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

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July 25th, 2016

NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st 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

2015	2025	2035
Evolutionary gains for carbon neutral growth by 2020	***Revolutionary*** improvements to fleet to achieve 2005 levels	***Transformational*** capabilities for 50% reduction of 2005 Levels

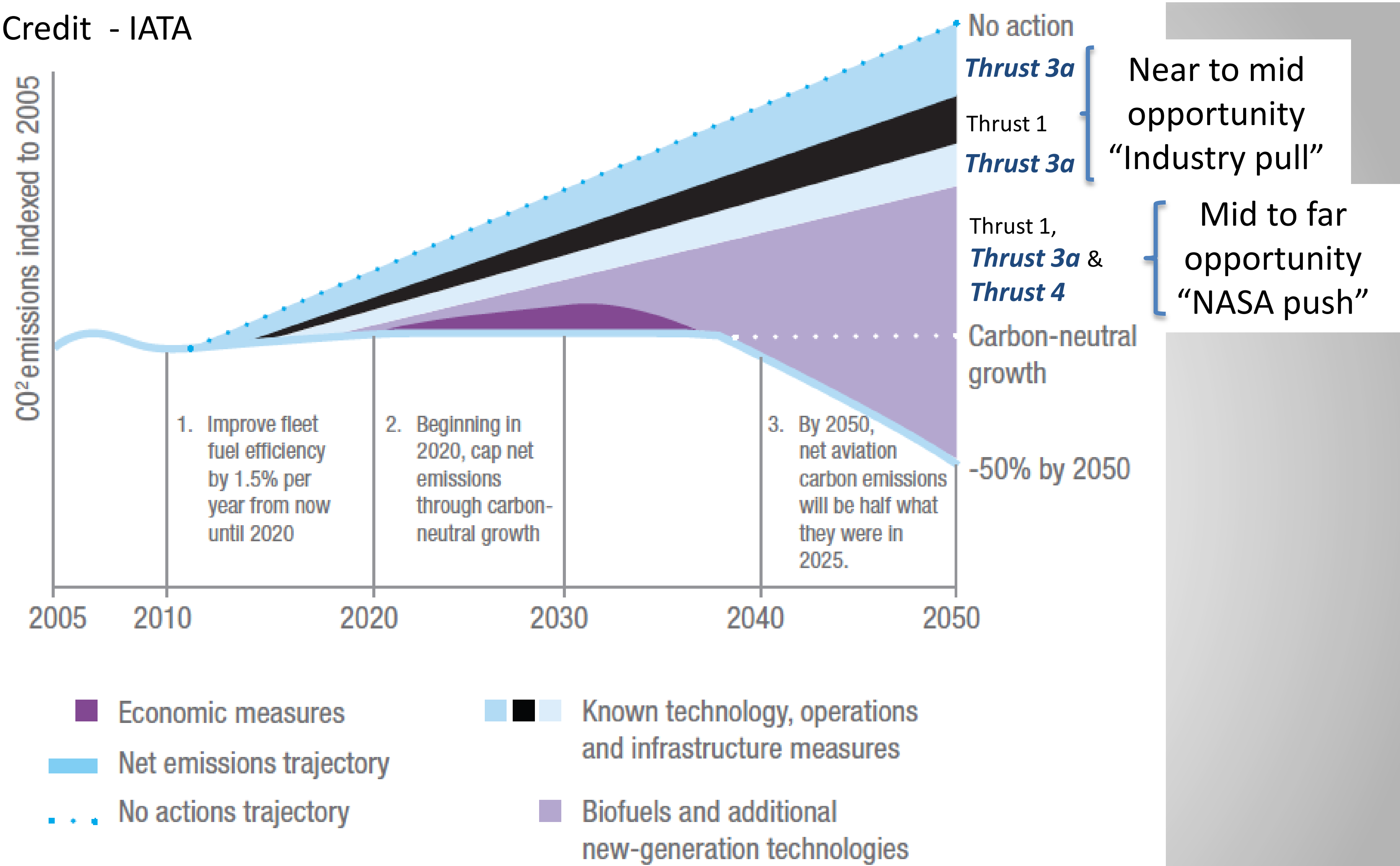
Strategic Thrust 4: Transition to Low Carbon Propulsion

2015	2025	2035
Low-carbon fuels for conventional engines	Introduction of Alternative Propulsion Systems	Alternative Propulsion Systems to Aircraft of All Sizes

