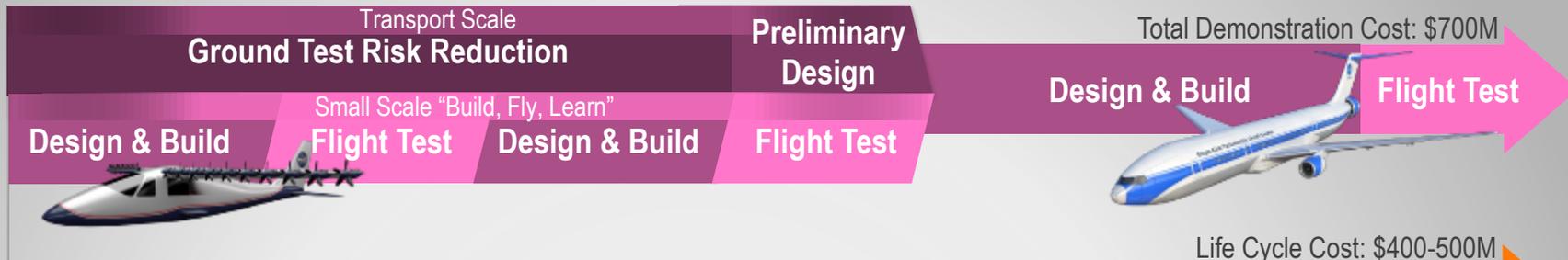
### Potential Flight Tests To Provide Early Verification of Key Benefits

- ### Ground Tests To Validate System Benefits
- Boundary layer ingestion
  - Propulsion-airframe integration
  - Turbine integration

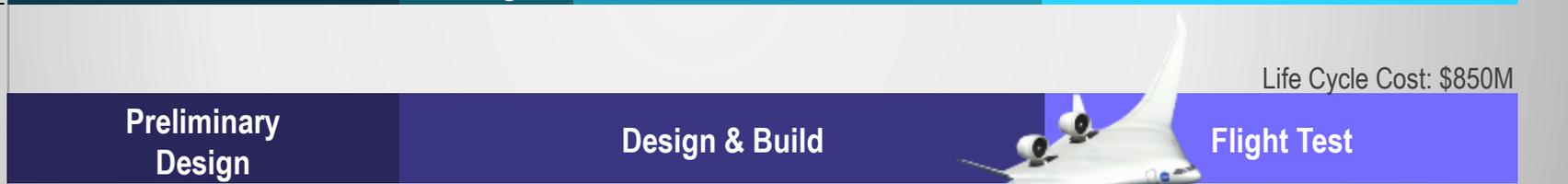
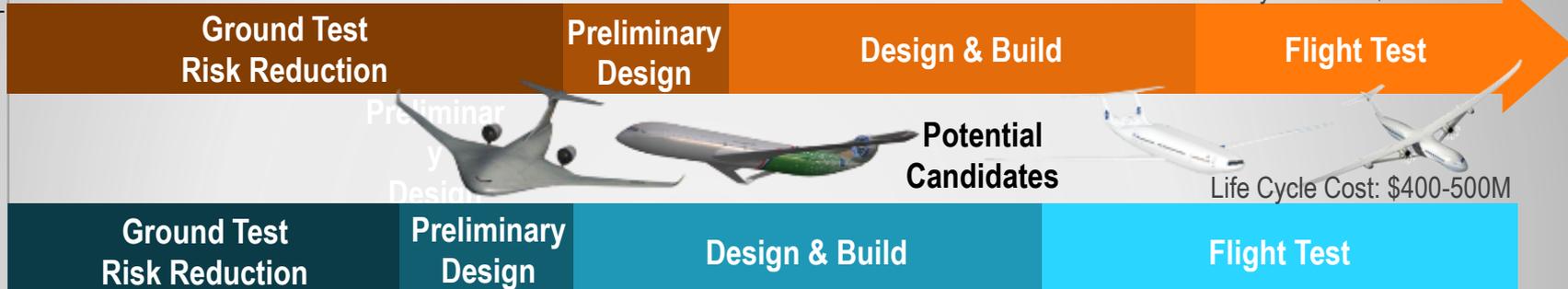
# Electric & Hybrid-Electric Flight Demonstration Plan



## Hybrid Electric Propulsion Demonstrators



"Purpose-Built" UEST Demonstrators



## Fully integrated UEST Demonstrator



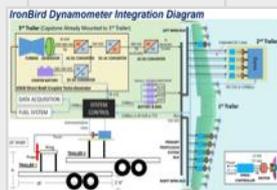
FY17    FY18    FY19    FY20    FY21    FY22    FY23    FY24    FY25    FY26

