National Aeronautics and Space Administration

NASA Aeronautics Research Mission Directorate

Spiral Development of Electrified Aircraft Propulsion from Ground to Flight

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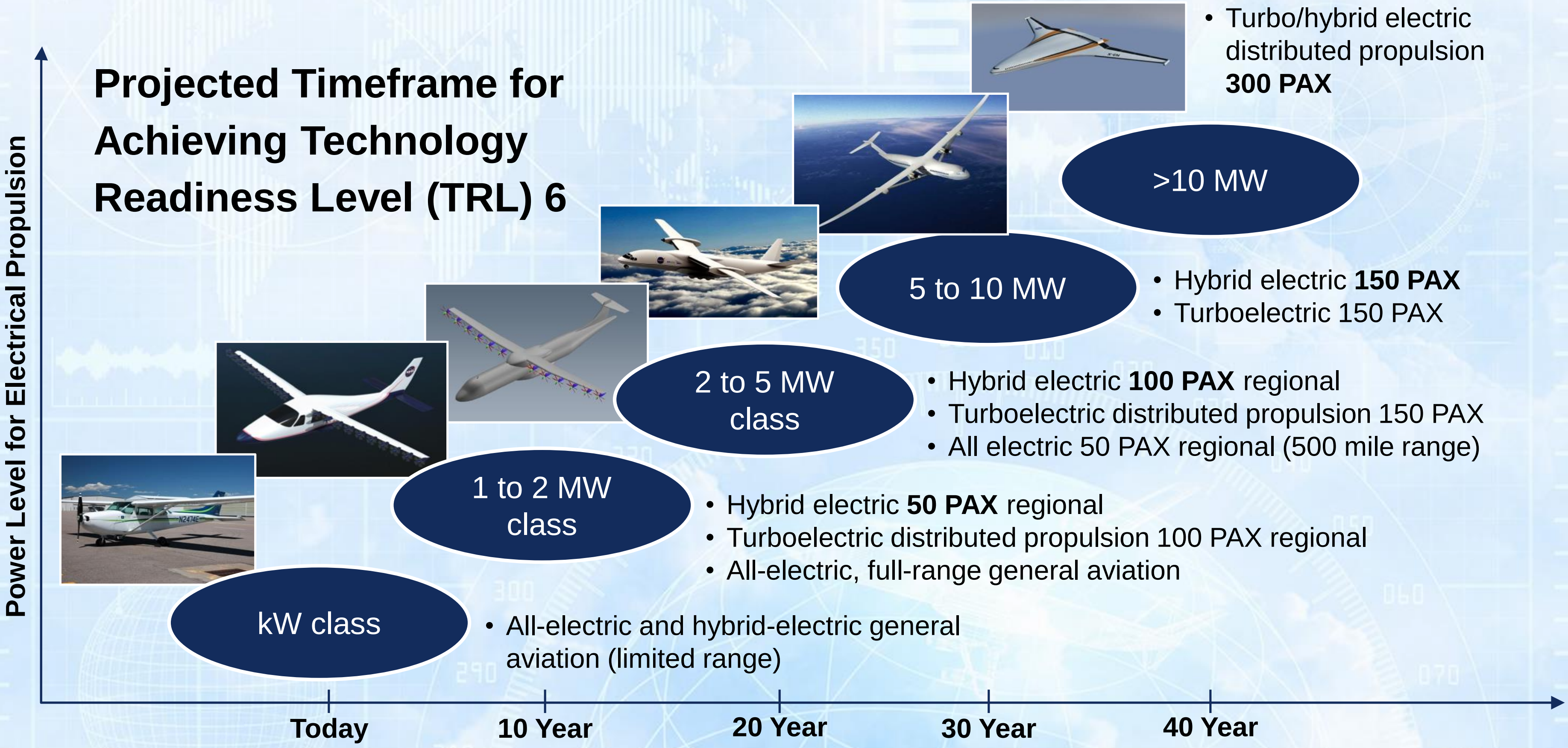
NASA Armstrong Flight Research Center

November 10, 2016

Electrified Aircraft Propulsion Development



History of Engine Development

1903	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020	2030

40 PAX turbine

50 PAX 1-2MW

1 PAX

1928 – Frank Whittle proposed jet engine

1937 – 1st jet engine

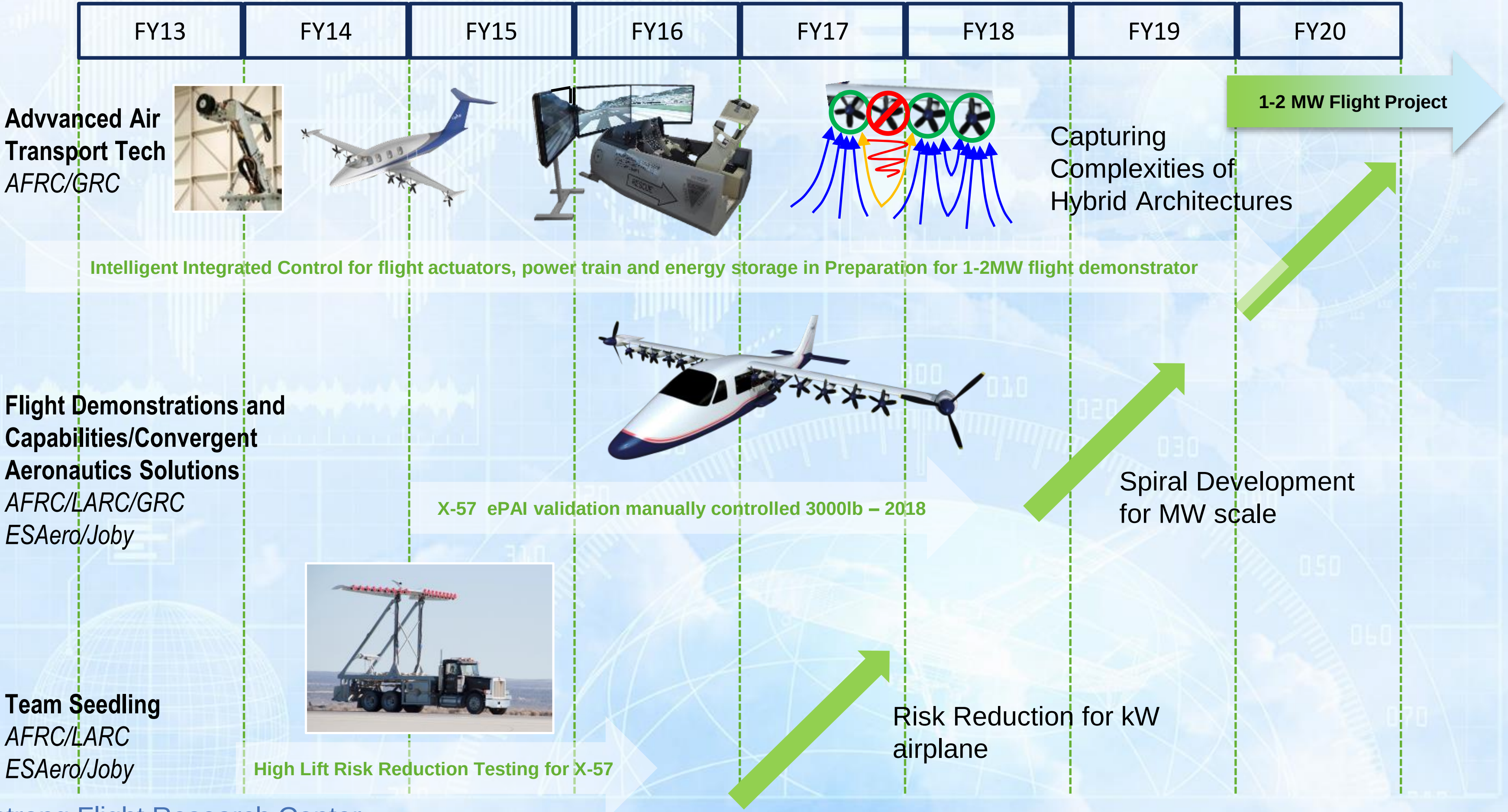
1944 – 1st jet aircraft "Me 262"

