



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 21st Century



U.S. leadership for a new era of flight

Strategic Thrusts 3 & 4

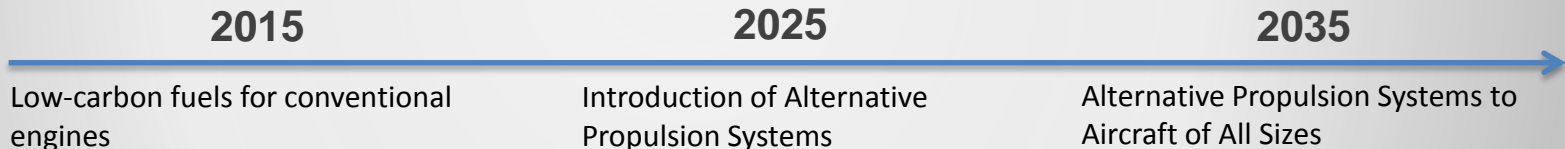
Hybrid Electric Propulsion Research Themes



Strategic Thrust 3: Ultra Efficient Commercial Vehicles



Strategic Thrust 4: Transition to Low Carbon Propulsion

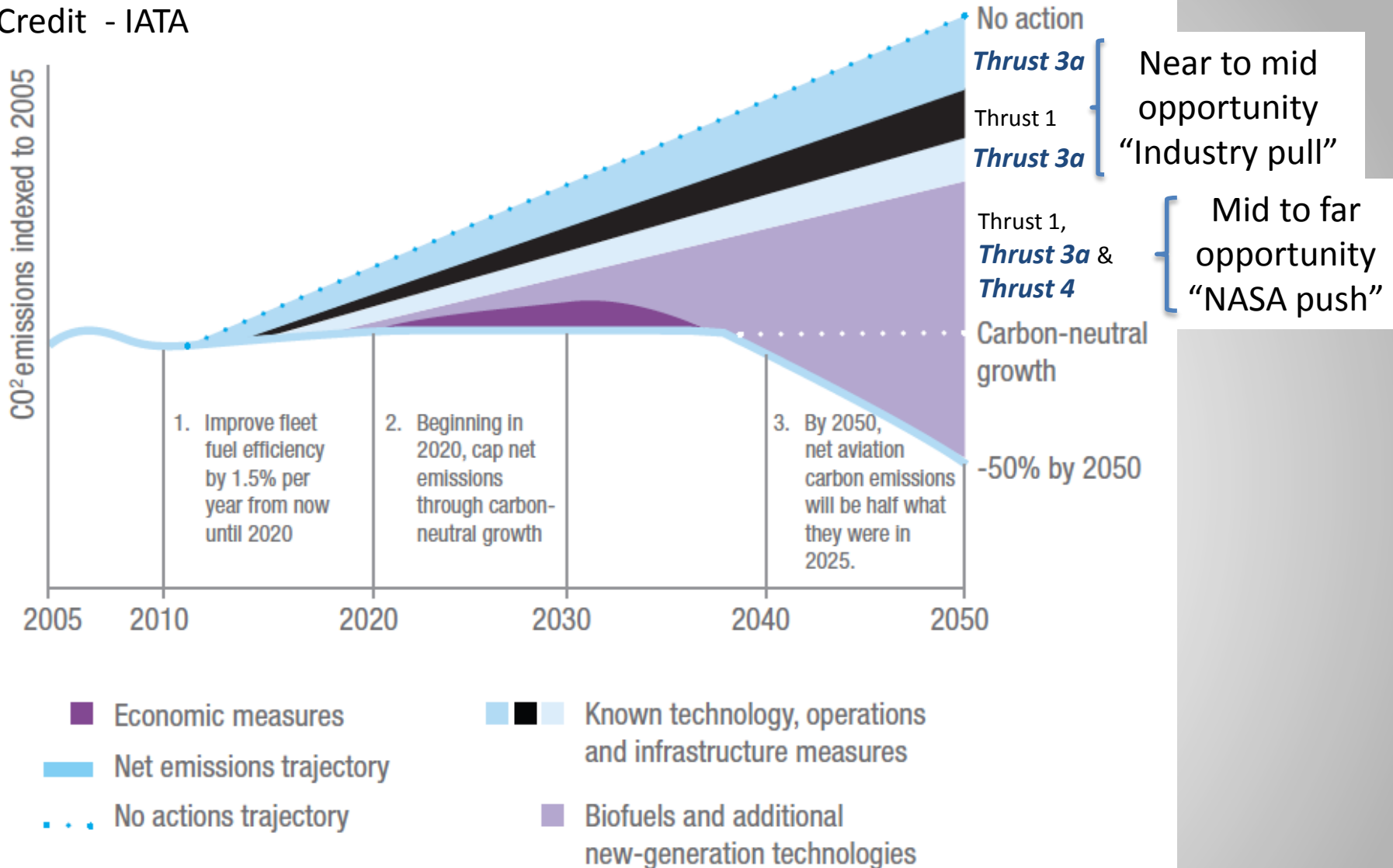


- Integrated Technology Concepts (Vehicle / Synergy)
- Power and Propulsion Architectures
- HEP Components / Enablers
- Modeling, Simulation, and Test Capability

CO₂ Emissions Forecast through 2050



Credit - IATA



NASA Electric and Hybrid-Electric Roadmap



A Vision for Electrified Aircraft

National Aeronautics and
Space Administration



Can
ALL-ELECTRIC and
Aircraft Fundamentally

HYBRID-ELECTRIC
Improve Mobility?