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

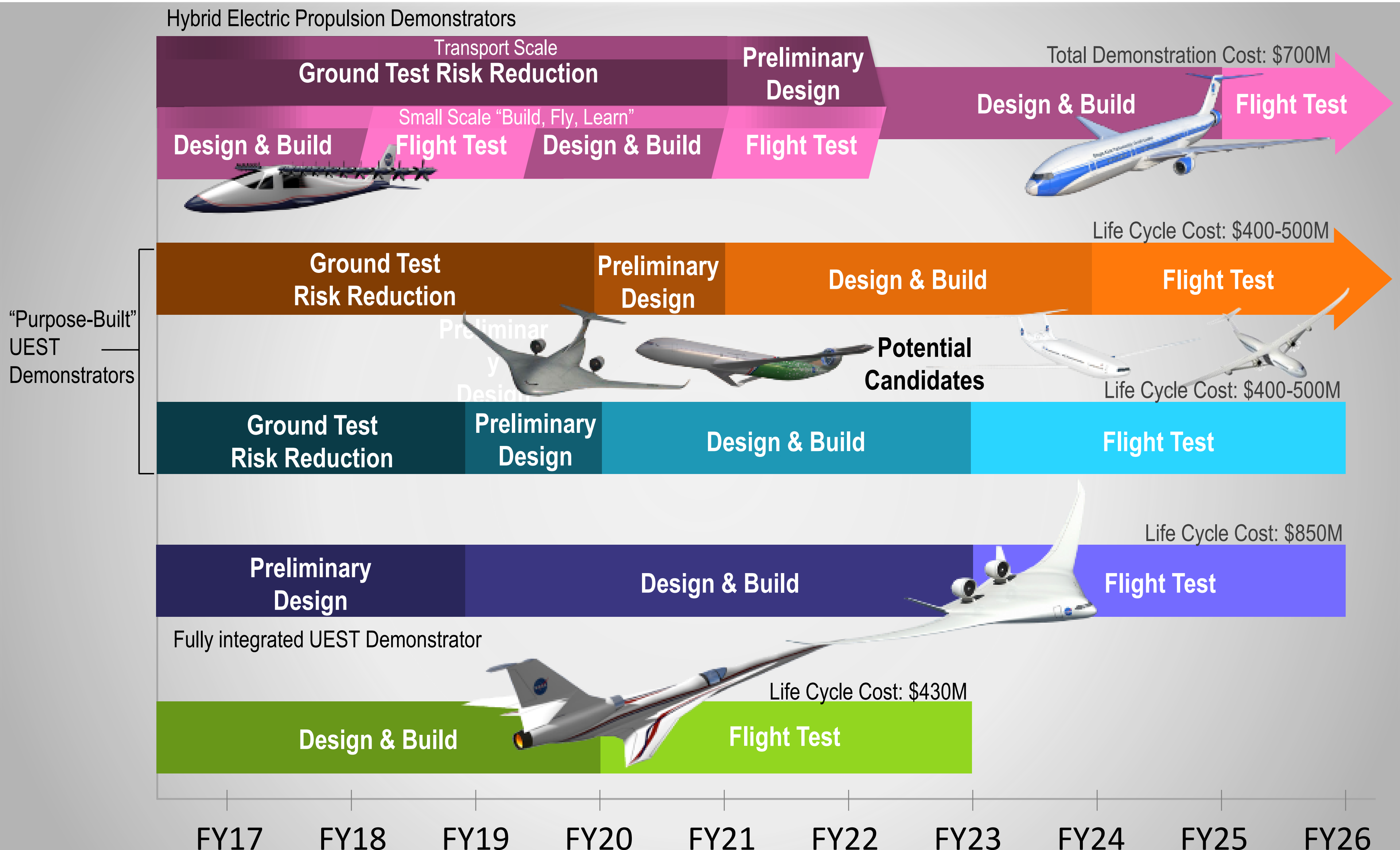
CO_2 Emissions Forecast through 2050

Credit - IATA



NASA Electric and Hybrid-Electric Roadmap

Electric & Hybrid-Electric Flight Demonstration Plan

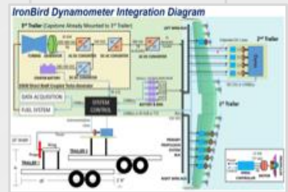


Armstrong Electric and Hybrid-Electric Propulsion Roadmap

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20

1-2 MW Flight Project

Adv Air Transport Technology AFRC/GRC



Capturing Complexities of Hybrid Architectures

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 Seedling 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

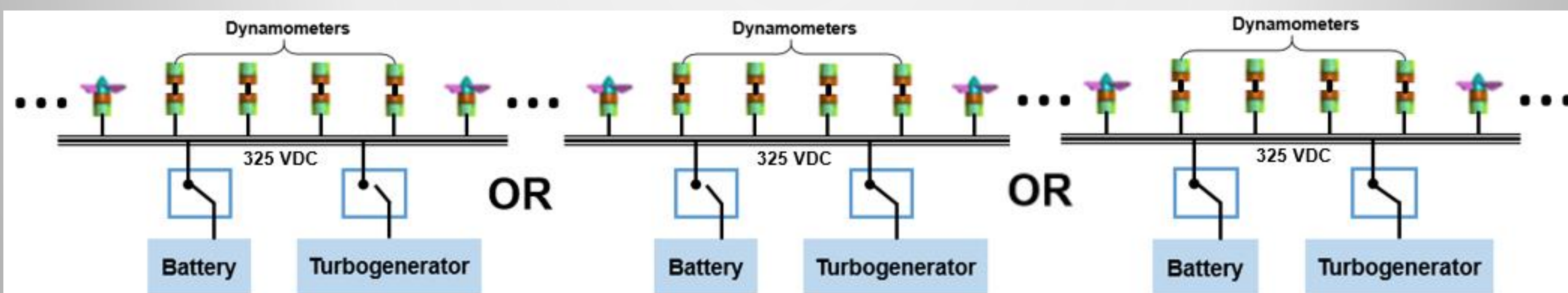
Turbo-electric Distributed Propulsion (TeDP) testbed connected to a piloted flight simulator