1949 – 1st all jet engine airliner "de Havilland Comet" 40 PAX

Jet aircraft development mostly in WWII and Cold War era

We are now in "Green War"

FY15 NASA Armstrong Electric Propulsion Roadmap



Convergent Aeronautics Solutions (CAS) Project

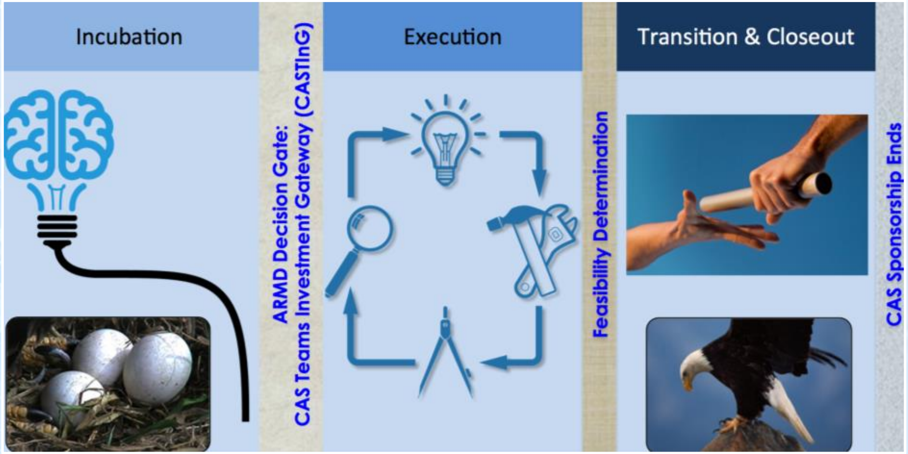
Convergent – Exploit the benefits of combining multiple disciplines and multiple partners (both within and external to NASA)

Transformative – Exhibit the potential for substantially greater impact than current approaches

Targeted – Address challenges and opportunities relevant to NASA's strategic objectives and outcomes reflected in the ARMD Strategic Investment Plan

Feasibility Focused – Determine whether and the degree to which the concept is feasible using existing technologies or requiring minimal development

Rapidly Executed – Complete feasibility assessments in less than 2.5 years



LEAPTech Lakebed Test Configuration

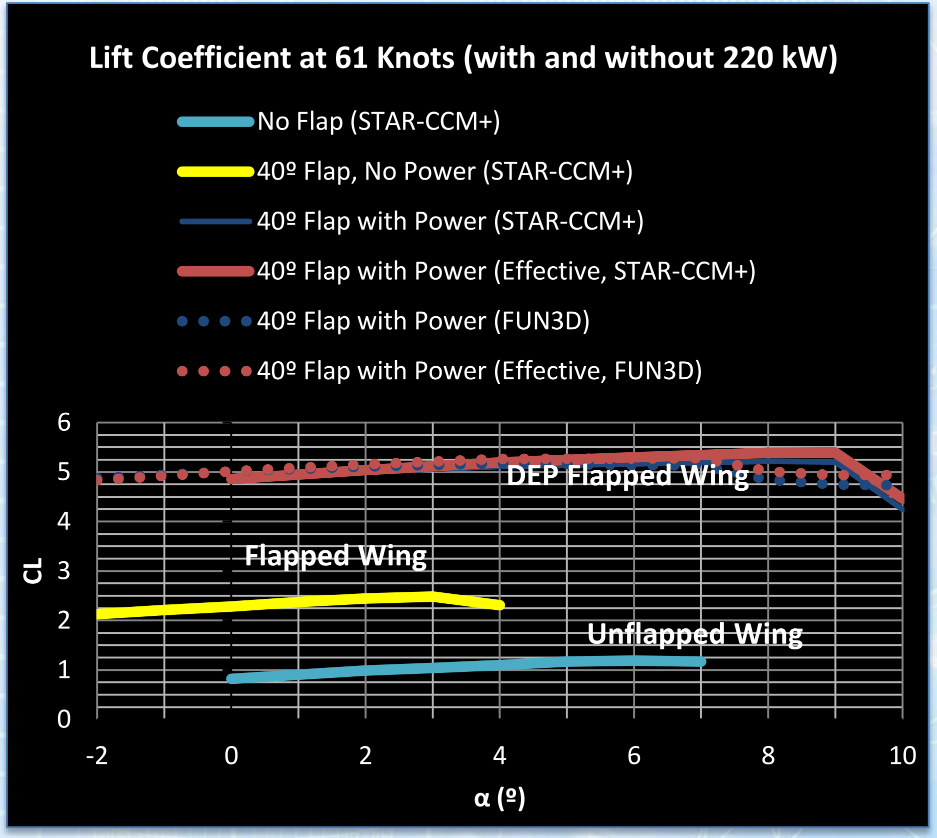
Truck Testing Configuration

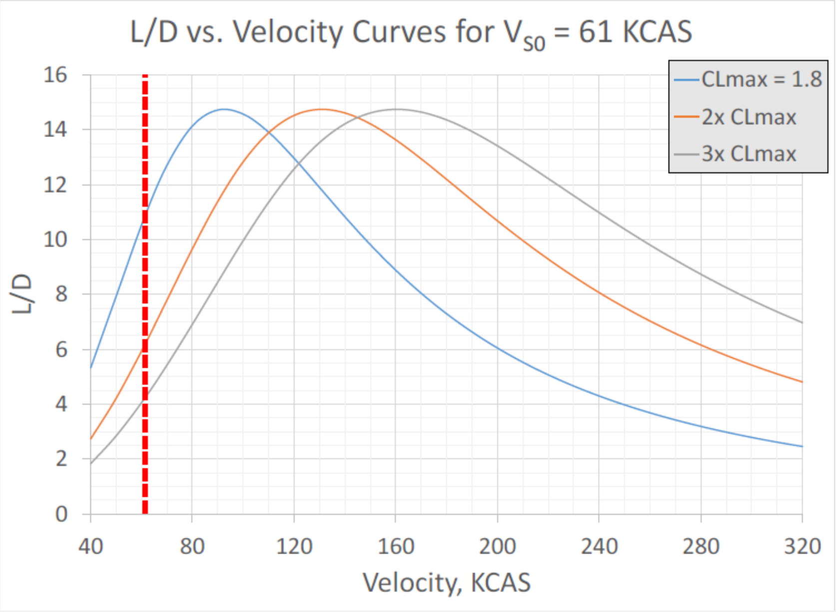
- Bolted Joints – on supporting truss work
- Airbag Suspension – to reduce transmitted road vibration
- Water Ballast Tanks – to lower center of gravity
- Sway Braces – to constrain airbag lateral displacement

