Electric Propulsion Adoption Pathways through Integrated Technology Development

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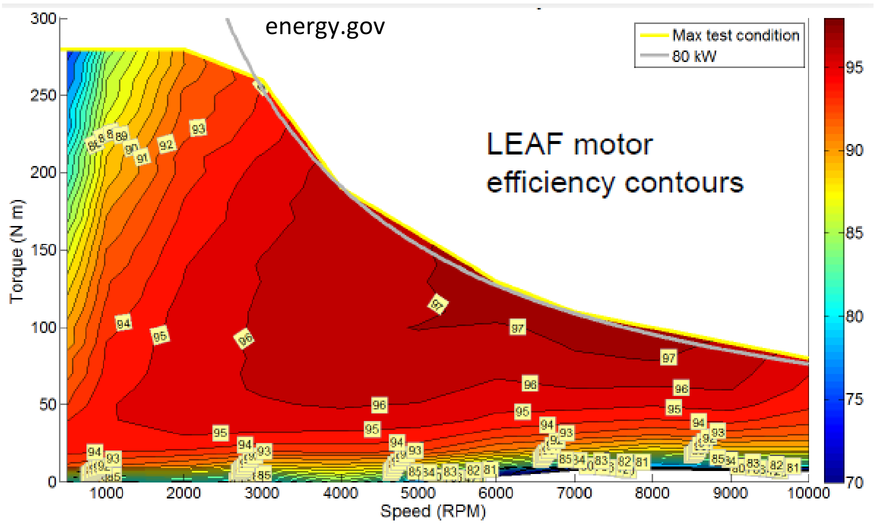
Electric Propulsion for Aviation



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?

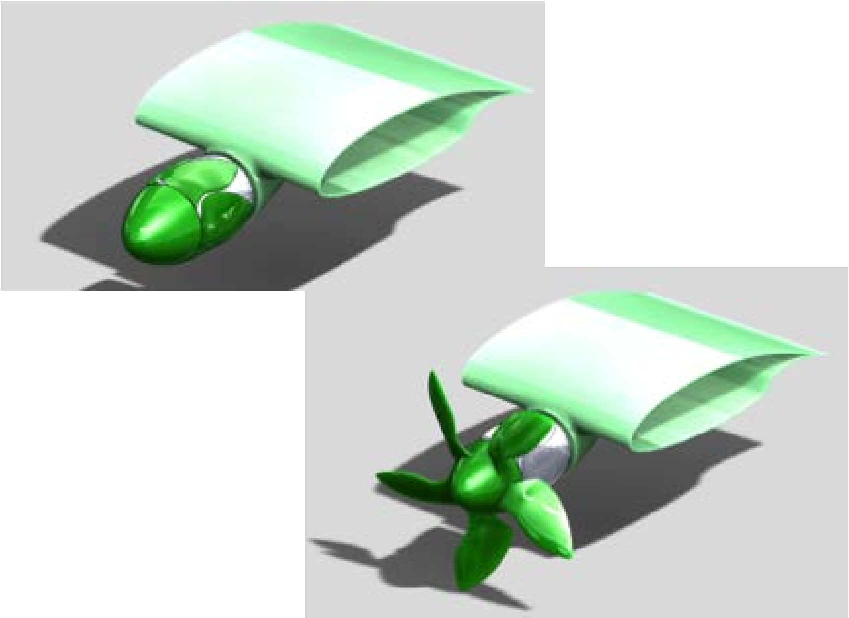
SCEPTOR – Propulsion-Airframe Integration
(Scalable Convergent Electric Propulsion Technology Operations Research)

- **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

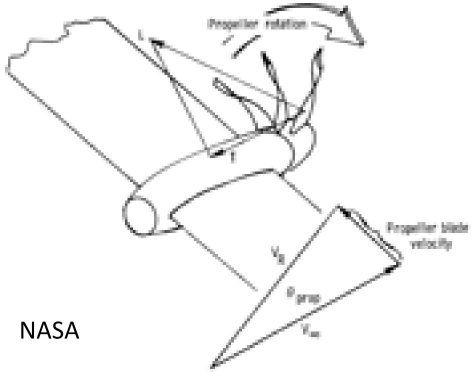
- **Idea/Concept:** Design and fabricate a DEP wing system, retrofit a Tecnam P2006T with a DEP wing, flight test to show the benefit achieved.
- **Feasibility Assessment:** Establish baseline cruise energy required, apply new technology, determine whether 5x reduction goal is achieved at 150 knot cruise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