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

NASA, ESAero, and Jolly Aviation

- Scalable convergent electric propulsion technology operations research

Leading Edge Asynchronous Propeller Technology (LEAPTech)

NASA, ESAero, and Jolly Aviation

- 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

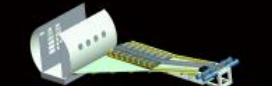


What
TECHNOLOGIES and



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

KNOWLEDGE
BASES are Required?



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

Can
HYBRID and **TURBO**
Propulsion Enable
Carbon Use and

ELECTRIC
Significant Reductions in
Emissions?



Boeing SUGAR Freeze



Parallel Hybrid-Electric Geared Turbofan Architecture

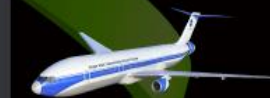
NASA, United Technologies Research Center, UTC Aerospace, and Pratt & Whitney



N3-X



Boeing SUGAR Volt

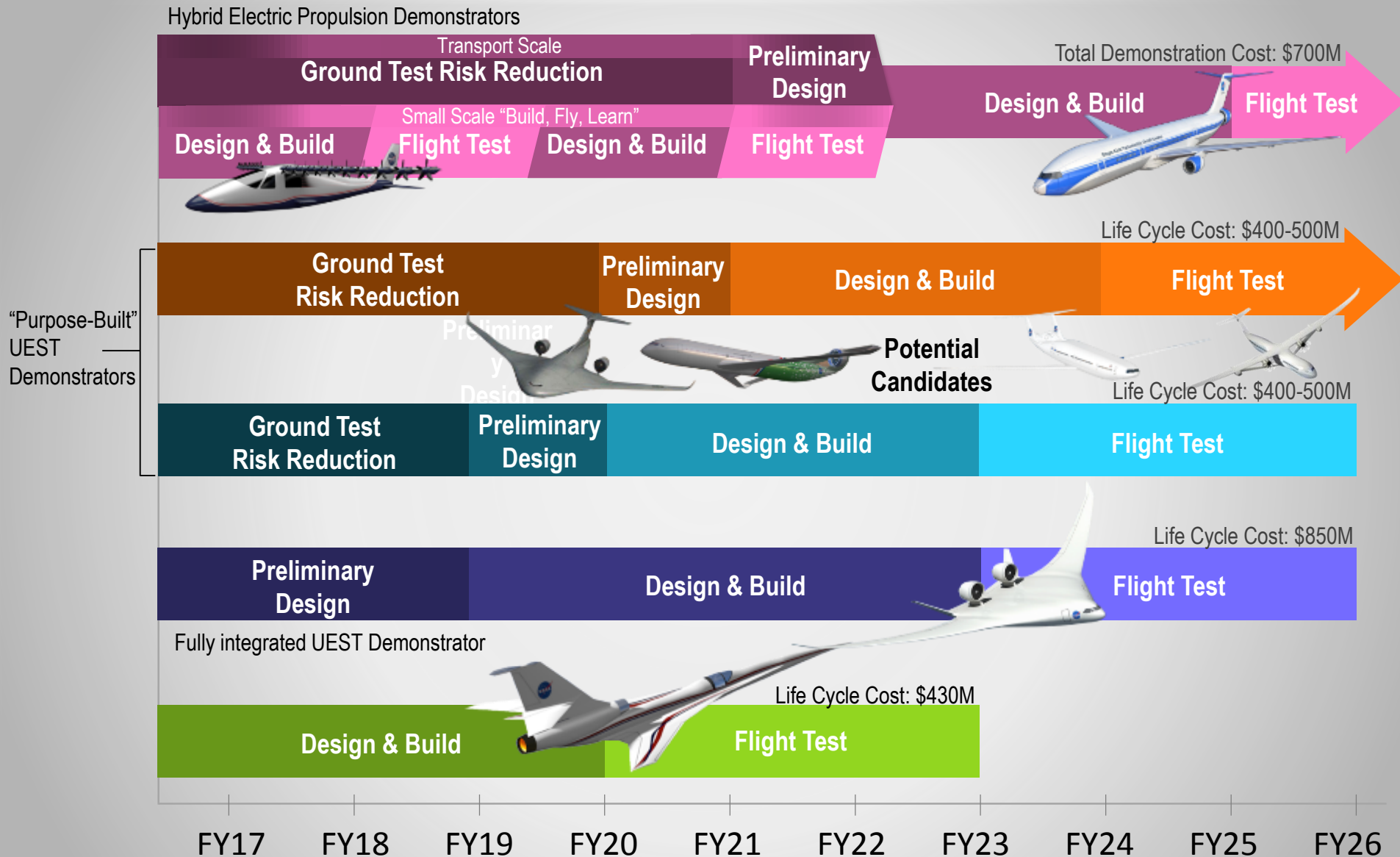


Potential Flight Tests To Provide Early Verification of Key Benefits

Ground Tests To Validate System Benefits

- Boundary layer ingestion
- Propulsion-airframe integration
- Turbine integration