Force and Moment Instrumentation

- Load Cells
  - Lift/pitch/roll load cells (four each – over-constrained)
  - Drag/yaw load cells (two each)
  - Lateral load cell (one each)
- AOA Adjustment (two each)

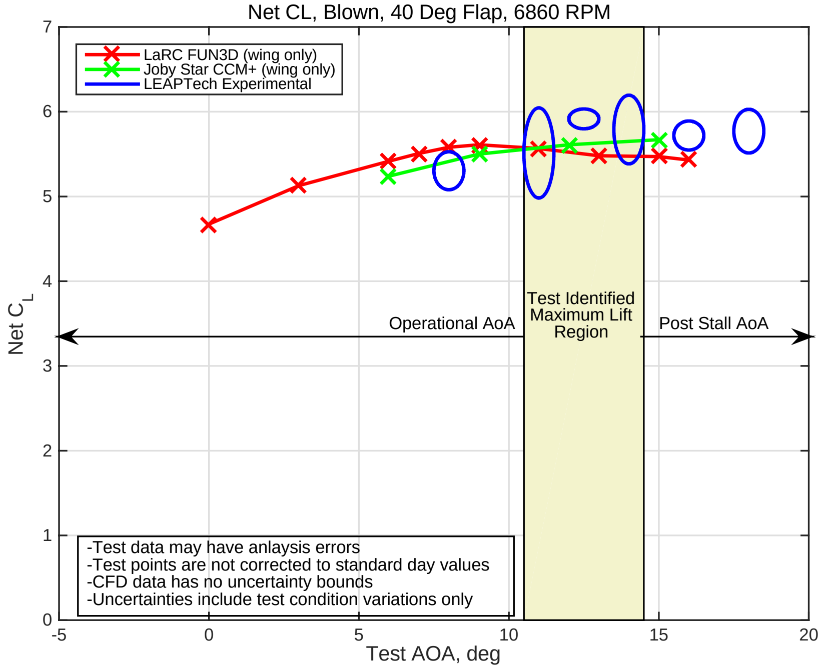
DEP Aero-Propulsion High-Lift Integration

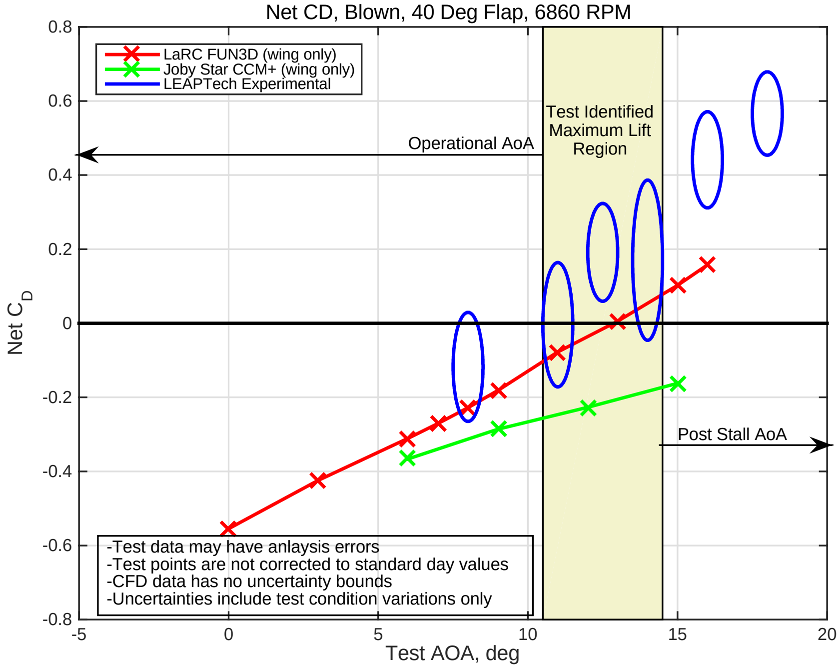


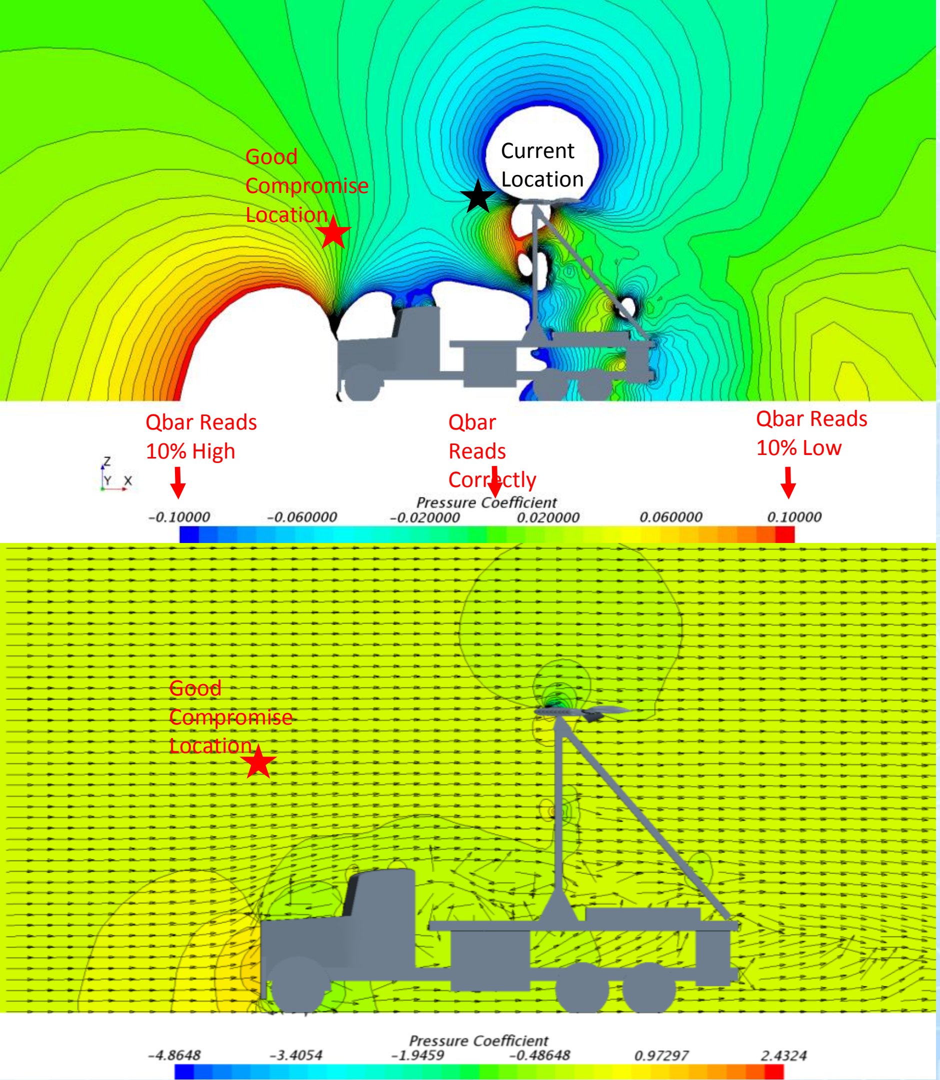


Distributed electric propulsion (DEP) enables design not only higher CL_{max}, but also higher L/D_{max} and higher $\eta_{propulsive}$ at high speed