# Armstrong Electric and Hybrid-Electric Propulsion Roadmap



FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
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**Adv Air Transport Technology**  
AFRC/GRC



Capturing Complexities of Hybrid Architectures

**1-2 MW Flight Project**

Performance and Control of Integrated Systems Testing in Preparation for 1-2MW flight demonstrator

**Convergent Aeronautics Solutions**  
AFRC/LARC/GRC  
ESAero/Joby



**SCEPTOR 3000lb – 2019**

Spiral Development for MW scale

**Team Seeding**  
AFRC/LARC  
ESAero/Joby



**Risk Reduction Testing for Airplane**

Risk Reduction for kW airplane



## Turbine Benefits:

- Long-duration power req'd (cruise)
- Battery charging
- High specific power/energy

## Electric Benefits:

- Reduce emissions
- Reduce direct operating costs
- Increase propulsive efficiency
- Power augmentation
- Windmilling energy
- Size engines for cruise instead of climb / one-engine-out takeoff

## Full System Benefits:

- Hybrid-electric propulsion is NOT replacement technology
  - Allows for completely redesigned vehicles
  - Propulsors located to reduce drag
  - *Propulsion-airframe interactions* (PAI)
- Develop technologies, integration strategies, and flight control algorithms
- *Spiral development* to larger MW systems
- airworthiness

# Hybrid Electric Integrated Systems Testbed

Turbo-electric Distributed Propulsion (TeDP) testbed connected to a piloted flight simulator

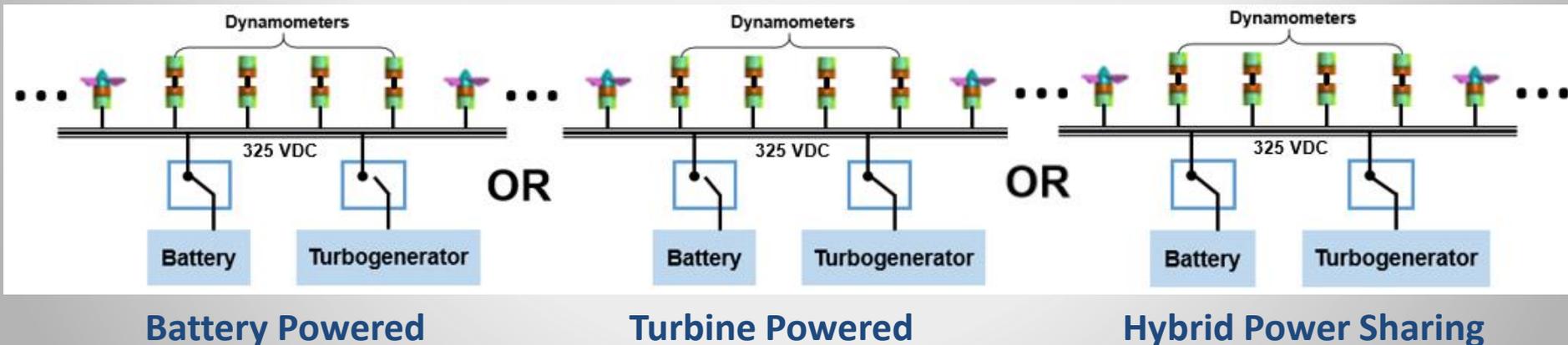


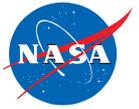
## Architecture Description

- TeDP
- 18 electric motors/controllers
- Total Power: 265-kW
- 65-kW turbogenerator
- 200-kW battery system
- 325V bus architecture

## Hardware-in-the-Loop Testbed

- Cockpit
- Simulation computer
- Hardware & software disconnects
- Emulate multiple failure types
- Aerodynamic feedback using dynamometers

