Spiral Development of Electrified Aircraft Propulsion from Ground to Flight

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Electrified Aircraft Propulsion Development

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Power Level for Electrical Propulsion

- **Today**: kW class
  - All-electric and hybrid-electric general aviation (limited range)

- **10 Year**
  - 1 to 2 MW class
    - Hybrid electric 50 PAX regional
    - Turboelectric distributed propulsion 100 PAX regional
    - All electric 50 PAX regional (500 mile range)

- **20 Year**
  - 2 to 5 MW class
    - Hybrid electric 100 PAX regional
    - Turboelectric distributed propulsion 150 PAX
  - 5 to 10 MW
    - Hybrid electric 150 PAX
    - Turboelectric 150 PAX

- **30 Year**
  - >10 MW
    - Turbo/hybrid electric distributed propulsion 300 PAX

- **40 Year**
  - All-electric, full-range general aviation
  - Hybrid electric 100 PAX regional
  - Turboelectric distributed propulsion 150 PAX
  - All electric 50 PAX regional (500 mile range)
History of Engine Development

1903 – 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

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- Intelligent Integrated Control for flight actuators, power train and energy storage in Preparation for 1-2MW flight demonstrator
- Capturing Complexities of Hybrid Architectures
- Spiral Development for MW scale
- Risk Reduction for kW airplane
- X-57 ePAI validation manually controlled 3000lb – 2018
- High Lift Risk Reduction Testing for X-57
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)
Distributed electric propulsion (DEP) enables design not only higher $C_{L_{\text{max}}}$, but also higher $L/D_{\text{max}}$ and higher $\eta_{\text{propulsive}}$ at high speed.
Blown Wing (Props Powered) – Lift and Drag Coefficients

Test AOA, deg
-5 0 5 10 15 20
Net CD
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Operational AoA
Test Identified
Maximum Lift Region
Post Stall AoA

Test data may have analysis errors
-Test points are not corrected to standard day values
-CFD data has no uncertainty bounds
-Uncertainties include test condition variations only

Test AOA, deg
-5 0 5 10 15 20
Net CL
0
1
2
3
4
5
6
7
Operational AoA
Test Identified
Maximum Lift Region
Post Stall AoA

Test data may have analysis errors
-Test points are not corrected to standard day values
-CFD data has no uncertainty bounds
-Uncertainties include test condition variations only
Desirable attributes:
- \( Cp = 0 \) \((V_{\text{local}} = V_\infty)\)
- Low pressure gradients
- 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

Wingtip Vortex Propeller Integration

Viva and Alisport Motorgliders

Higher Cruise Speed Regional Commuter Aircraft @ 300 mph

SCEPTOR DEP X-Plane with Wing at High Cruise $C_L@175$ mph

Conventional General Aviation Aircraft (Piper Arrow NASA Testing 1980's)

Cruise Velocity/Propeller Tip Speed

Propeller Efficiency Increase %
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 highlift system

Goals:
- Establish Baseline Tecnam Performance
- Pilot Familiarity

Mod 2
Flight testing of baseline Tecnam P2006T
Ground and flight test validation of electric motors, battery, and instrumentation.

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

Achieves Primary Objective of High Speed Cruise Efficiency

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).

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
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
Impact
- Same takeoff/landing speed
- Large reduction in wing area
- Decreases the friction drag
- Allows cruise at high lift coefficient
- Less gust/turbulence sensitivity
Test flights conducted on a commercial Tecnam P2006T

Flights supported both pilot familiarization, and a validation data source for the Mod II piloted simulation
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.
Vehicle IPT: Mega-Model Development

Mega-model will provide 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.