Blown Wing (Props Powered) – Lift and Drag Coefficients







CFD for Selection of Air Data Measurement Location

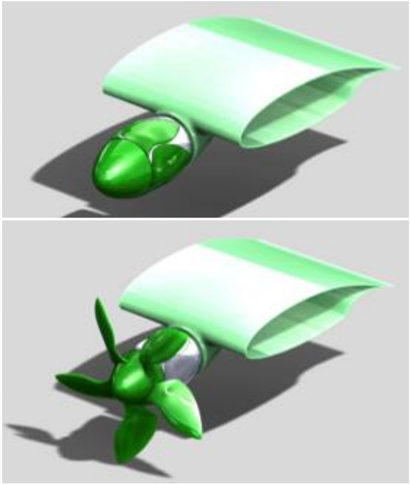
Desirable attributes:

- Cp = 0 (V_local = V∞)
- Low pressure gradients
- Low flow angularity
- Invariant with wing AOA
- Short, faired support shaft

In 1983, they didn't have the benefit of CFD for air data probe location selection.

DEP Integration Synergistic Design

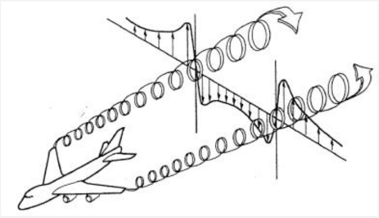
Folding Inboard Propellers with Low Tip Speeds