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



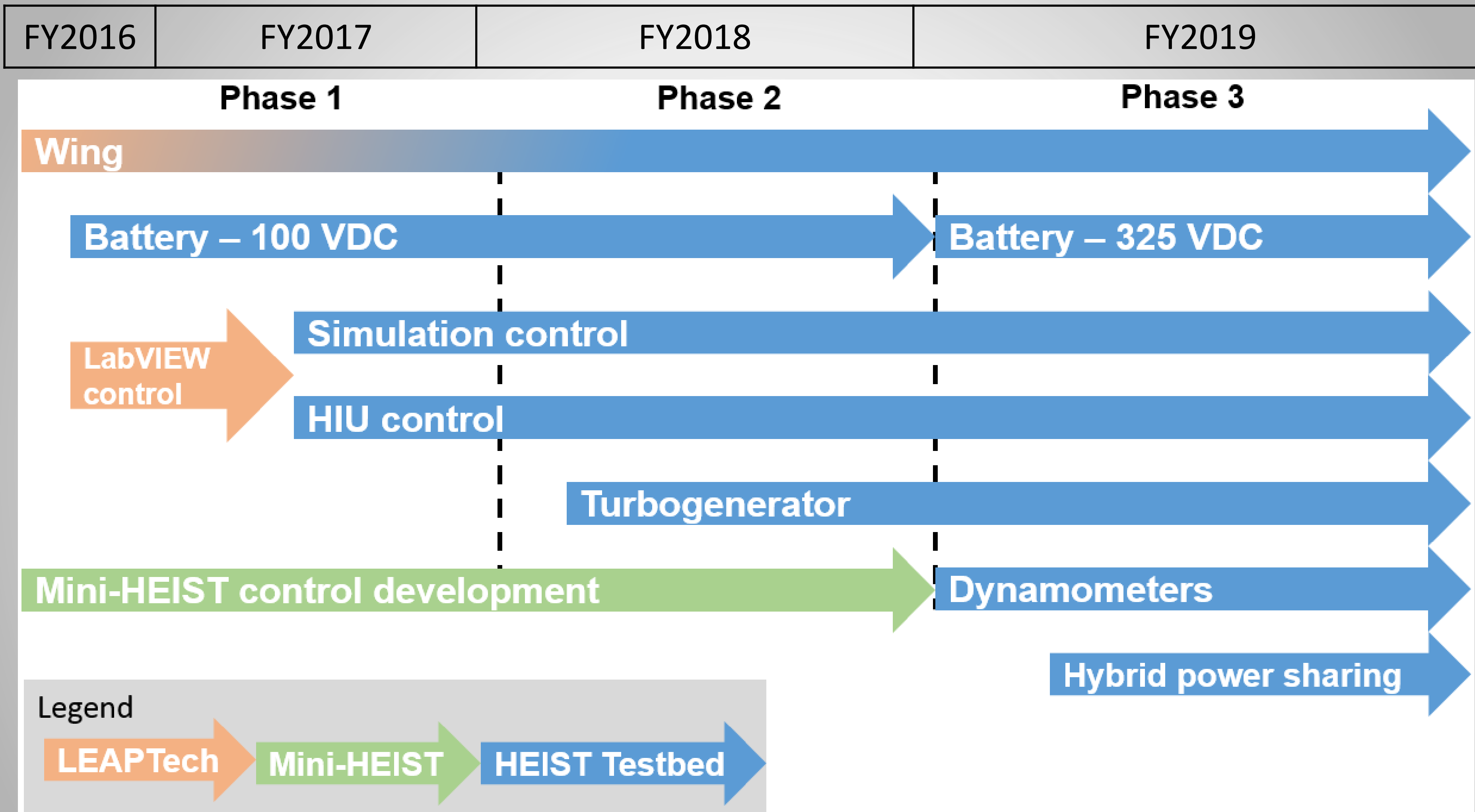
Battery Powered **Turbine Powered** **Hybrid Power Sharing**

HEIST Objectives

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

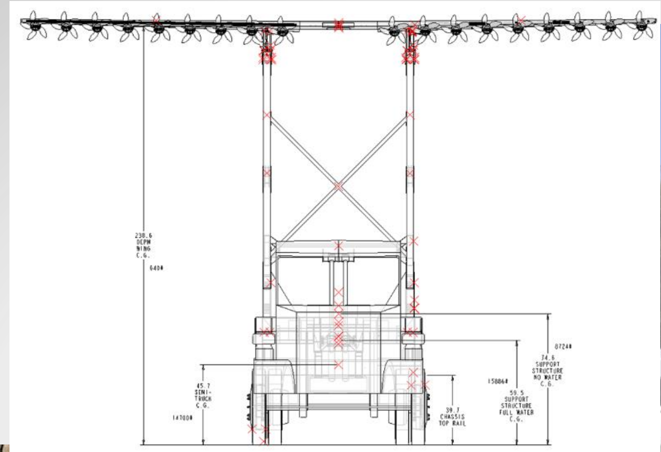
**NOTE: This list is abbreviated, several other lower-priority objectives also apply*