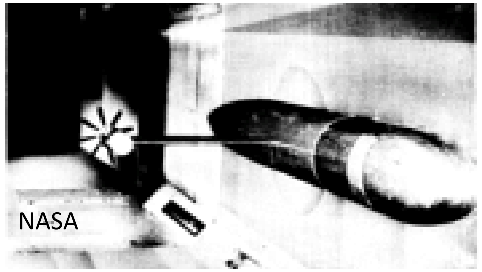
SCEPTOR Key Technologies

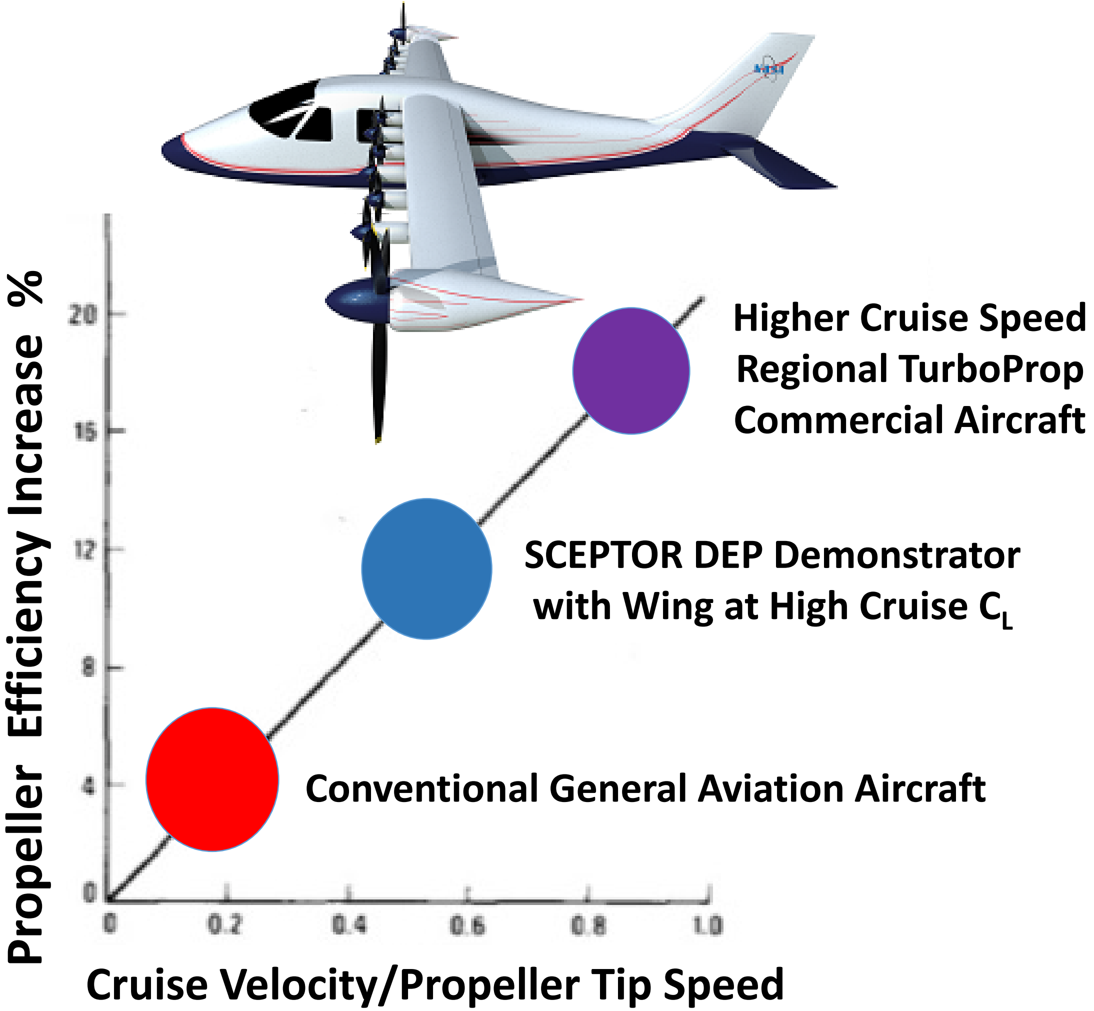
Folding High-Lift Low Tip Speed Propeller (Inboard)