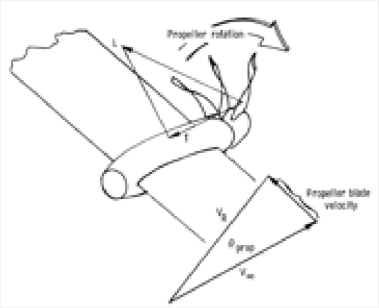


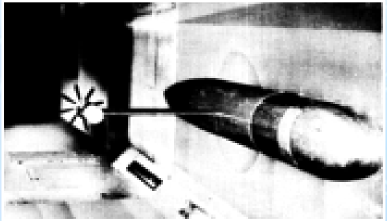
Viva and Alisport Motorgliders

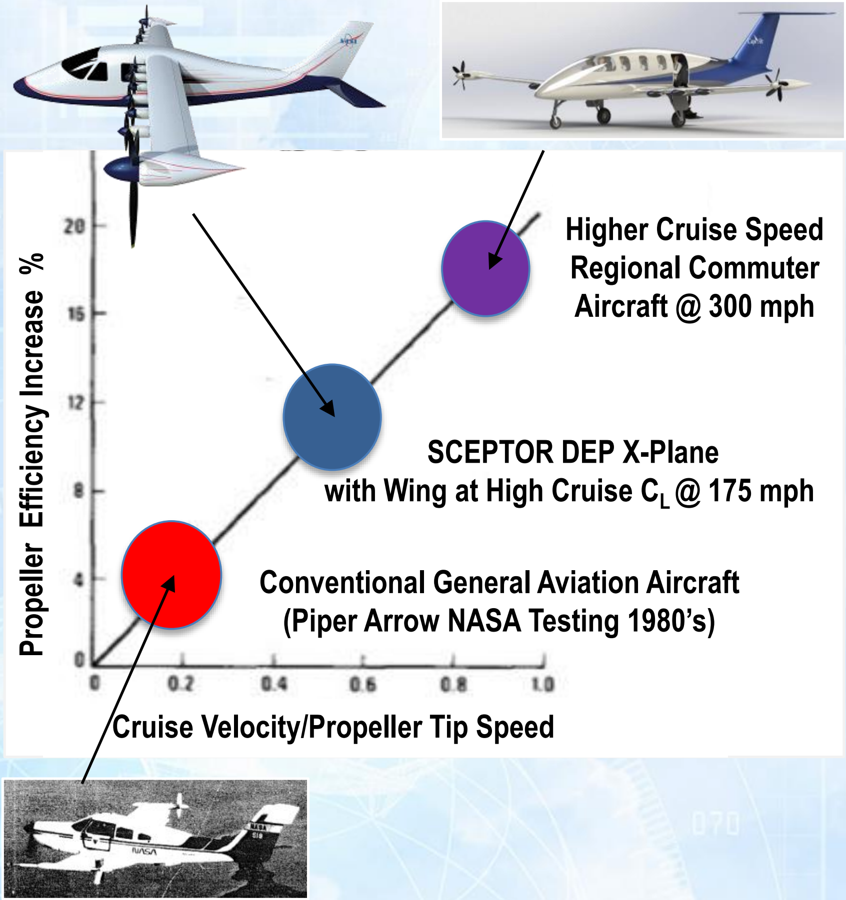
+

Wingtip Vortex Propeller Integration



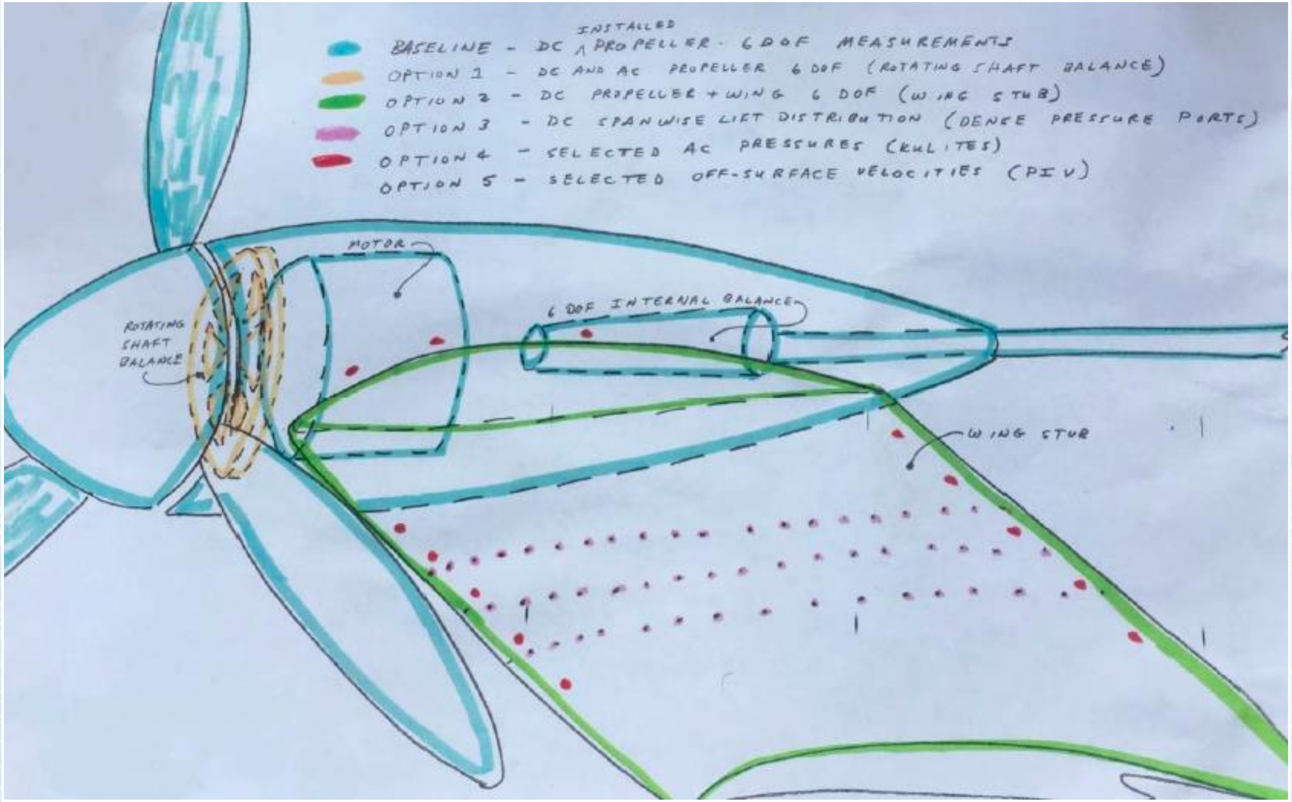






Measurements Techniques and Tool Validation

For Wingtip Propulsion Airframe Integration (PAI) Effects



Example layout of test article for the measurement of PAI effects.

Flight Demonstrations and Capabilities Project

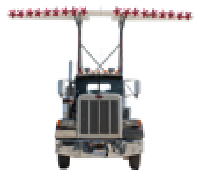
Brent Cobleigh, PM

Mike Guminsky, DPM for Flight Demos

Tom Horn, DPM for Flight Capabilities

Project Approach

Mod 1



Ground validation of DEP high lift system

Flight testing of baseline Tecnam P2006T

Goals:
- Establish Baseline Tecnam Performance
- Pilot Familiarity

Mod 1

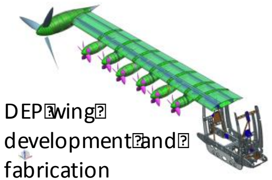
Mod 2

Ground and flight test validation of electric motors, battery, and instrumentation.

Goals:
- Establish Electric Power System Flight Safety
- Establish Electric Tecnam Retrofit Baseline

Mod 2

Mod 3



DEP wing development and fabrication

Flight test electric motors relocated to wingtips on DEP wing including nacelles (but no DEP motors, controllers, or folding props).

Achieves Primary Objective of High Speed Cruise Efficiency

Mod 3

Spiral development process
- Build – Fly – Learn

Mod 4

Flight test with integrated DEP motors and folding props (cruise motors remain in wing-tips).

Achieves Secondary Objectives
- DEP Acoustics Testing
- Low Speed Control Robustness
- Certification Basis of DEP Technologies

Mod 4

Tecnam P2006

Shipped from Italy to California in June 2016

- PDR – November 2015
- CDR – November 2016
- Mod II Flights –
  First quarter 2018

SCEPTOR X-Plane Objectives

Primary Objective

- Goal: 5x Lower Energy Use (Compared to Original P2006T @ 175 mph)
  - IC Engine vs Electric Propulsion Efficiency changes from 28% to 92% (~3.3x)
  - Synergistic Integration (~1.5x)

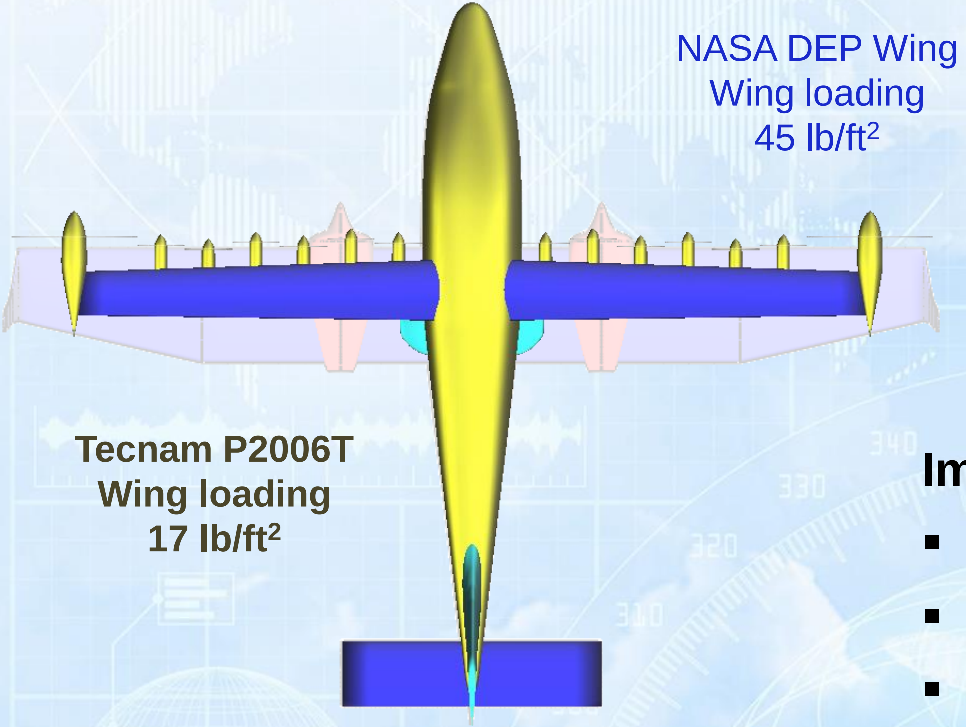
Derivative Objectives

- ~30% Lower Total Operating Cost
- Zero In-flight Carbon Emissions

Secondary Objectives

- 15 dB Lower community noise
- Flight control redundancy and robustness
- Improved ride quality
- Certification basis for DEP technologies

SCEPTOR Wing Sizing Impact



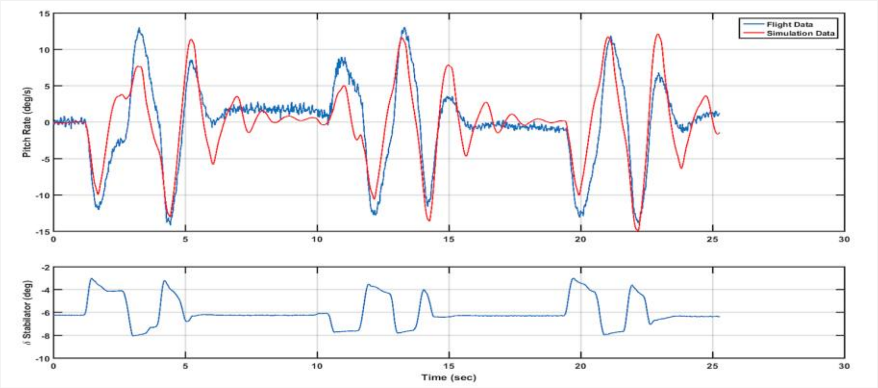
Impact

- Same takeoff/landing speed
- Large reduction in wing area
- Decreases the friction drag
- Allows cruise at high lift coefficient
- Less gust/turbulence sensitivity