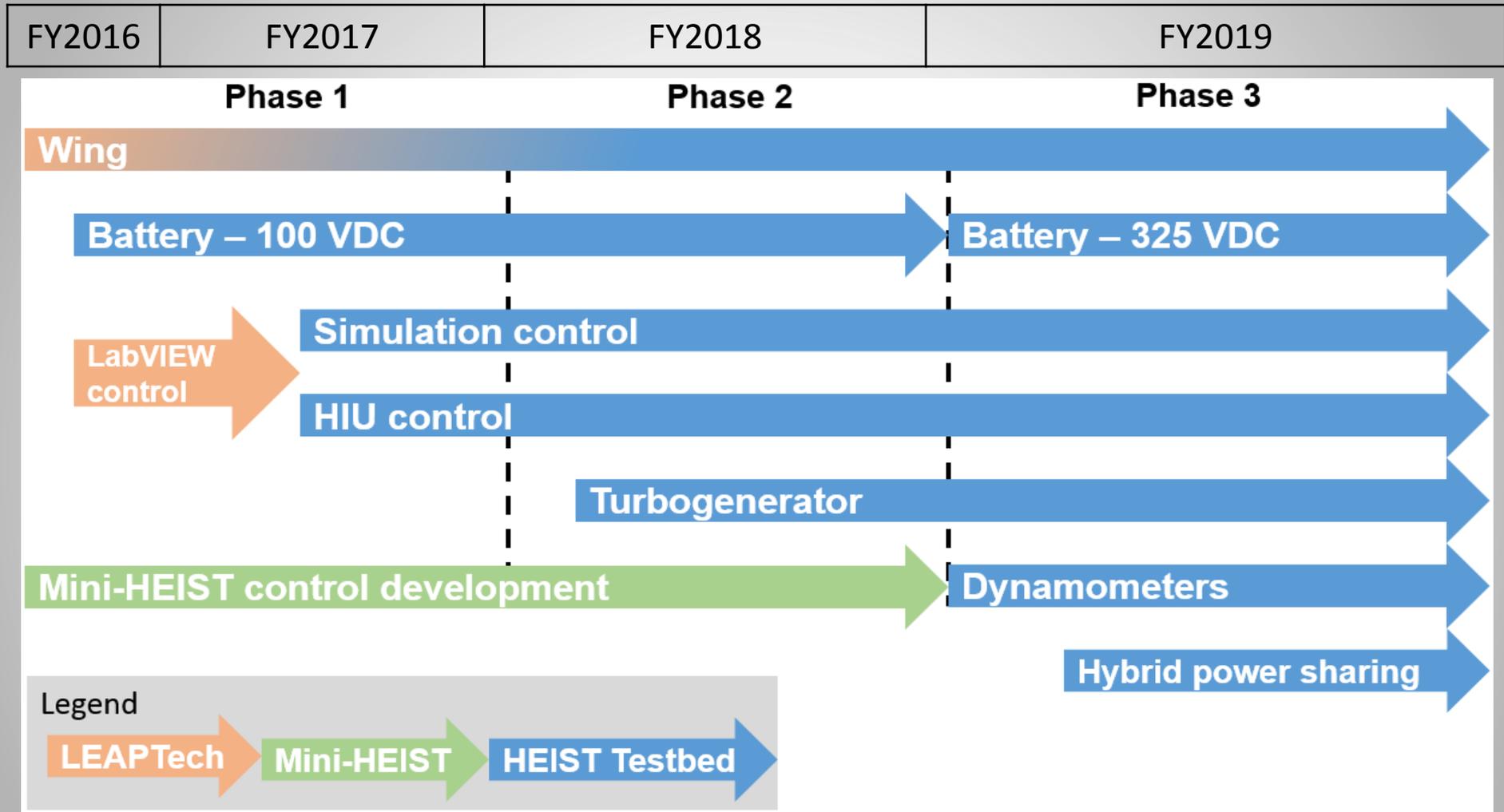




1. Hardware-in-loop testbed & control scalable to 1-2 MW
2. Test HEIST in flight-like manner with piloted SIM
3. Flight controls requirements for large benches
4. Degradation & failure modes of TeDP system
5. Hybrid power management
6. Explore different bus architectures
7. Design, fabrication, test, and lessons learned
8. New design trades for TeDP systems
9. Improved flight maneuvers for TeDP systems

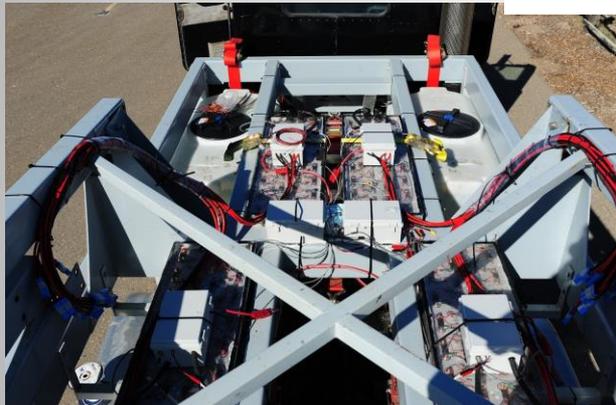
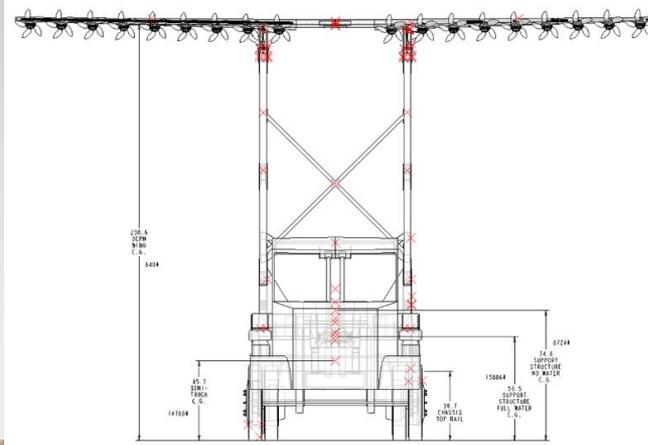
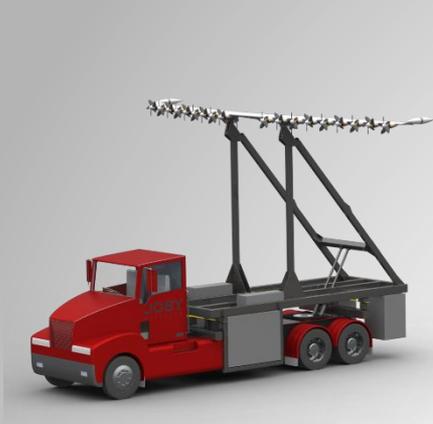
*\*NOTE: This list is abbreviated, several other lower-priority objectives also apply*