Electric & Hybrid-Electric Flight Demonstration Plan

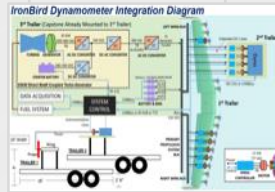


Armstrong Electric and Hybrid-Electric Propulsion Roadmap



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 for kW
airplane

Risk Reduction Testing for Airplane

Turbo-Electric Distributed Propulsion (TeDP)



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

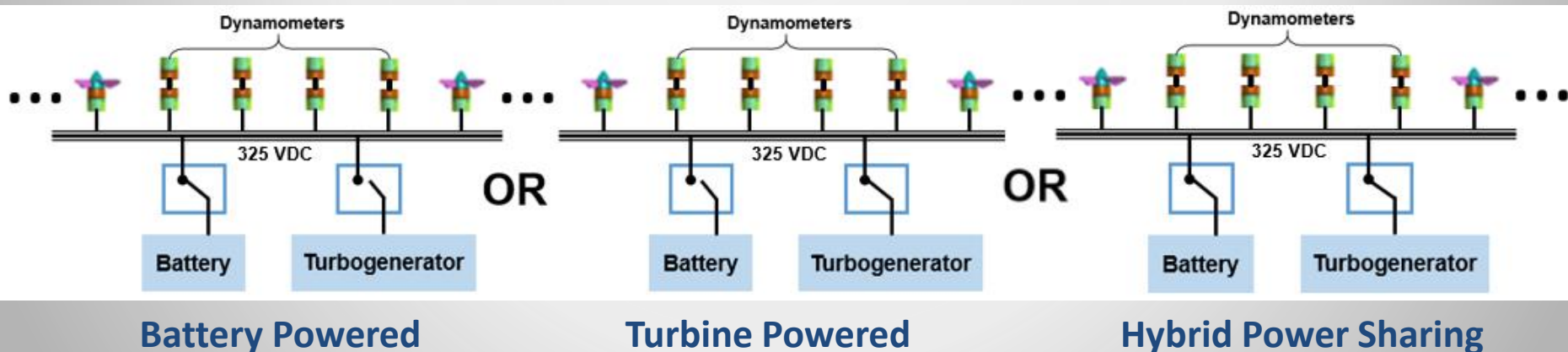


Architecture Description

- 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

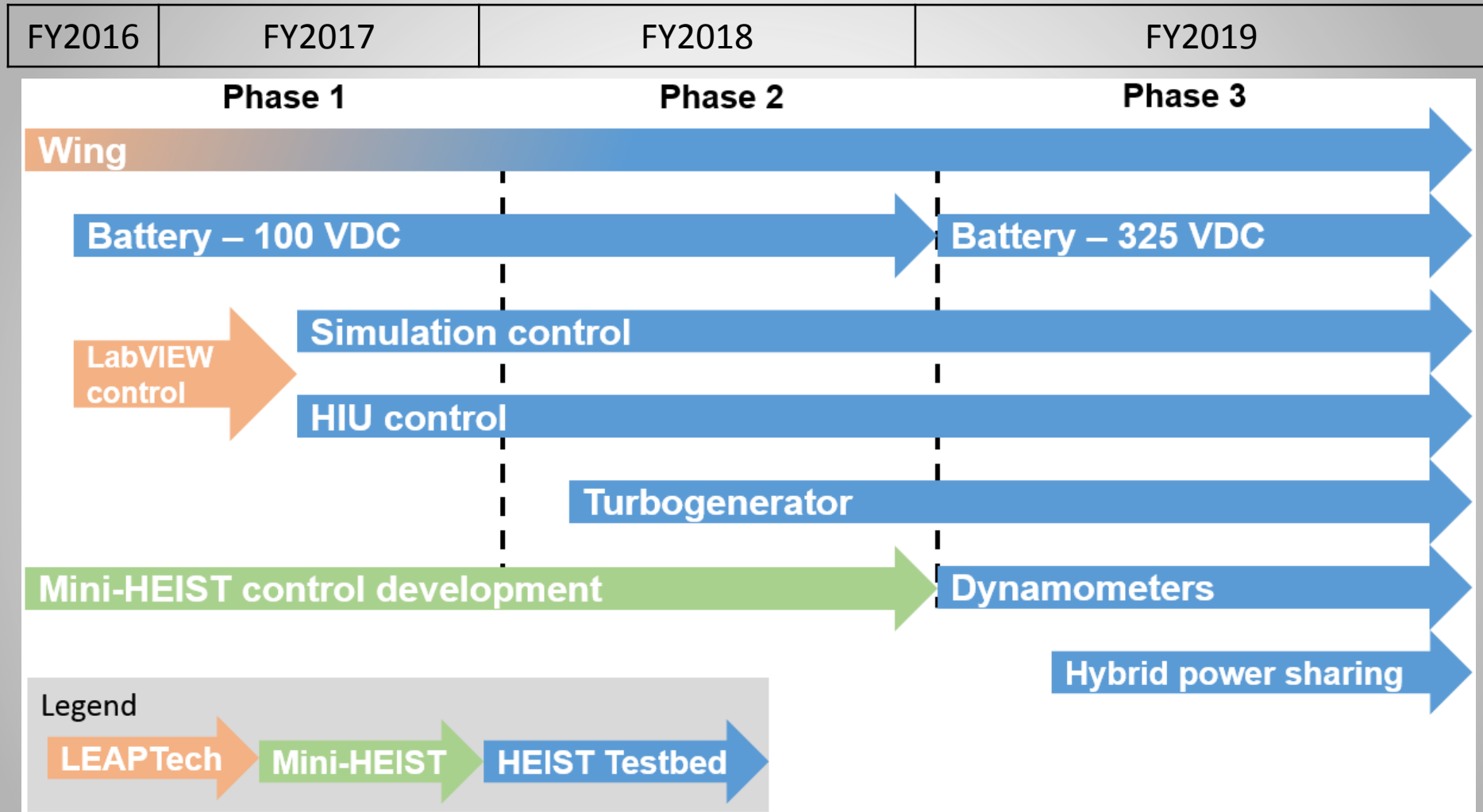