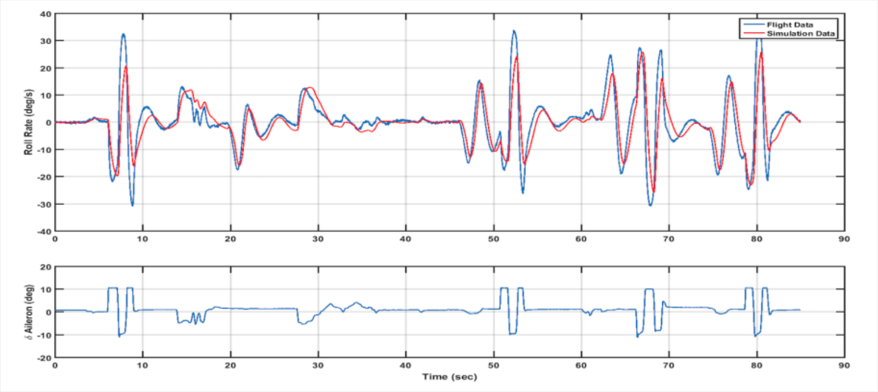
Controls IPT: Mod I Flight Test at NASA Armstrong

Test flights conducted on a commercial Tecnam P2006T

Flights supported both pilot familiarization, and a validation data source for the Mod II piloted simulation

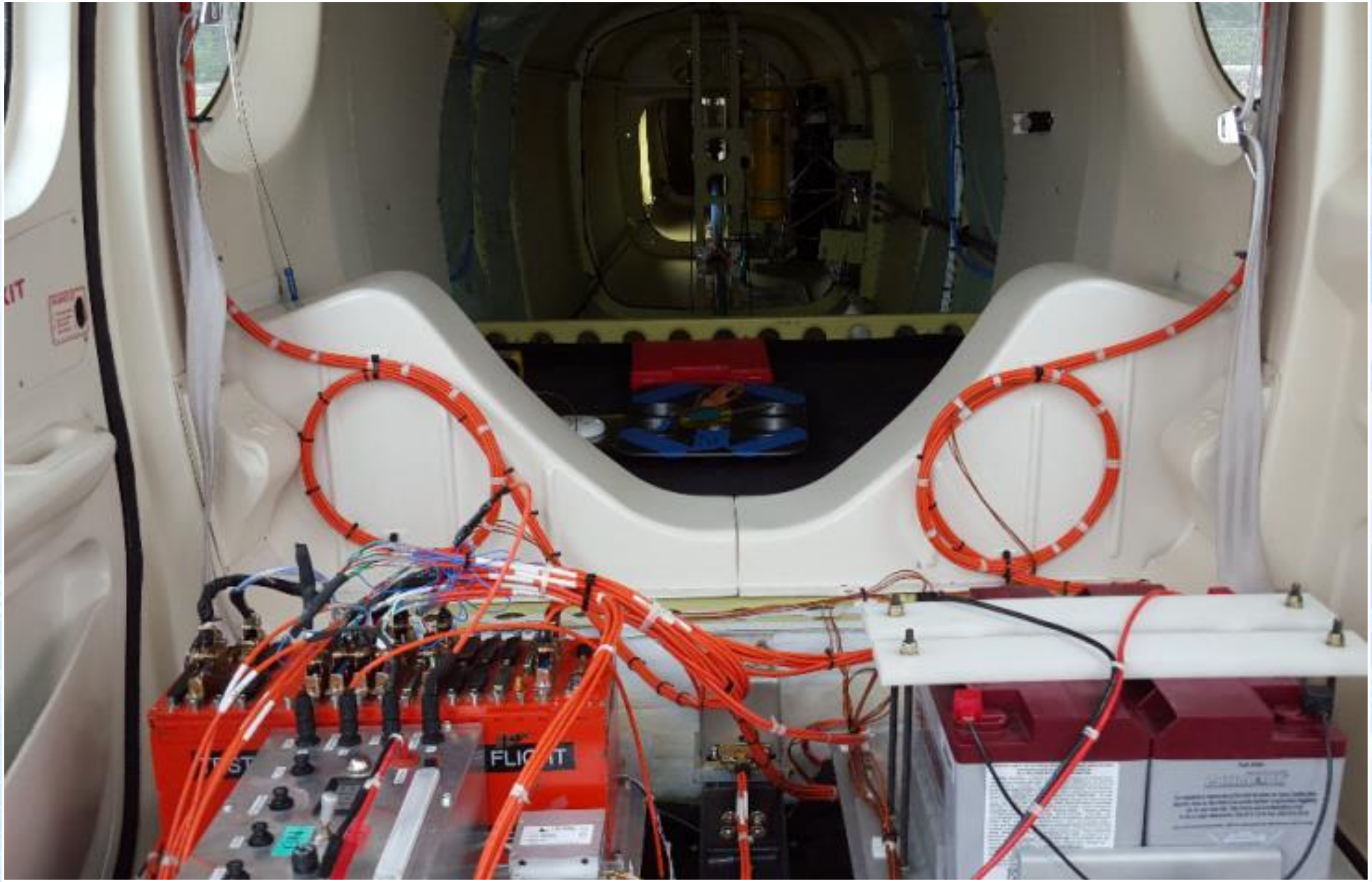


Simulation versus flight response, pitch rate



Simulation versus flight response, roll rate

Instrumentation IPT: Mod I



Controls IPT: X57 Piloted Simulation

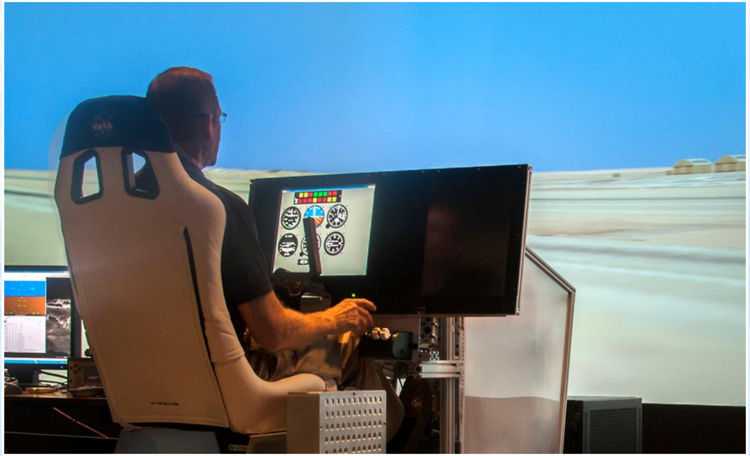
Mod II Simulation

- Updated with data from flight test
- Common aero-database between piloted and desktop simulations

Cockpit Buildup

- New force feedback yoke
- Throttle/RPM Controls
- Primary Instruments and Alarms