# HEIST Project Timeline



# The LEAPTech Truck Experiment

1<sup>st</sup> Experiment of HEIST

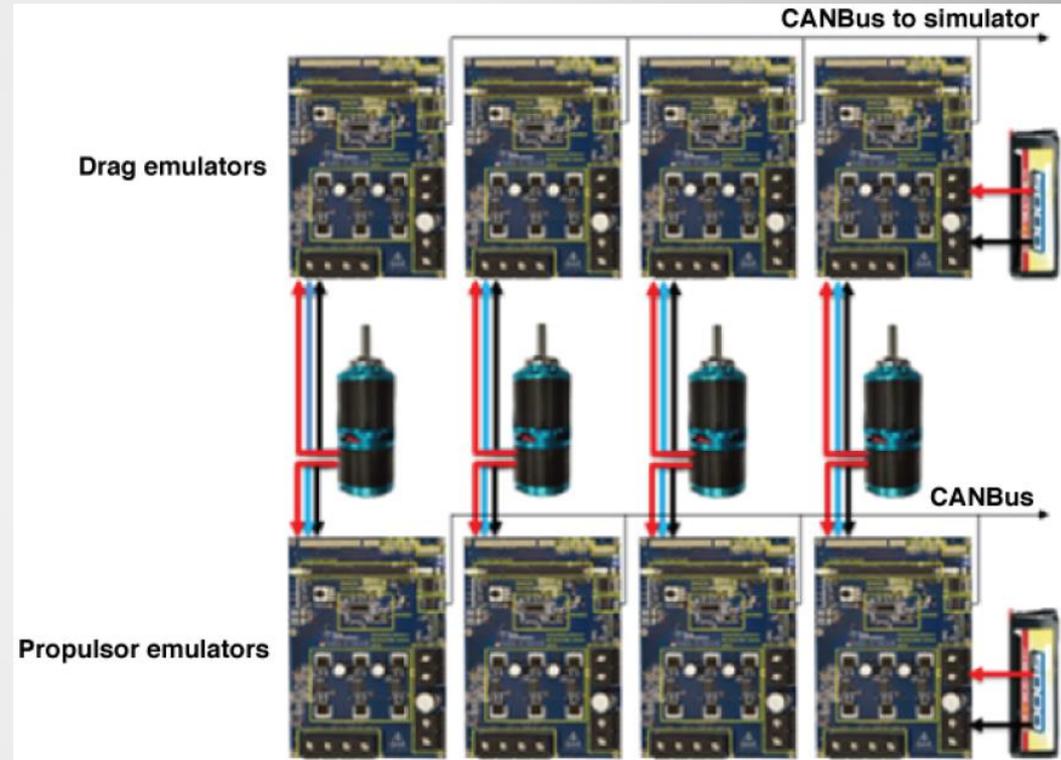


# Mini-HEIST

Dynamometer Simulator

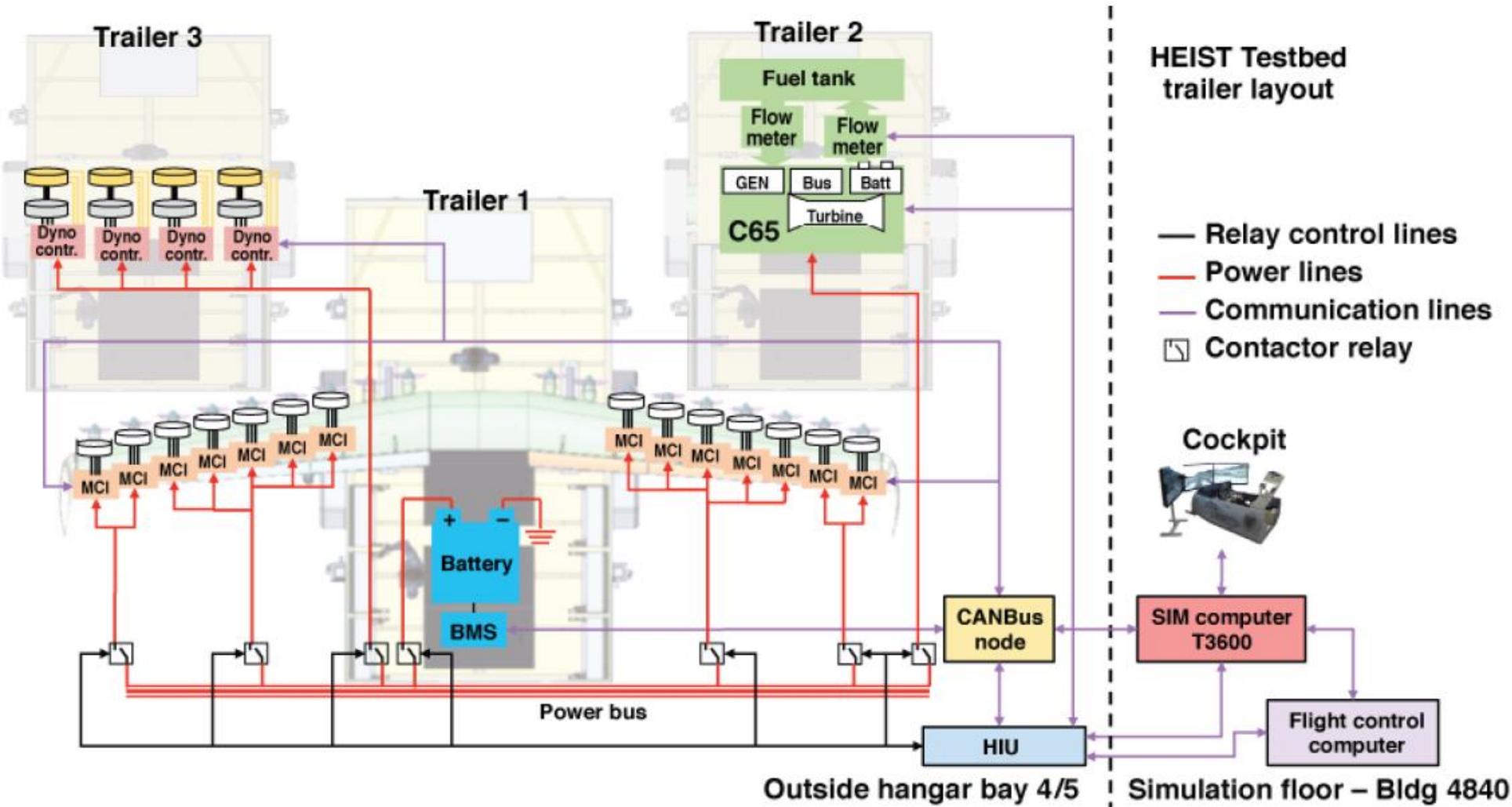


- Aid in dynamometer development
- Identify CANBus protocols
- Connect to simulator for aerodynamic feedback
- Aid in flight controls research and feedback
- Drag emulator:  
*torque control*
- Propulsor emulator:  
*speed control*