HEIST Project Timeline



The LEAPTech Truck Experiment

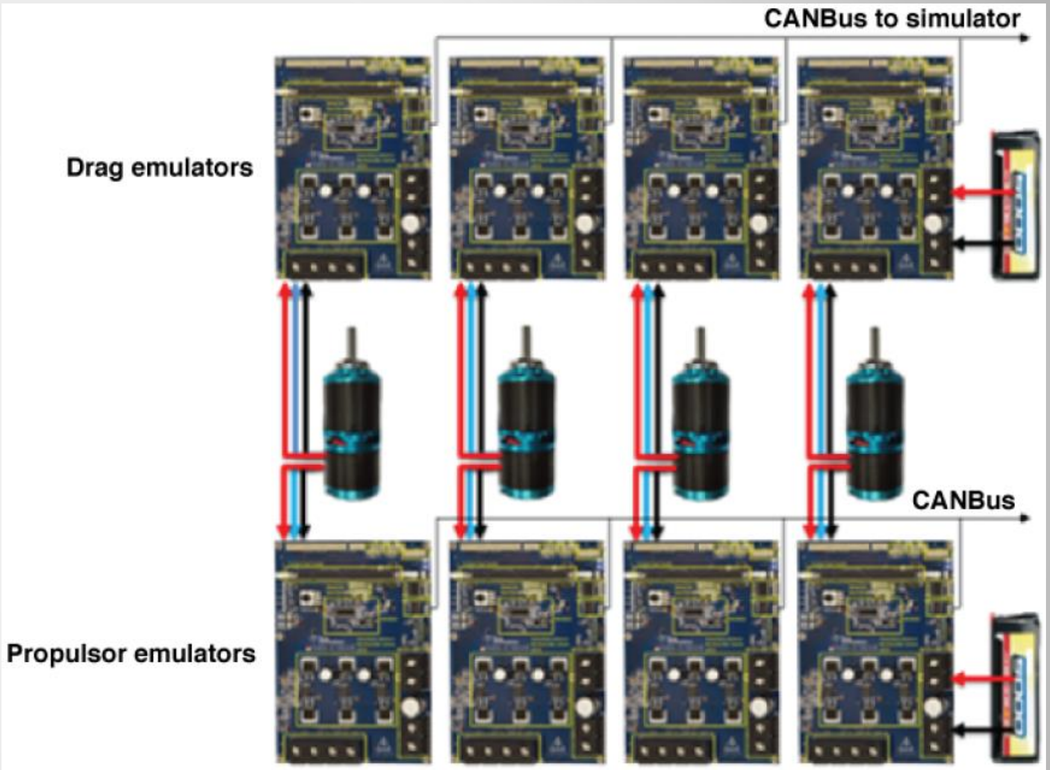
1st Experiment of HEIST



Mini-HEIST

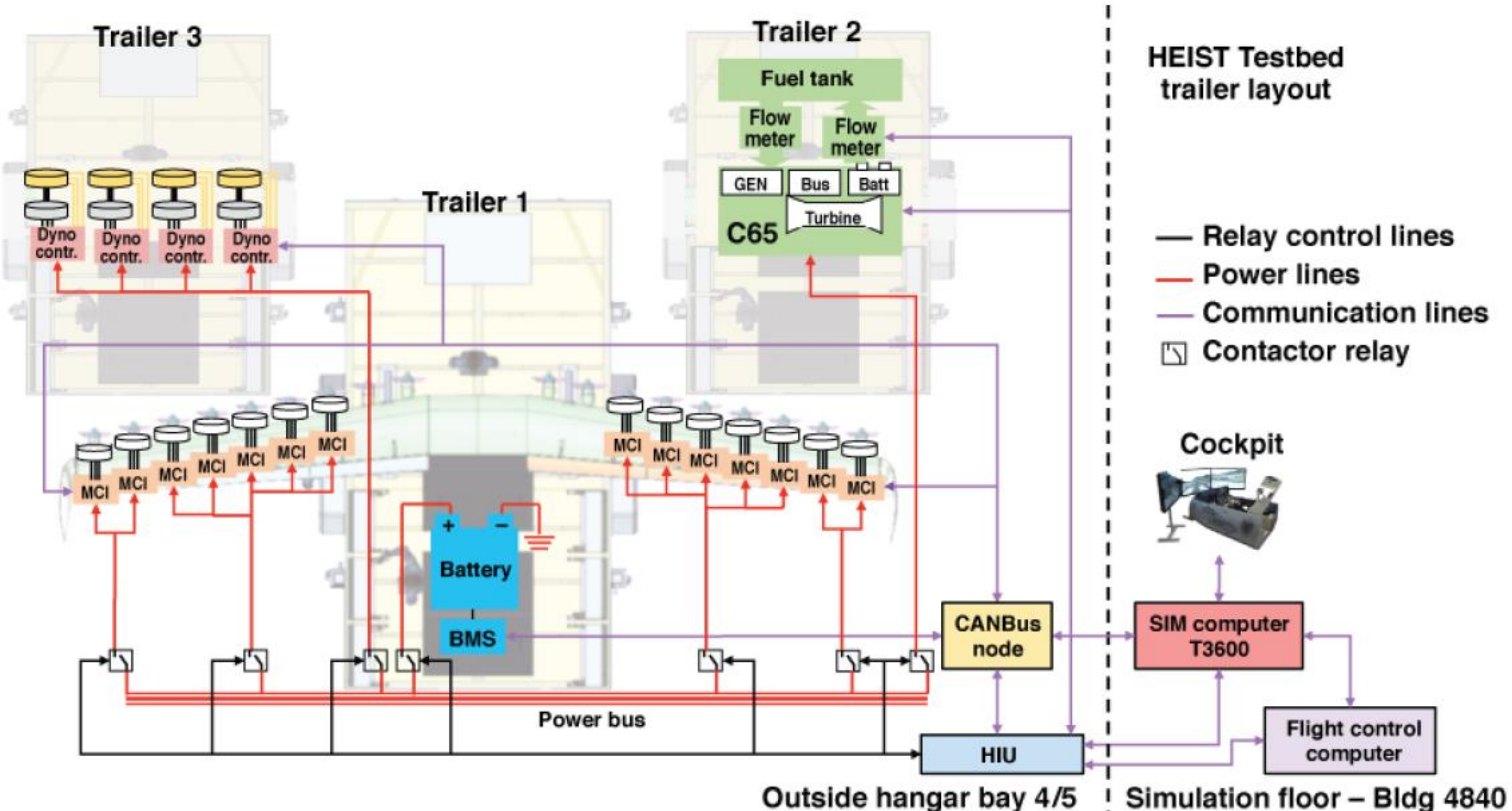