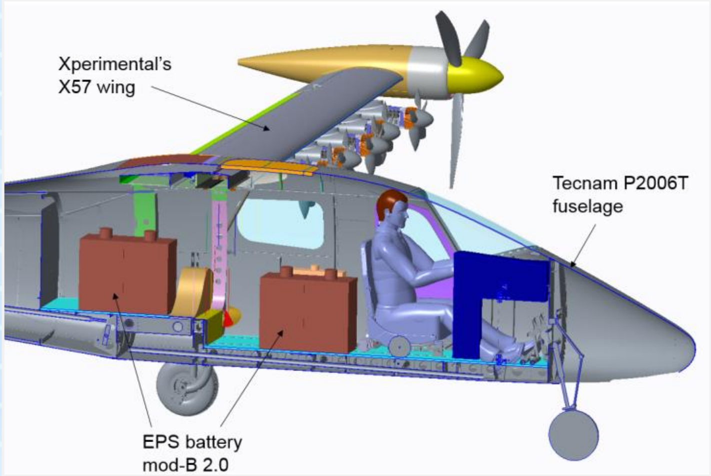
Piloted simulation will be used to train for test flights and verify acceptable performance and handling qualities.

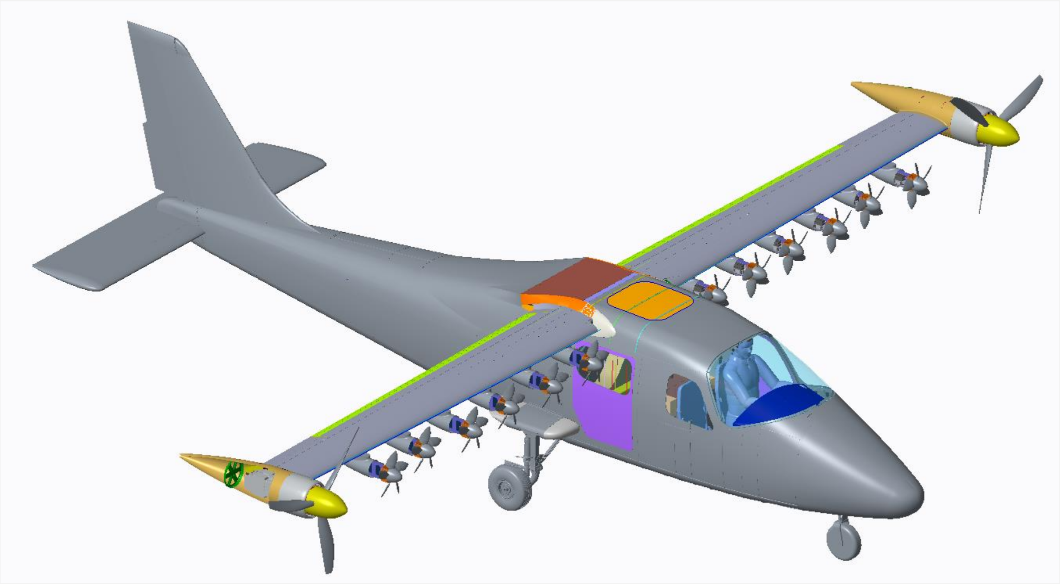


Cockpit view

Tower/chase external view, Mod III

Vehicle IPT: Mega-Model Development





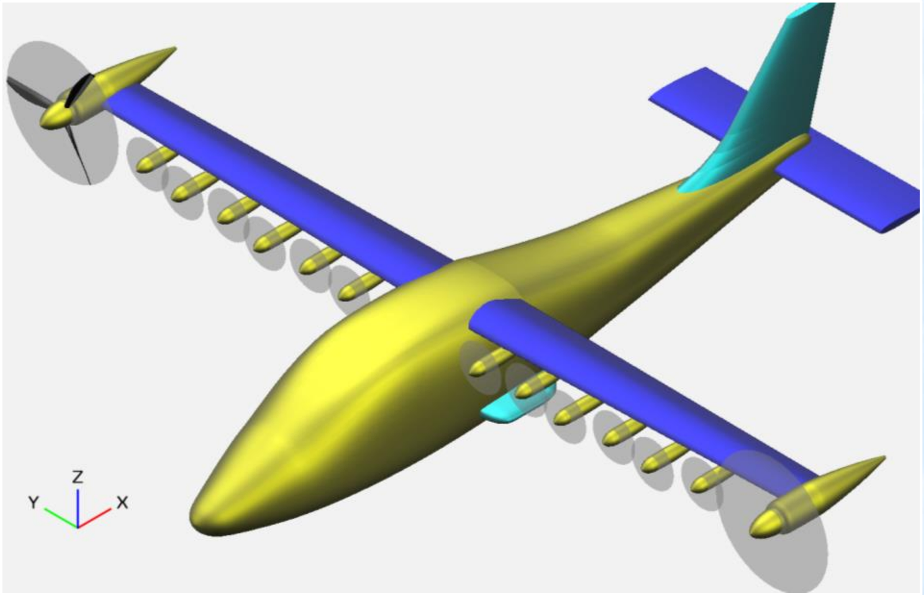
Mega-model will provided configuration control of weight, CG, inertias, and geometry

WING IPT: Structural Design

Controls IPT: X57 on Roll Rig

Performance IPT: Latest X-57 Design Features

- MTV-7-152/64 FAA-certified wingtip propellers
- Longer tip nacelles to house JMX57 outrunning motors, inverter cooling flowpath, and instrumentation
- Staggered high-lift nacelles to mitigate impact of blade-out failures to adjacent nacelles
- Air cooled, direct drive outrunner
- Replaces 100 HP Rotax 912S engine with 60 kW Joby motor
- Tailoring FAA engine design acceptance testing (Part 33) for NASA flight qualification