1. Hardware-in-loop testbed & control scalable to 1-2 MW
2. Test HEIST in flight-like manner with piloted SIM
3. Flight controls requirements for large benches
4. Degradation & failure modes of TeDP system
5. Hybrid power management
6. Explore different bus architectures
7. Design, fabrication, test,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

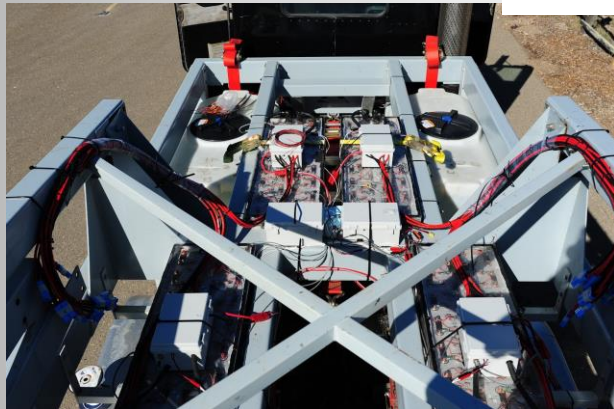
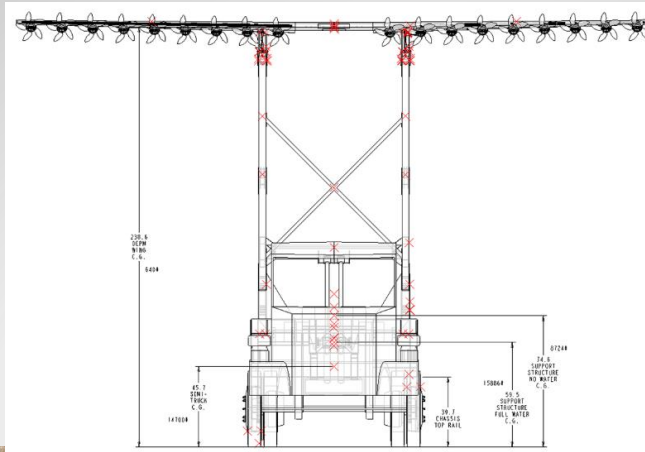
**NOTE: This list is abbreviated, several other lower-priority objectives also apply*