Dynamometer Simulator

- 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*



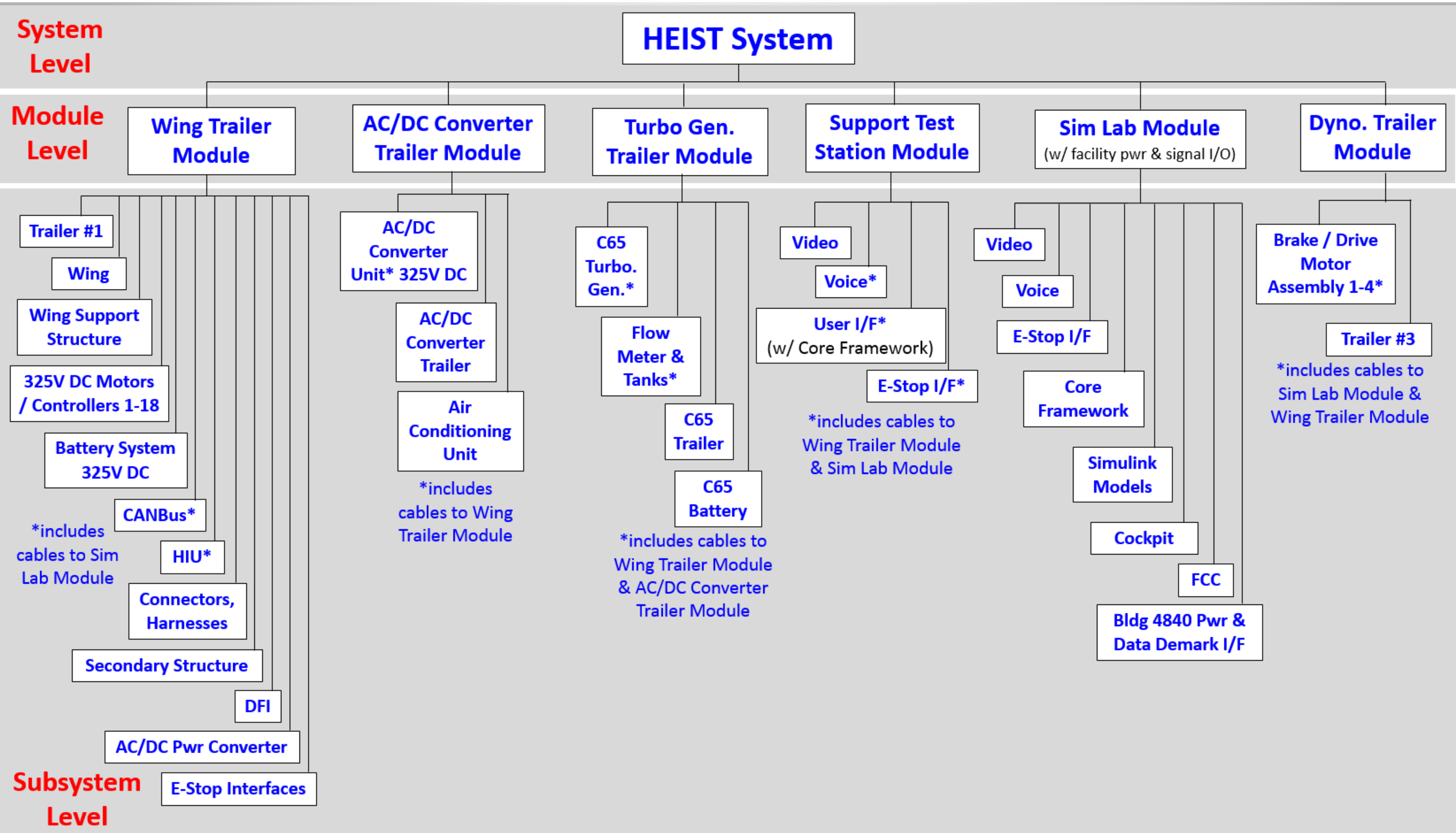
HEIST System Architecture

Mobile Trailer Setup