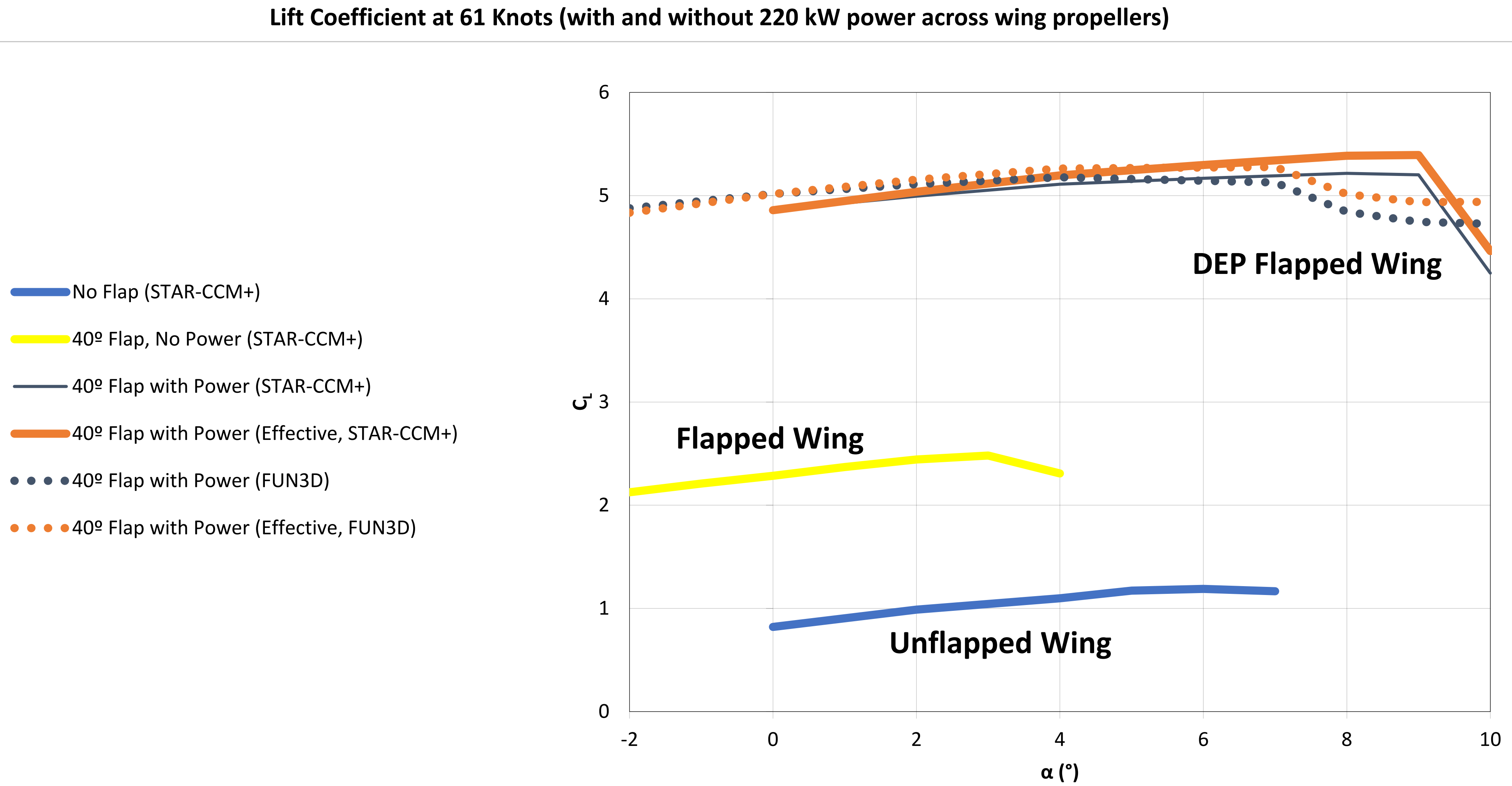
Wingtip Vortex Propeller Integration



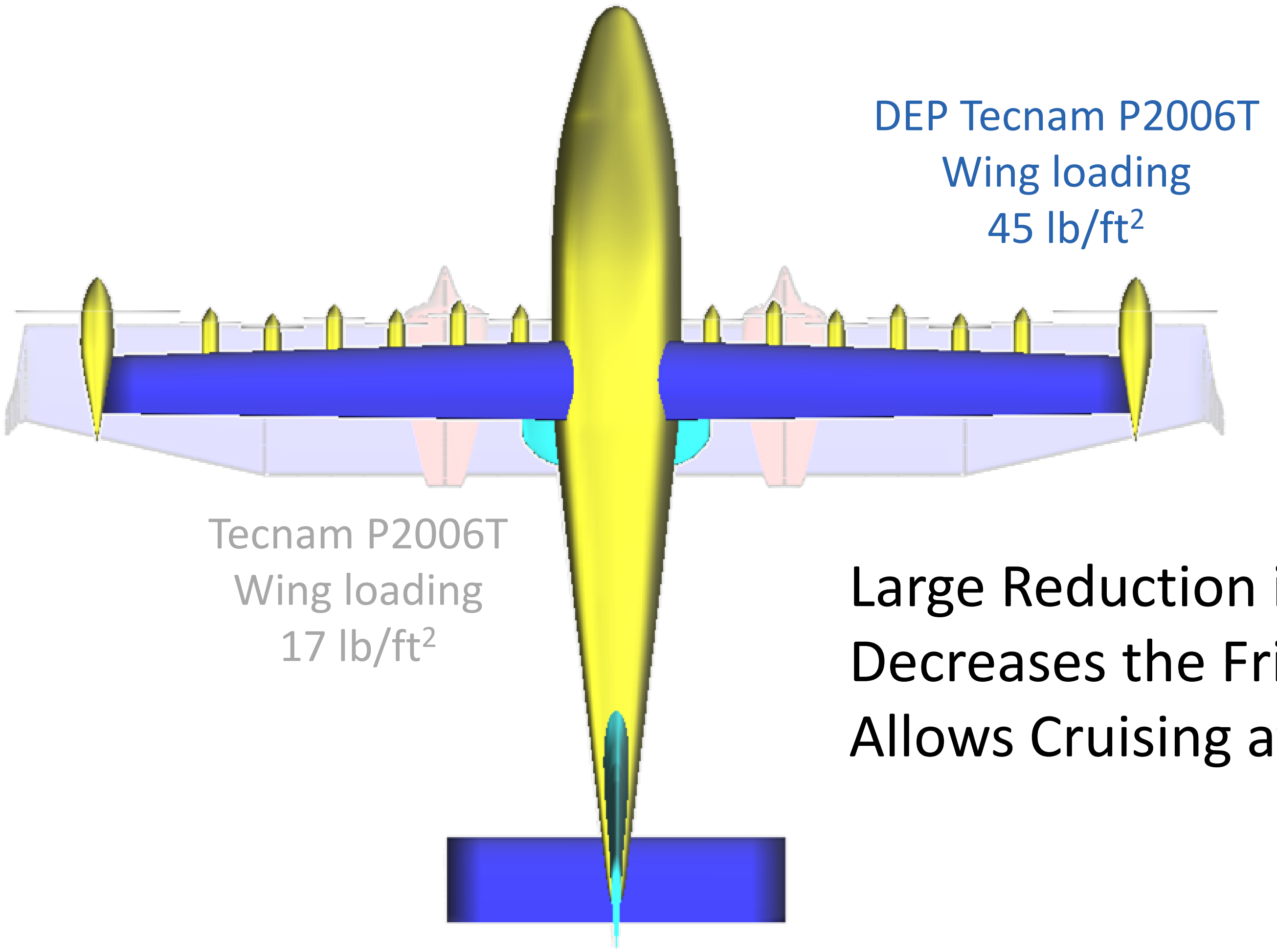




Distributed Electric Propulsion High-Lift Benefit



Wing Planform Comparison



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

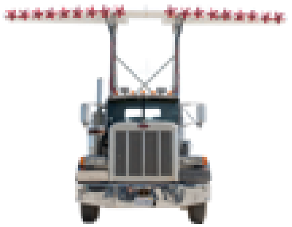
- ~30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