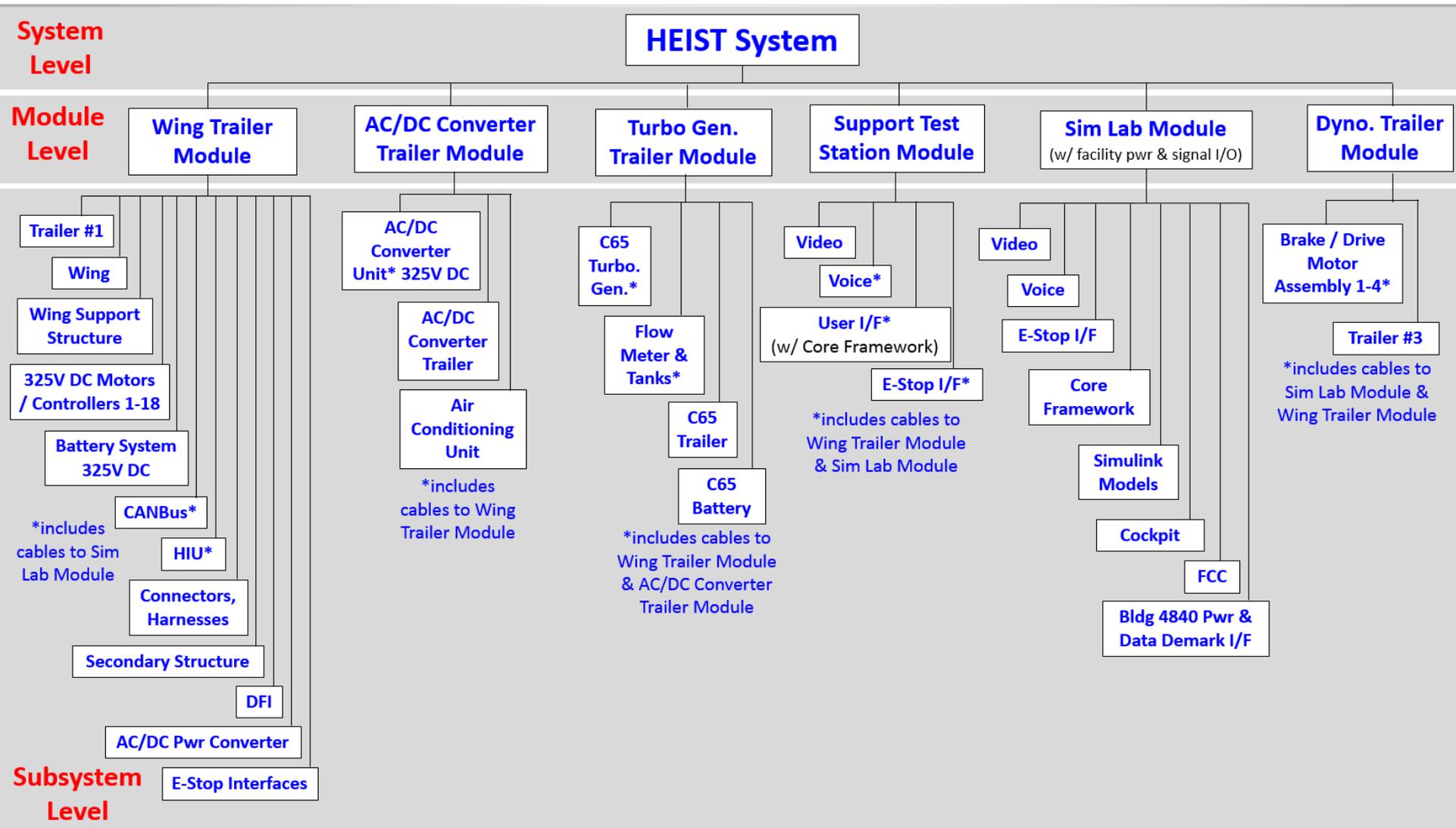
# HEIST System Architecture

Mobile Trailer Setup

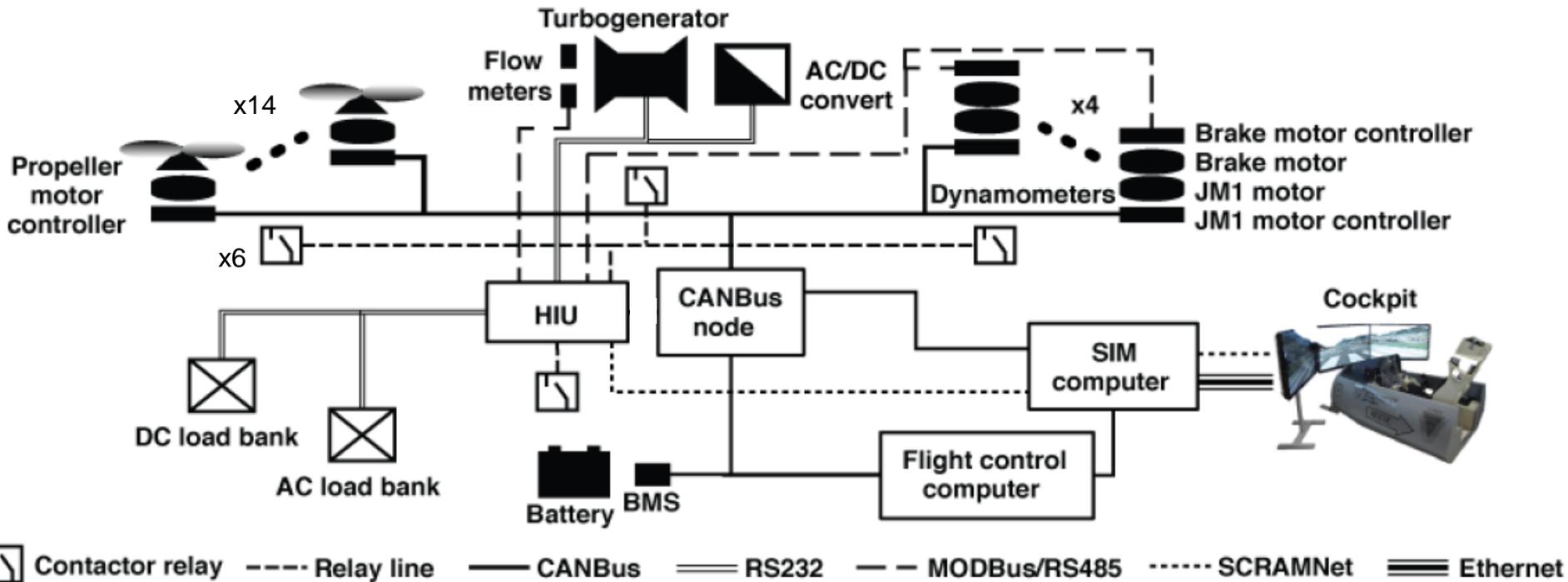


\*NOTE: AC Power from turbogenerator is converted to DC power using an AC/DC converter on its own trailer (omitted for clarity)