HEIST Project Timeline

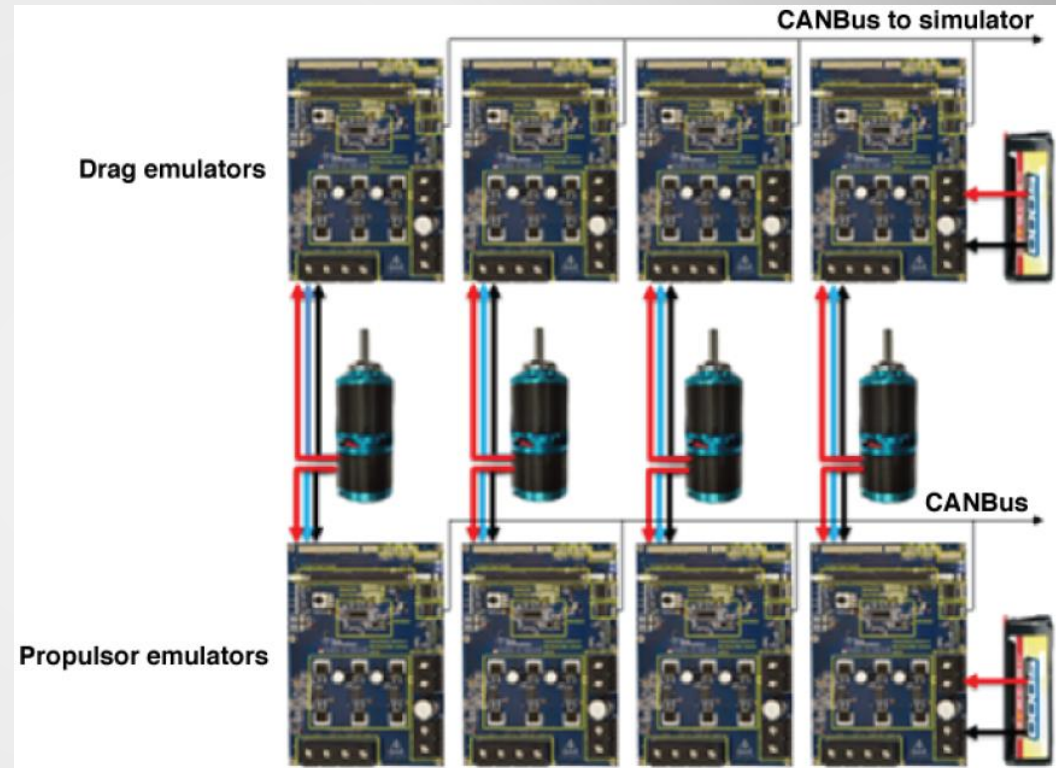


The LEAPTech Truck Experiment

1st Experiment of HEIST

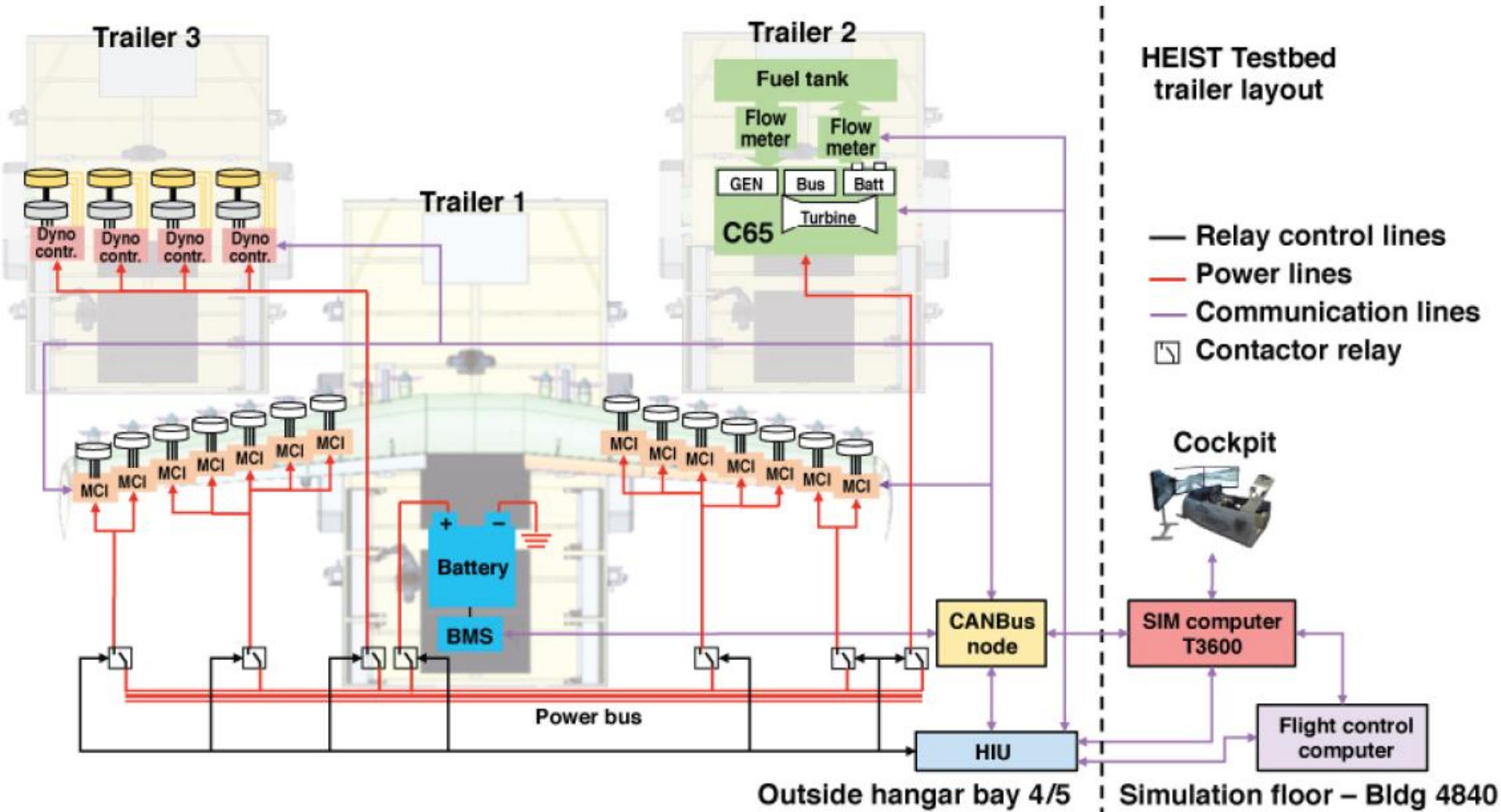


- Aid in dynamometer development
- Identify CANBus protocols
- Connect to simulator for aerodynamic feedback
- Aid in flight controls research and feedback
- Drag emulator:
torque control
- Propulsor emulator:
speed control



