Electric Propulsion Adoption Pathways through Integrated Technology Development

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**Benefits**
- High efficiency
- Wide operating envelope
- High power-to-weight ratio
- High reliability
- "Scale-invariant"

**Challenges**
- Mass of onboard stored energy system
- Lack of supporting infrastructure
- Certification/safety assurance

Component-level technology development abounds... but what can we get out of smarter integration?
SCEPTOR – Propulsion-Airframe Integration
(Scalable Convergent Electric Propulsion Technology Operations Research)

- **Lead Center & Partner Centers**: Langley (VA), Armstrong (CA), Glenn (OH)
- **External Collaborators**: ESAero, Joby Aviation, Scaled Composites, Xperimental
- **Big Question**: *Can rapid, inexpensive sub-scale technology development and testing show Distributed Electric Propulsion (DEP) capable of ultra-high efficiency, low carbon emissions, and low operating costs at high-speed?*
- **NASA Aeronautics Strategic Thrusts and Associated Outcomes Addressed:**
  - Transition to Low Carbon Propulsion
  - Ultra Efficient Commercial Vehicles

- **Idea/Concept**: Design and fabricate a DEP wing system, retrofit a Tecnam P2006T with a DEP wing, flight test to show the benefit achieved.
- **Feasibility Assessment**: Establish baseline cruise energy required, apply new technology, determine whether 5x reduction goal is achieved at 150 knot cruise speed.
- **Duration of Execution**: 3.5 years, ~$16M full-cost
SCEPTOR Key Technologies

Folding High-Lift Low Tip Speed Propeller (Inboard)

Wingtip Vortex Propeller Integration

- Higher Cruise Speed Regional TurboProp Commercial Aircraft
- SCEPTOR DEP Demonstrator with Wing at High Cruise $C_L$
- Conventional General Aviation Aircraft

Cruise Velocity/Propeller Tip Speed vs. Propeller Efficiency Increase %
Distributed Electric Propulsion High-Lift Benefit

Lift Coefficient at 61 Knots (with and without 220 kW power across wing propellers)

- No Flap (STAR-CCM+)
- 40° Flap, No Power (STAR-CCM+)
- 40° Flap with Power (STAR-CCM+)
- 40° Flap with Power (Effective, STAR-CCM+)
- 40° Flap with Power (FUN3D)
- 40° Flap with Power (Effective, FUN3D)

Unflapped Wing

Flapped Wing

DEP Flapped Wing
Wing Planform Comparison

Tecnam P2006T
Wing loading
17 lb/ft²

DEP Tecnam P2006T
Wing loading
45 lb/ft²

Large Reduction in Wing Area
Decreases the Friction Drag, and
Allows Cruising at High Lift Coefficient
SCEPTOR X-Plane Objectives

**NASA SCEPTOR Primary Objective**
- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 knots)
  - Motor/controller/battery conversion efficiency from 28% to 92% (3.3x)
  - Integration benefits of ~1.5x (2.0x likely achievable with non-retrofit)

**NASA SCEPTOR Derivative Objectives**
- ~30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

**NASA SCEPTOR Secondary Objectives**
- 15 dB Lower community noise (with even lower true community annoyance).
- Flight control redundancy, robustness, reliability, with improved ride quality.
- Certification basis for DEP technologies.
**Schedule**

**PHASE I**
- Ground validation of DEP highlift system
- Baseline Tecnam P2006T testing

Goals:
- Establish Baseline Tecnam Performance
- Test Pilot Familiarity

**PHASE II**
- DEP wing development and fabrication
- Ground and flight test validation of electric motors, battery, and instrumentation.

**PHASE III**
- Flight test electric motors relocated to wing-tips, with DEP wing including nacelles (but no DEP highlift system).

Achieves Primary Objective of High Speed Cruise Efficiency

**PHASE IV**
- 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
SCEPTOR Phase III/IV Cruise Performance
Heavy Fuel Hybrid-Electric SOFC
Leverage Existing Infrastructure with Compelling On-Board Efficiency

- Developing dual-use system concept for hybrid-electric Solid Oxide Fuel Cell (SOFC) power system
  - Leverage technology developed for DARPA by Boeing
  - Reforms heavy fuel onboard the aircraft
  - Sized for average rather than peak power
  - Tightly integrated to make judicious use of “waste” products

Diagram:
- Reformer
- Fuel Cell
- Combustor
- Turbocharger
- Elec. Bus

Inputs:
- Heavy fuel
- Steam
- Pressurized air

Outputs:
- Hydrogen
- CO, CO2
- Heat
- Exhaust
- Electrical power
Hybrid SOFC Power System Work in Progress

- Developed conceptual system for Cessna 172 retrofit as potential fast concept-to-flight vehicle
  - COTS motor, no integration benefits, ~100kW
- Total system >300 W/kg at >60% efficiency
  - Translates to ~2-3x reduction in fuel cost, 2x reduction in carbon emissions, zero NOx for primary propulsion
  - *Can use typical hydrocarbon fuel infrastructure*
- Developing follow-up effort for design and tested of dual-use system targeting >100kW power class

**Cessna 172P w/ SuperHawk STC**

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Questions?