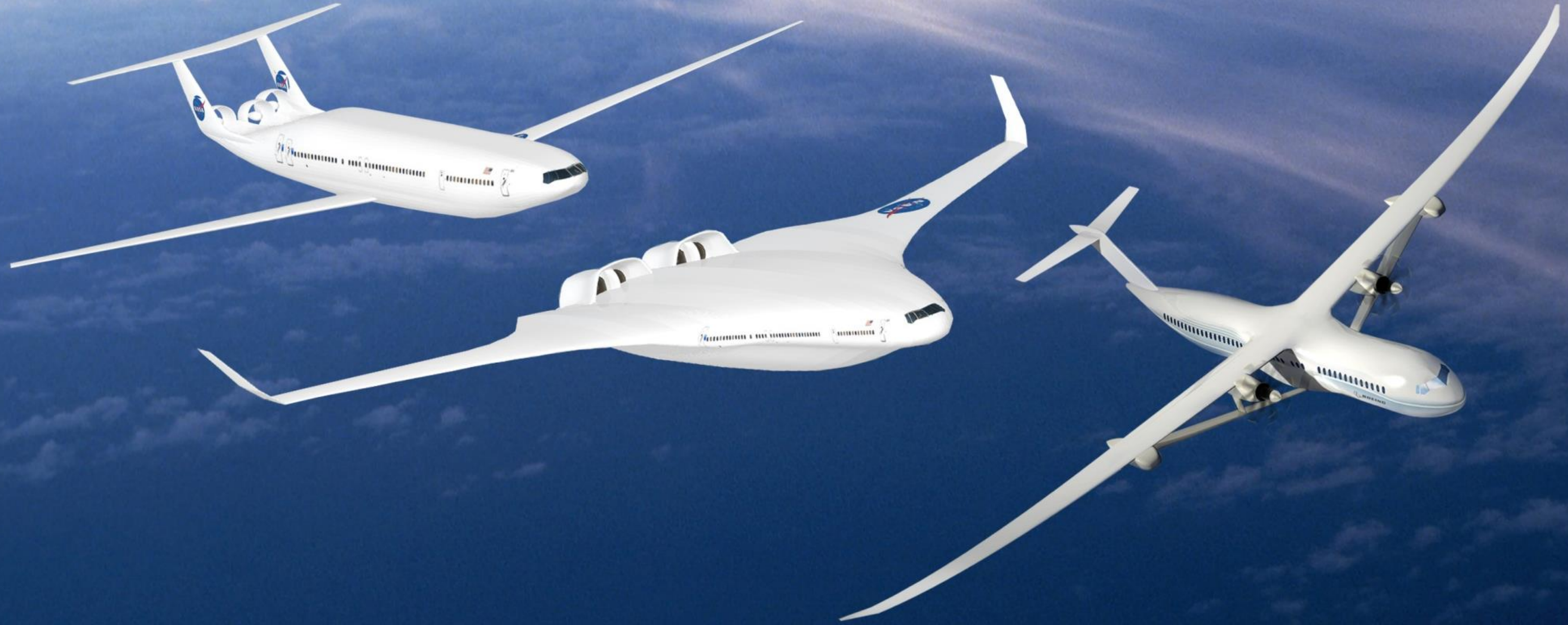


Advanced Air Transport Technology (AATT) Project

Dr. James Heidmann, Project Manager (Acting)
Scott Anders, Deputy Project Manager (Acting)
Steve Helland, Associate Project Manager, Execution
Jennifer Cole, Associate Project Manager, Integrated Testing
Dr. Nateri Madavan, Associate Project Manager, Technology

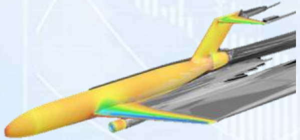
Centers:

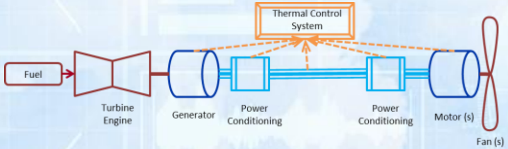
- Glenn Research Center (Host)
- Langley Research Center
- Ames Research Center
- Armstrong Flight Research Center

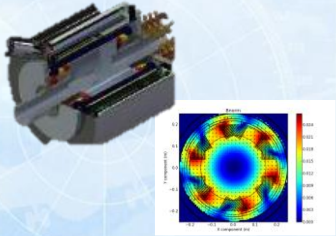


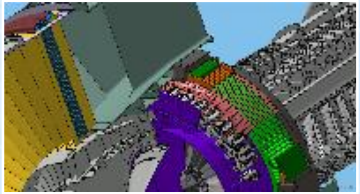
Advanced Air Transport Technology (AATT) Project

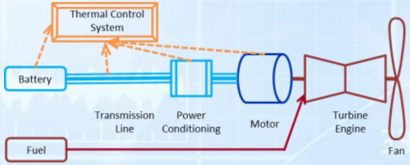
Hybrid Gas-Electric Propulsion Subproject

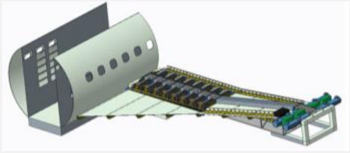


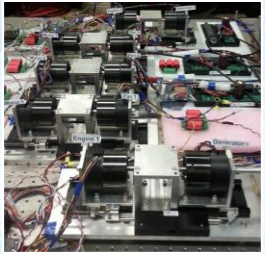


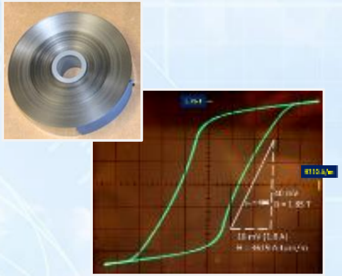












Amy Jankovsky,	**Subproject Manager**
Cheryl Bowman,	**TC5.2 Technical Lead**
Rodger Dyson,	**TC5.2 Technical Lead**

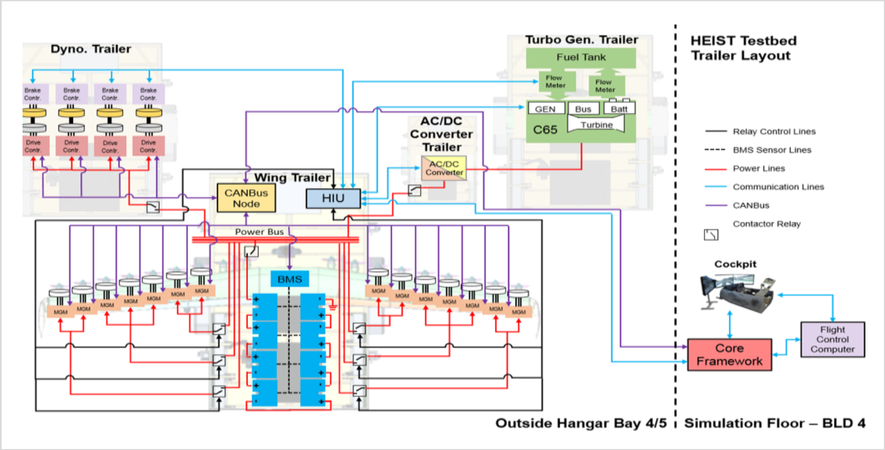
Hybrid Electric Integrated System Testbed (HEIST)

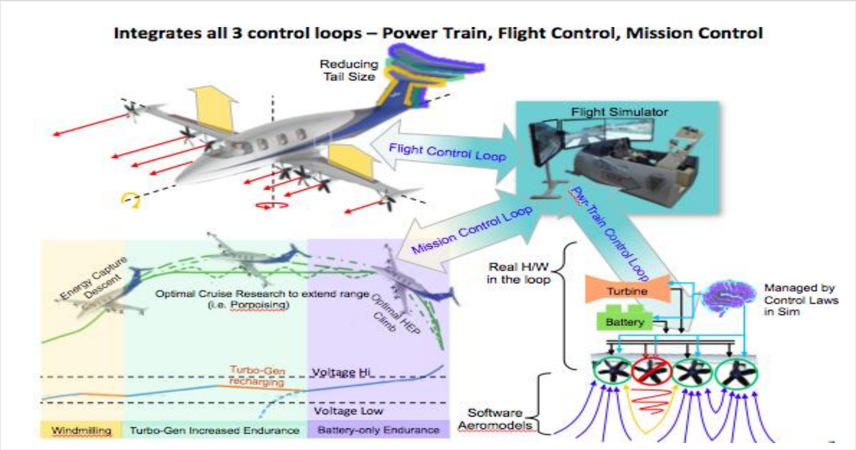
Hardware-in-the-loop (HIL)

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



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