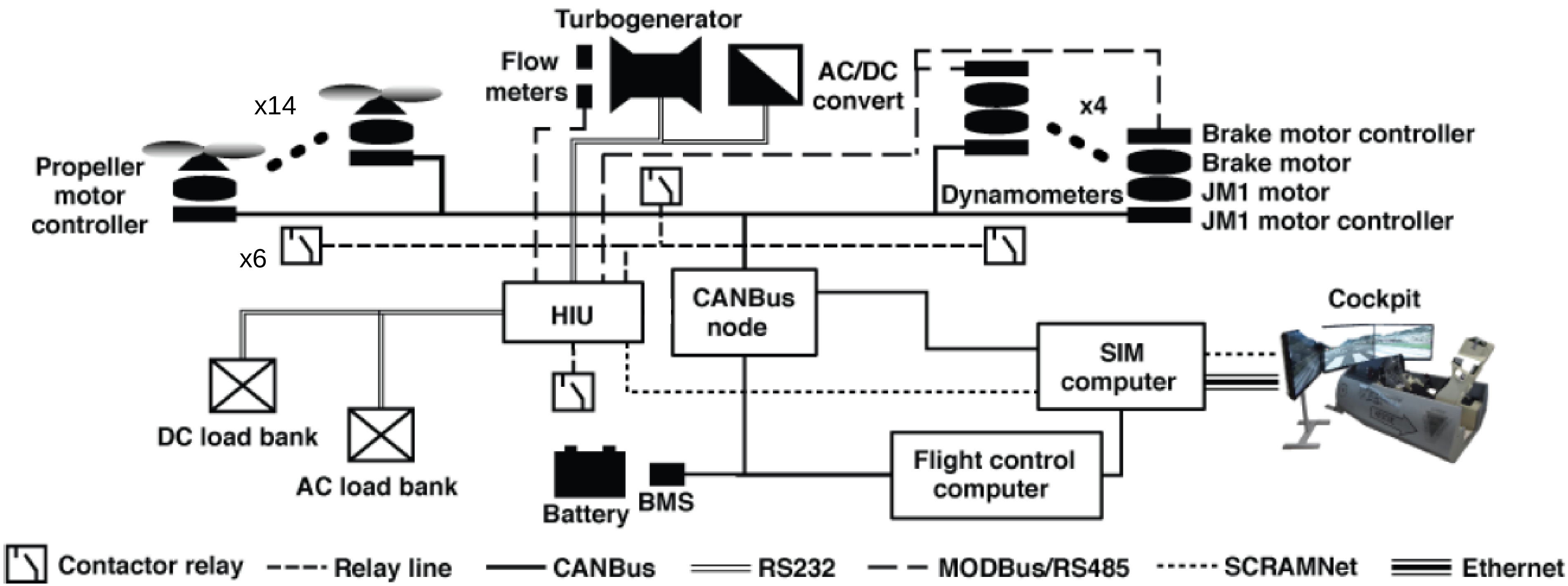


*NOTE: AC Power from turbogenerator is converted to DC power using an AC/DC converter on its own trailer (omitted for clarity)