# HEIST System Hierarchy



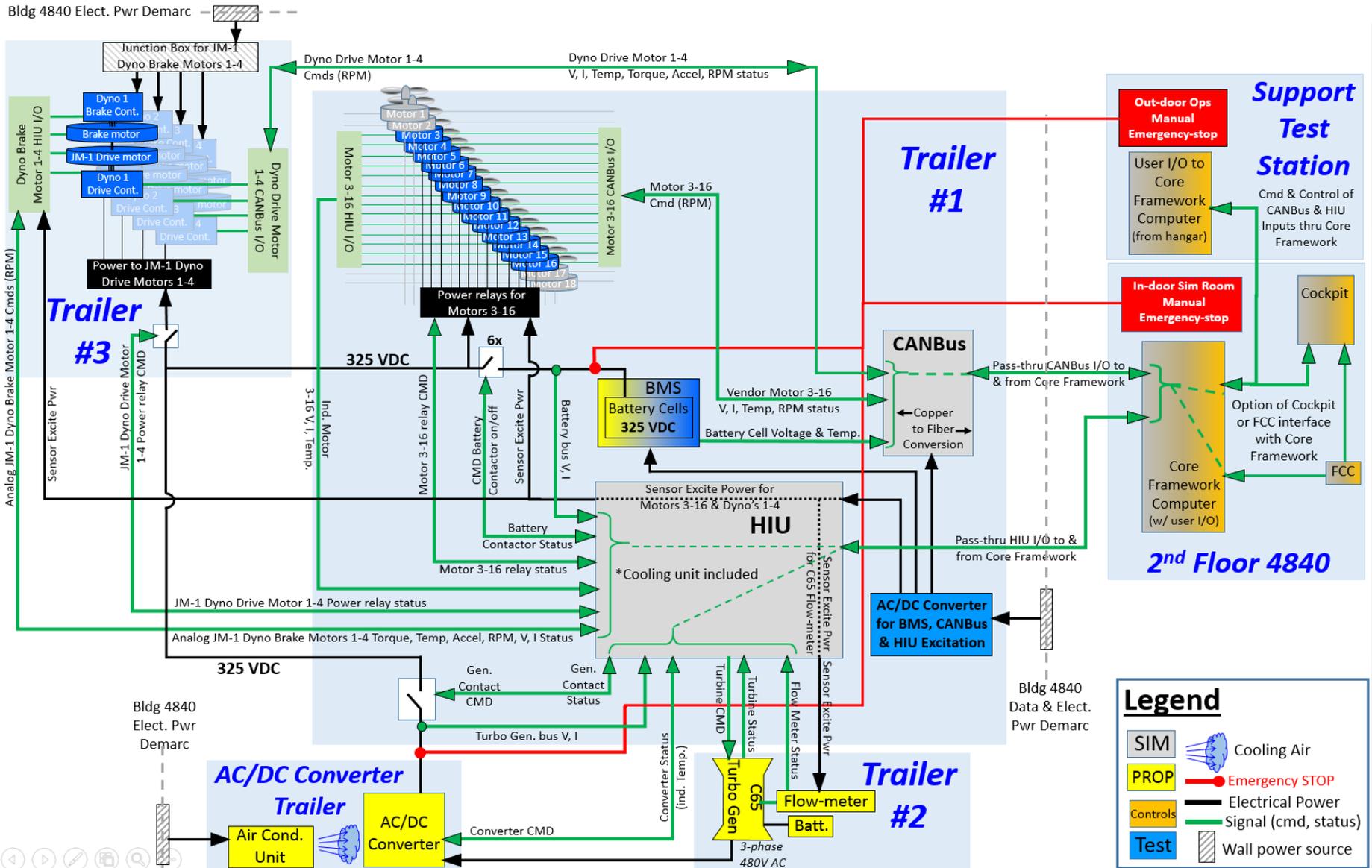
# HEIST Communication Architecture



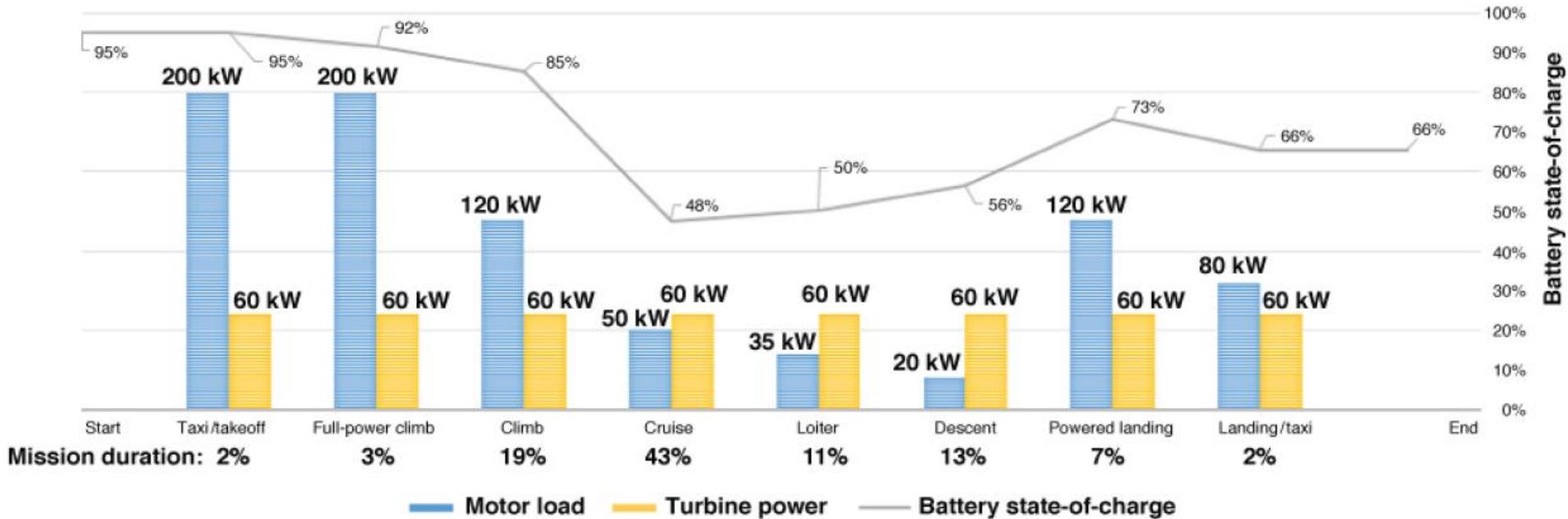
Hardware Interface Unit (HIU) handles all motor commands and sensor values other than the Joby JM1 motor controller and BMS systems, which communicate via CANBus

SCRAMNet is a shared memory fiber optic network connecting the HIU to the core framework (SIM)

# HEIST Architecture Description / Interconnect Diagram



# Notional Hybrid-Electric Mission Profile



## Capabilities to demonstrate:

- 100% battery powered
- 100% turbine powered
- Hybrid power sharing
- Notional missions (like the mission shown above)
- Windmilling (shown for cruise, loiter, and descent phases above)
- Use battery to quickly spool up turbine
- Lessons and scalability for larger MW-scale architectures

# How HEIST fits into the Electric & Hybrid-Electric Demos



2015 → 2035

Non-cryogenic	100 kW	Largest Electrical Machine on Aircraft			30 MW	Superconducting
		1 MW	3 MW	10 MW		

Scaled-up hardware using lessons from HEIST

**9 Seat**  
0.5 MW Total Propulsive Power

50-250 kW Electric Machines



**19 Seat**  
2 MW Total Propulsive Power

.1-1 MW Electric Machines



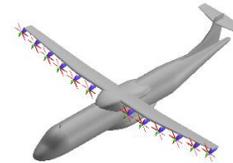
**50 Seat Turboprop**  
3 MW Total Propulsive Power

.3-6 MW Electric Machines



**50 Seat Jet**  
12 MW Total Propulsive Power

.3-6 MW Electric Machines



**150 Seat**  
22 MW Total Propulsive Power

1.5-2.6 MW Electric Machines



**150 Seat**  
22 MW Total Propulsive Power

1-11 MW Electric Machines



**300 Seat**  
60 MW Total Propulsive Power

3-30 MW Electric Machines



Right side is the size of a generator for a twin turboelectric system for a fully electrified airplane

# Backup Slides