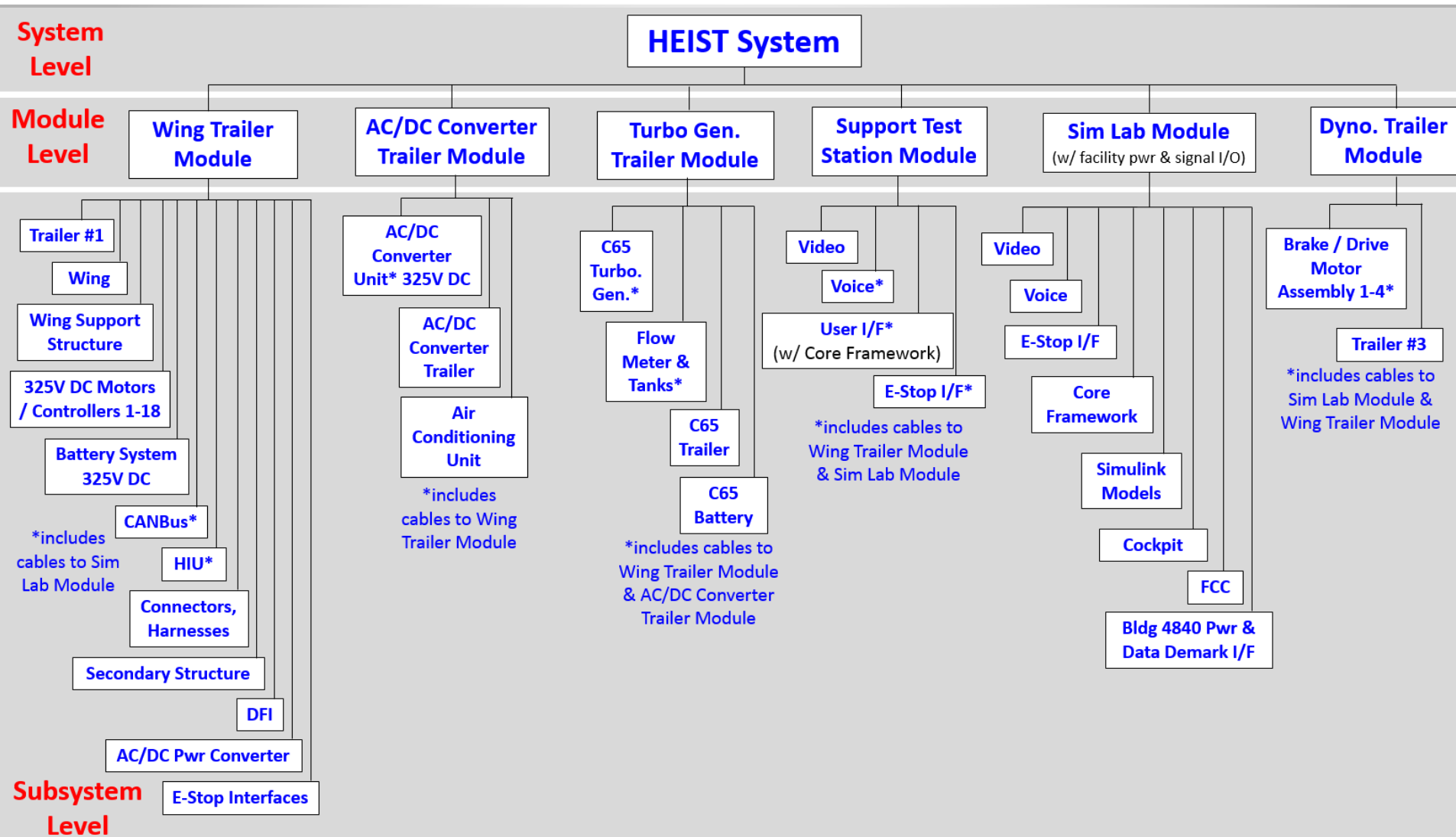
HEIST System Architecture

Mobile Trailer Setup

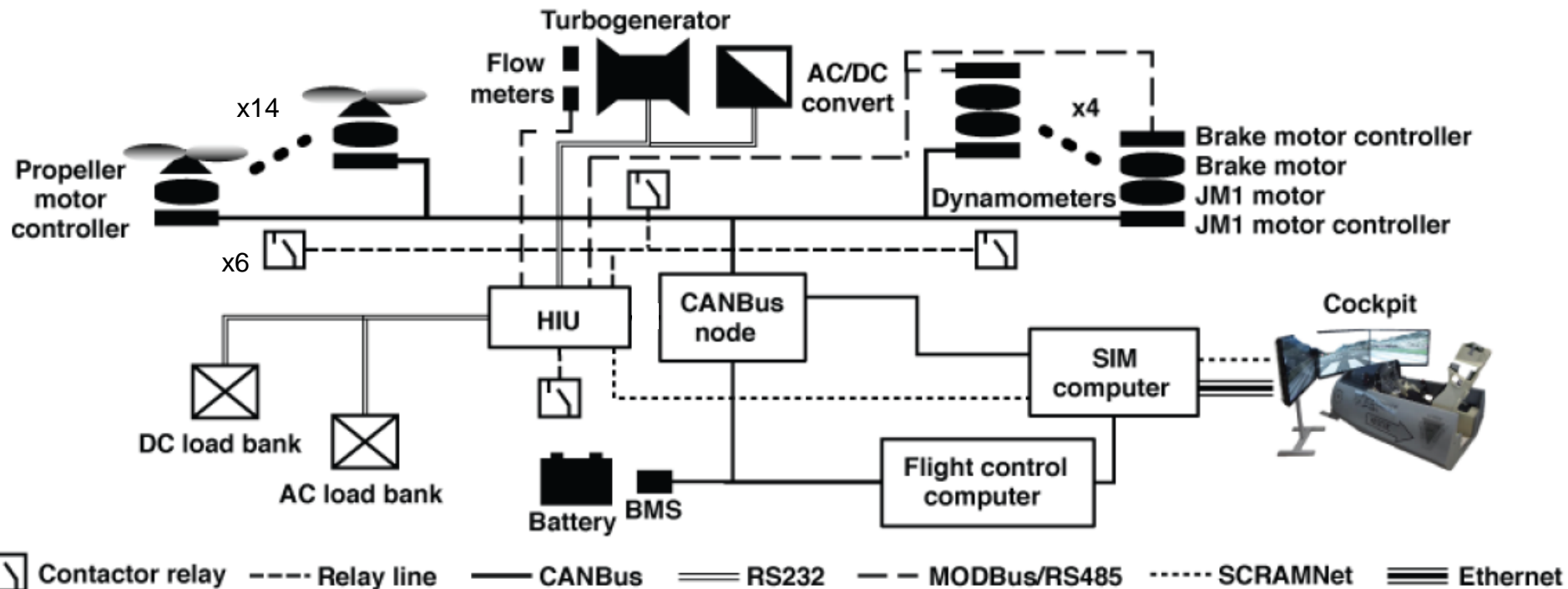


*NOTE: AC Power from turbogenerator is converted to DC power using an AC/DC converter on its own trailer (omitted for clarity)