HEIST System Hierarchy



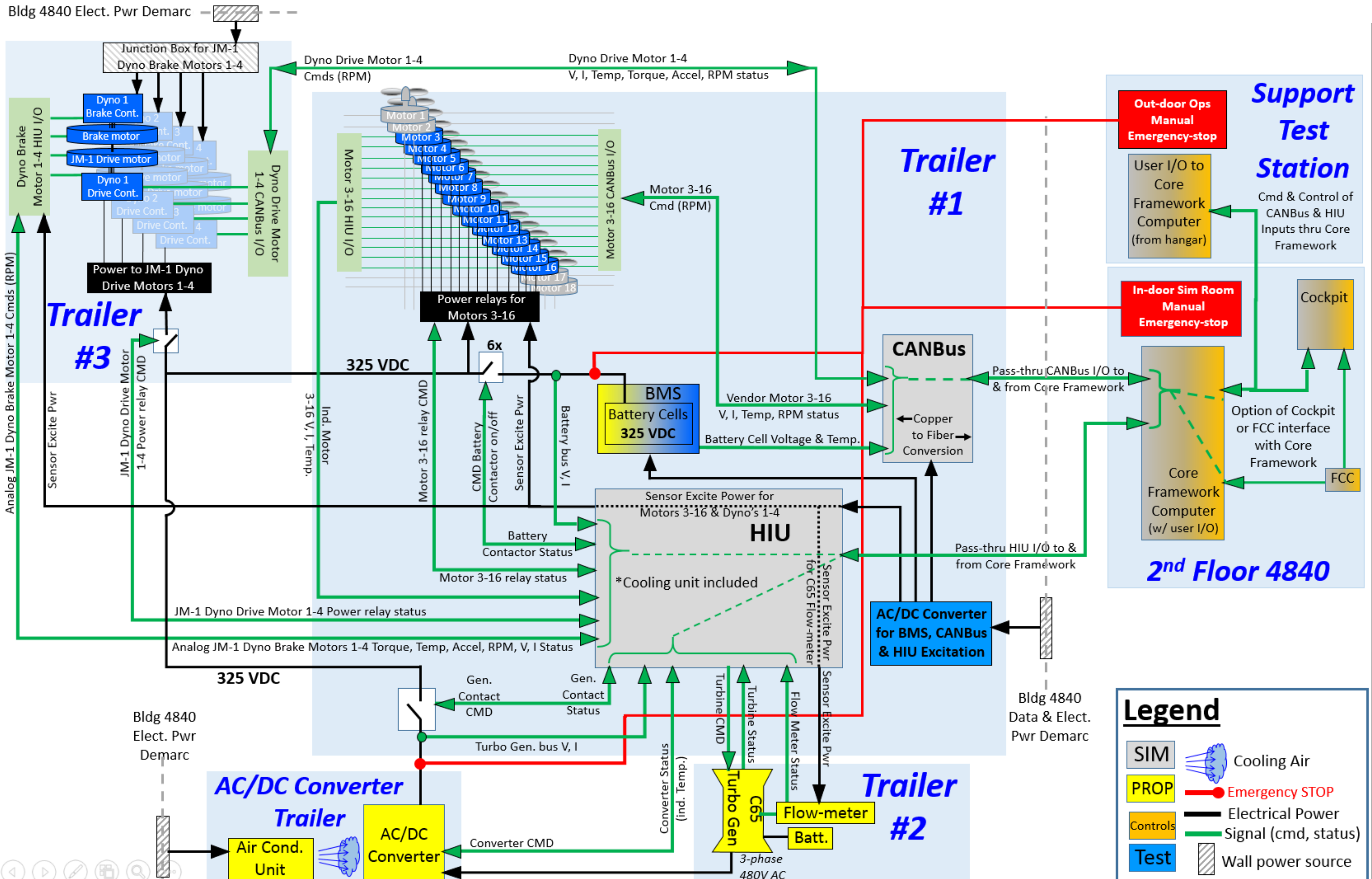
HEIST Communication Architecture



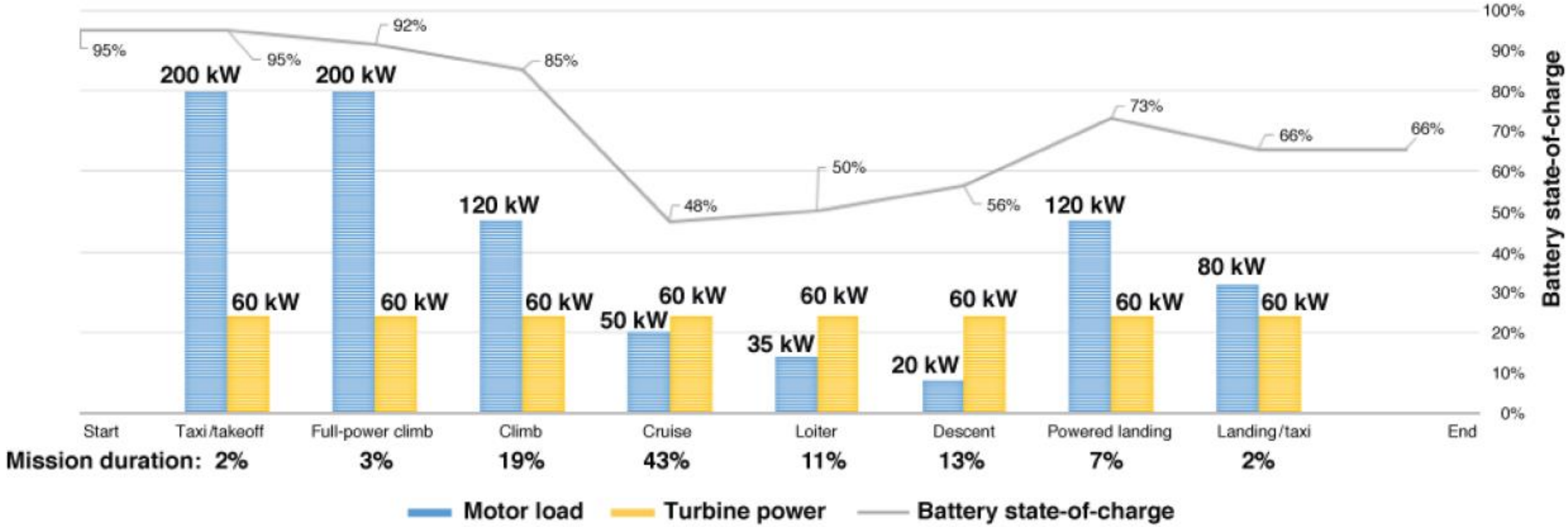
Hardware Interface Unit (HIU) handles all motor commands and sensor values other than the Joby JM1 motor controller and BMS systems, which communicate via CANBus