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



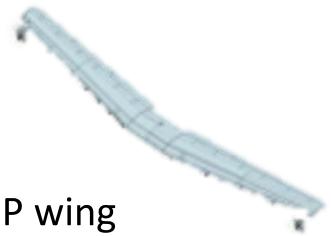
Ground validation of DEP highlift system

Baseline Tecnam P2006T testing

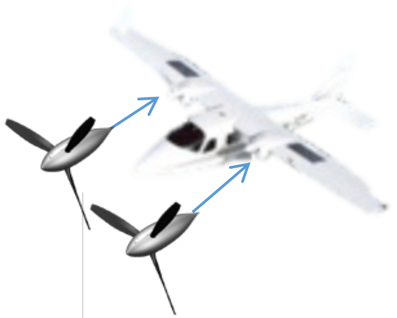
Goals:

- 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.

Goals:

- Establish Electric Power System Flight Safety
- Establish Electric Baseline

PHASE III

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

<u>Achieves Primary Objective</u> of High Speed Cruise Efficiency

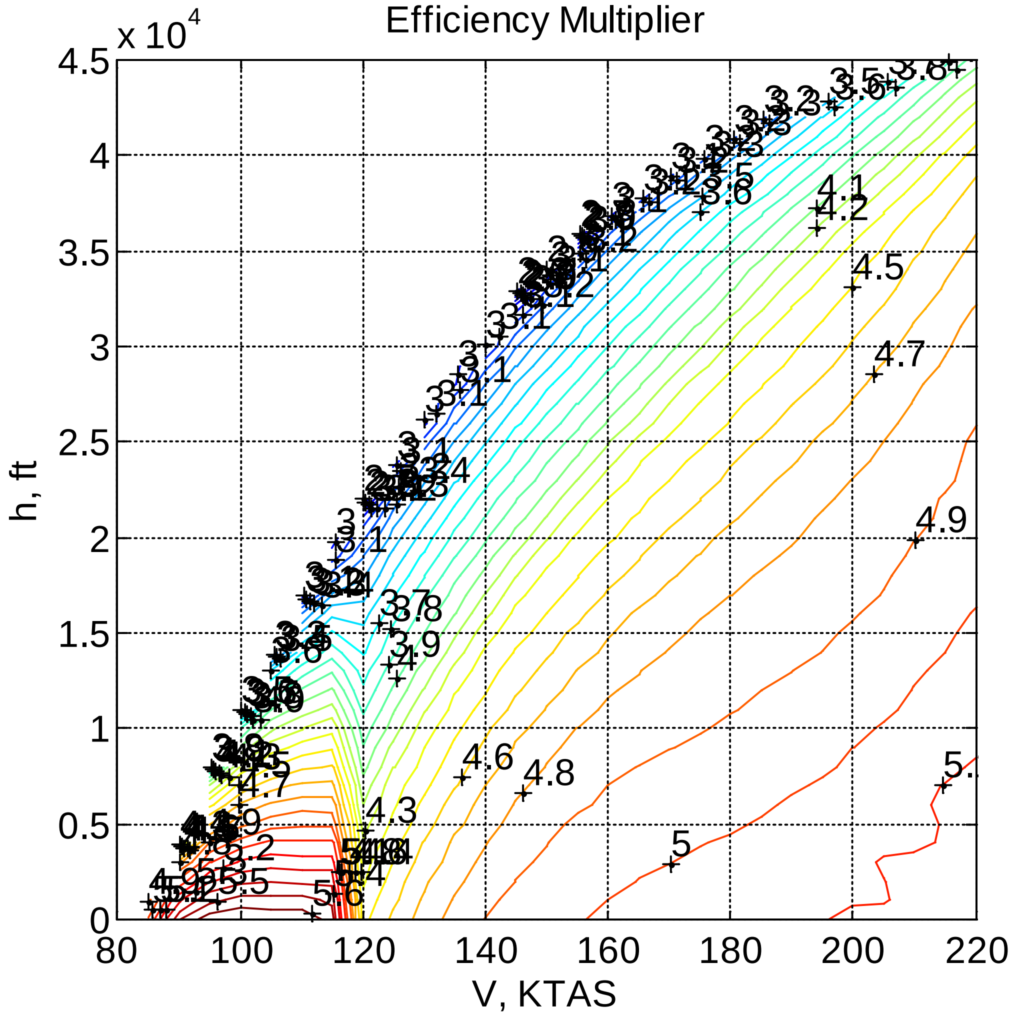
PHASE IV

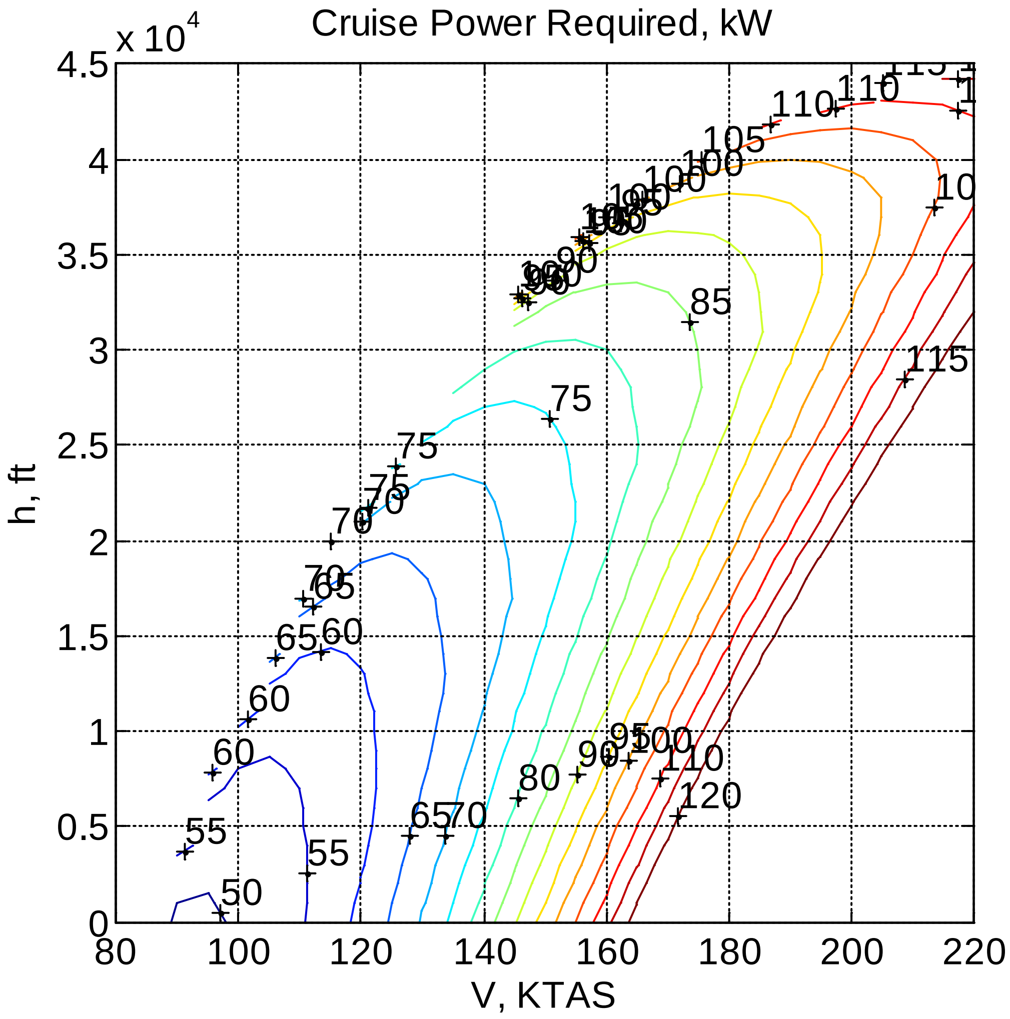
Flight test with integrated DEP motors and folding props (cruise motors remain in wing-tips).