HEIST System Hierarchy



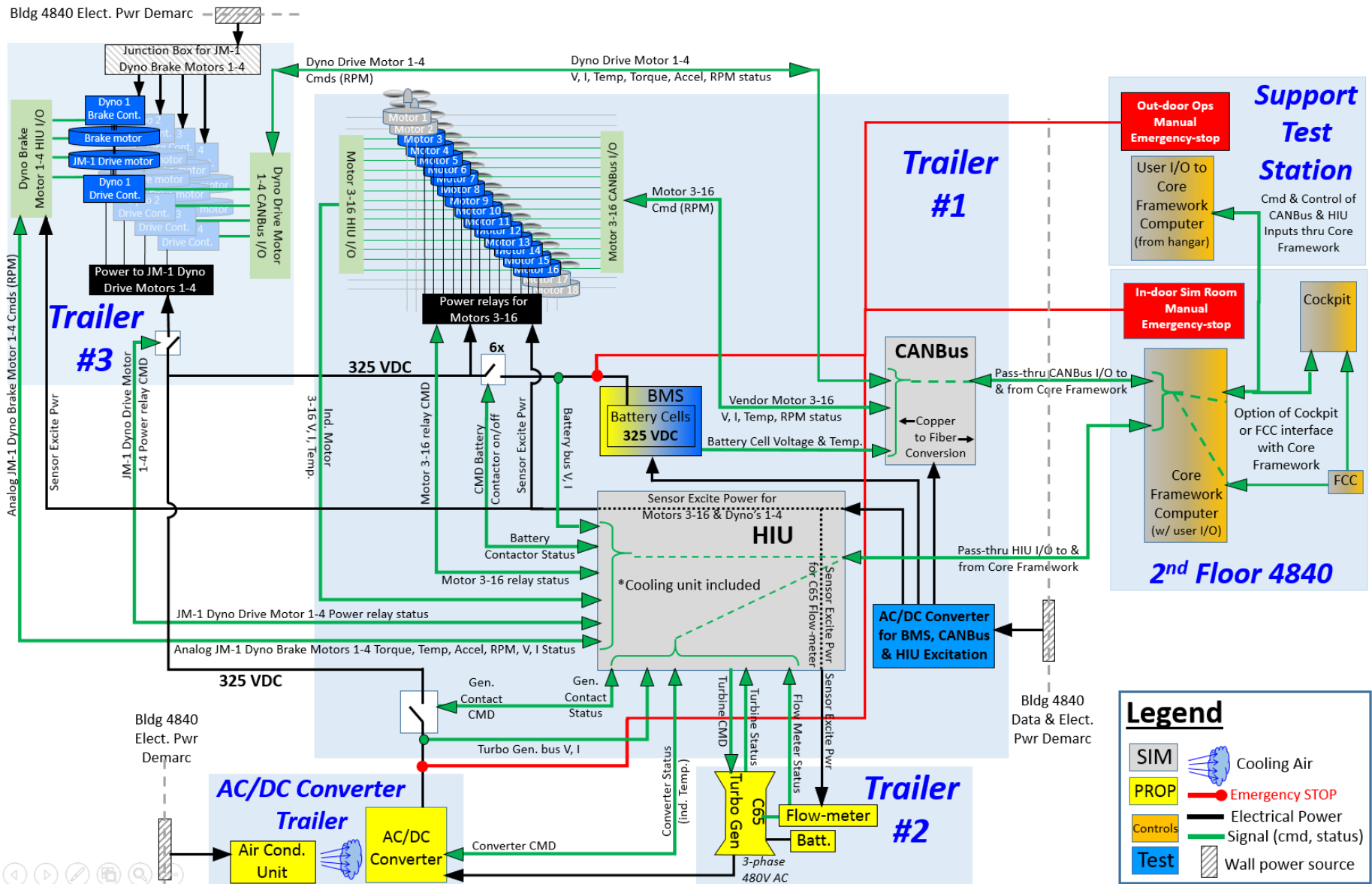
HEIST Communication Architecture



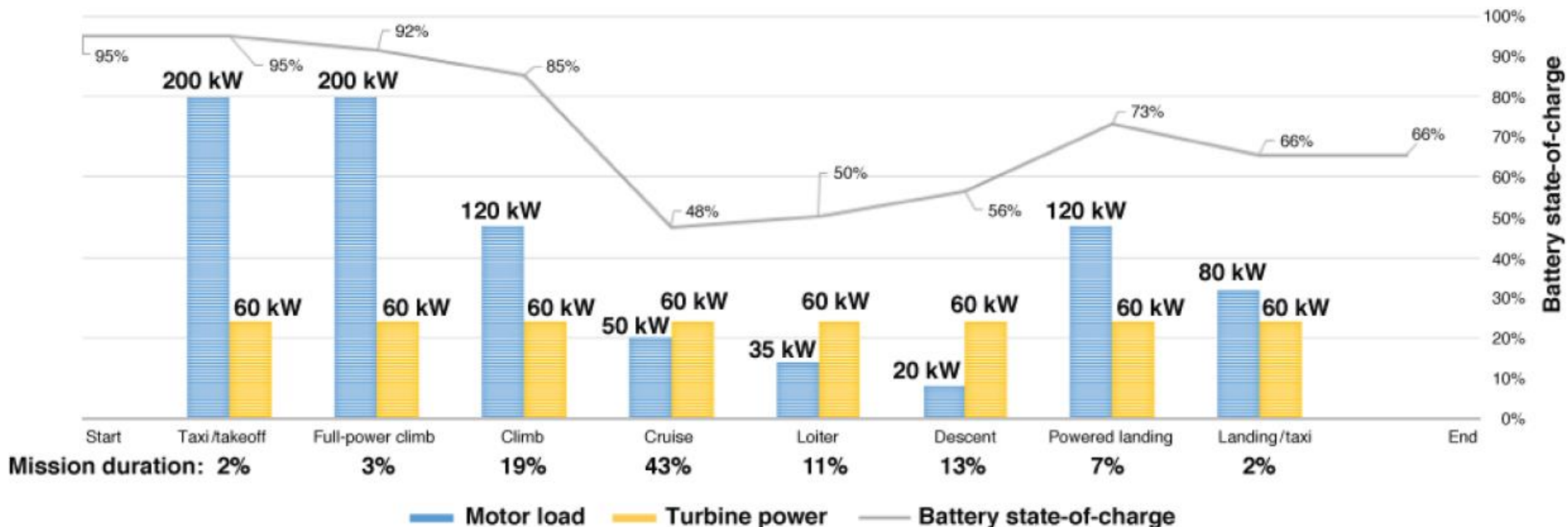
Hardware Interface Unit (HIU) handles all motor commands and sensor values other than the Joby JM1 motor controller and BMS systems, which communicate via CANBus

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

HEIST Architecture Description / Interconnect Diagram



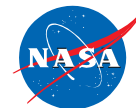
Notional Hybrid-Electric Mission Profile



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	1 MW	3 MW	10 MW	30 MW	Superconducting
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9 Seat
0.5 MW Total Propulsive Power

50-250 kW Electric Machines



Scaled-up hardware using lessons from HEIST

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



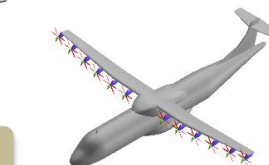
50 Seat Jet
12 MW Total Propulsive Power

.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