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

HEIST Architecture Description / Interconnect Diagram



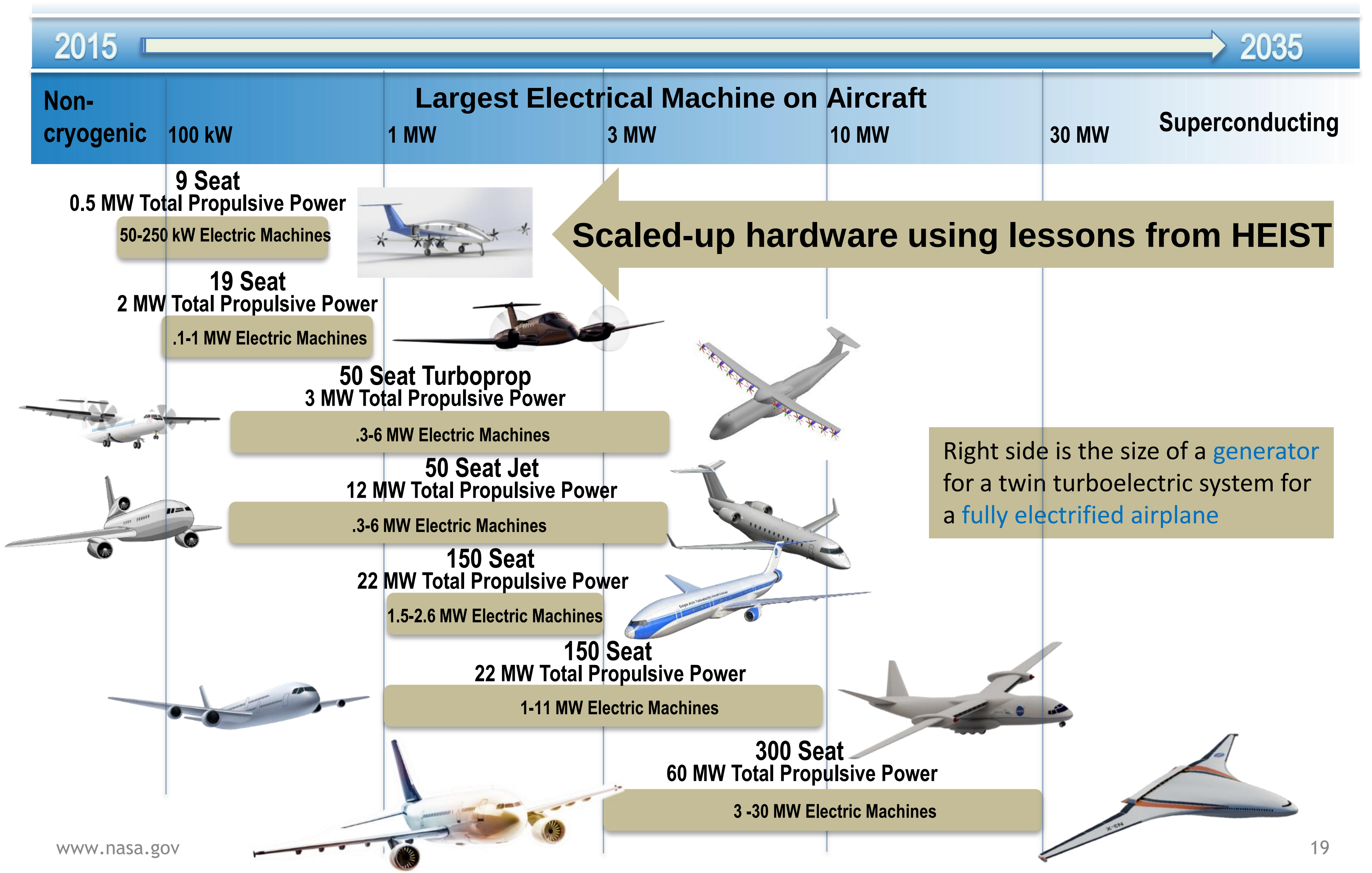
Notional Hybrid-Electric Mission Profile



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



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