<u>Achieves Secondary Objectives</u>

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

SCEPTOR Phase III/IV Cruise Performance

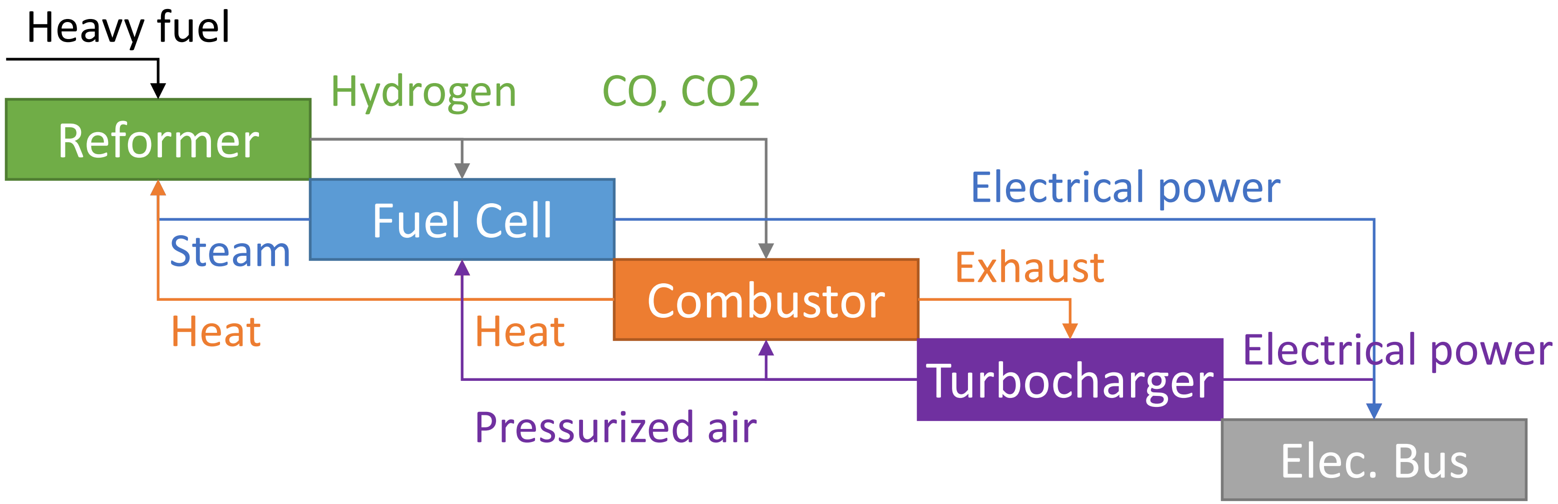


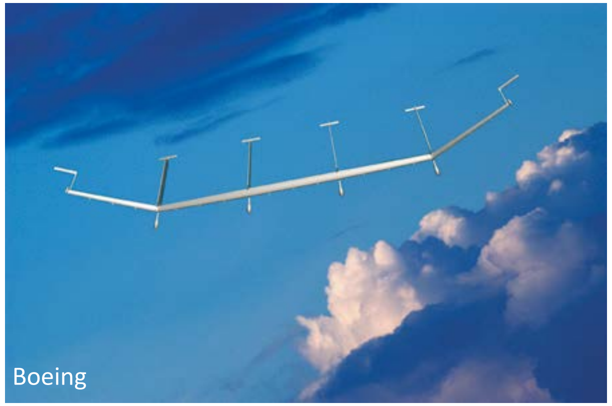


Heavy Fuel Hybrid-Electric SOFC

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





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
Takeoff gross mass, kg	1159
Typical unmodified empty mass, kg	695
Unmodified fuel flow at cruise, kg/hr	25
Exchange mass, kg	-161
Hybrid power system mass, kg	309
Electric powertrain mass, kg	85
Fuel mass remaining to gross weight, kg	51
Estimated cruise fuel flow, kg/hr	13.4
Change in cruise fuel flow, % mass	-46%
Change in cruise fuel flow, % volume	-54%

Questions?

Phase I Ground Testing Validation