Electric Distributed Propulsion Vehicles

Mark D. Moore
NASA Langley Research Center
mark.d.moore@NASA.gov

Outline

- *Unique Attributes of EP, Scale-Free Integration with Zero In-flight Emissions*
  - *Scale-Free: Specific Power and Efficiency, Other Benefits/Penalities*
  - *Characteristics Make EP a Unique Integration Tech, Not Merely a Propulsion Tech*
  - *Provides Path to Renewable-based Energy Solutions*
  - *NASA AFRC EP Life Cycle Emissions Study*
- *Near-Term Mission Application of Aviation Electric Propulsion*
  - *Existing Active Markets: Self-launched Glider Market, General Aviation, sUAS, HALE, AWE*
  - *NASA Green Flight Challenge, Industry Demonstrators, NASA Green Flight Challenge*
  - *GaTech EP Sizing Study*
- *My Research – Apply Tech to Leverage Inherent Benefits, Choice of Mission Application is Key*
  - *GL-10, SCEPTOR, Transformative Vertical Lift Concepts, AHS/AIAA Participation*
  - *Ultra-low Noise Operations at Close Proximity, Robust/Reliable/Redundant Control*
  - *Synergistic Highlift, Low Energy Consumption at High Speed, Ride Quality, Operating Cost*
- *EP Development Strategy*
  - *More Rapid, Lower Cost, TRL Advancement of EP Tech through Sub-Scale Demos*
  - *Technologies: Motors, Controllers, Range-Extenders, Flight Batteries, Redundant Bus Architectures, Thermal Management, Synergistic Techs, Early FAA Certification Paths*
  - *Early Adopter Opportunity: Commuter Commercial Operations, Cape Air*
  - *Incentivizing Low Carbon through Min DOC for the 50% of Aviation Operations at <500 nm*

Electric Propulsion Offers a New Value Proposition

- **Electric propulsion offers fundamentally different characteristics, that are highly enabling to the distributed propulsion solutions due to their scale-free nature.**
- **New integration strategies are enabled that would have never before been feasible; providing completely new Degrees of Freedom in aircraft design.**
- **High technology accelerations exist across the battery, motor, controller markets.**
  - **Batteries have achieved an average rate of improvement in energy density of ~8% per year over the past 30 years. Current available cells are ~250 Whr/kg at 2C ratings.**
  - **Electric motors are currently being tested at 4-6 hp/lb specific power with 95% to 97% efficiency.**
  - **Lightweight controllers with extremely high precision.**

Electric Propulsion Benefits

6x the motor power to weight
3-4x efficiency of SOA Engines
Scale-free efficiency and power to weight
High efficiency from 30 to 100% power
Extremely compact
High Reliability
Safety through Redundancy
Low Cooling Drag
+100% Power for 30-120 Seconds
Continuously Variable Transmission
Extremely Quiet
No power lapse with altitude or hot day
10x lower energy costs
Reduction of engine-out sizing penalty
Zero vehicle emissions

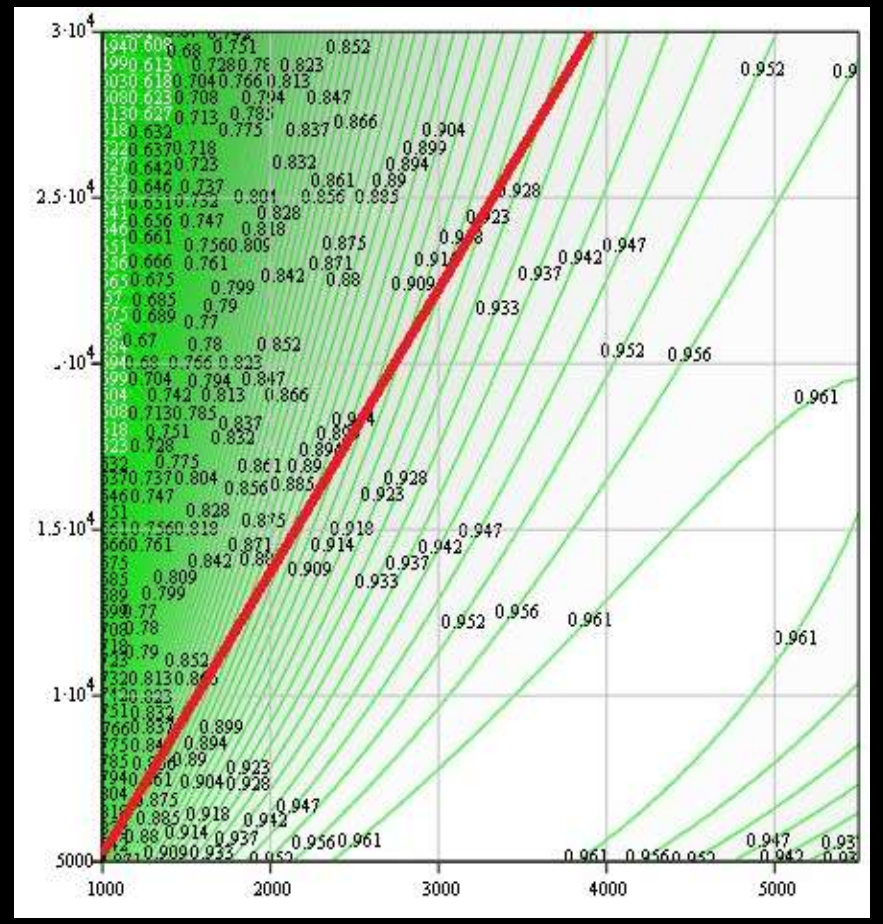
Electric Propulsion Penalties

Energy Storage Weight
Energy Storage Cost
Certification/Safety?

Representative Advanced Technology Electric Motor

NASA Funded Launchpoint Alternator/Motor

- **Halbach Array architecture**
- **8 hp, < 2 lb weight (4 hp/lb)**
- **7.25” diameter with direct drive of 30” diameter propeller**
- **94% at max continuous**
- **97% at part power (~30% power)**
- **Low inductance controller**



Distributed Electric Propulsion (DEP) let's us put thrust wherever we want it…

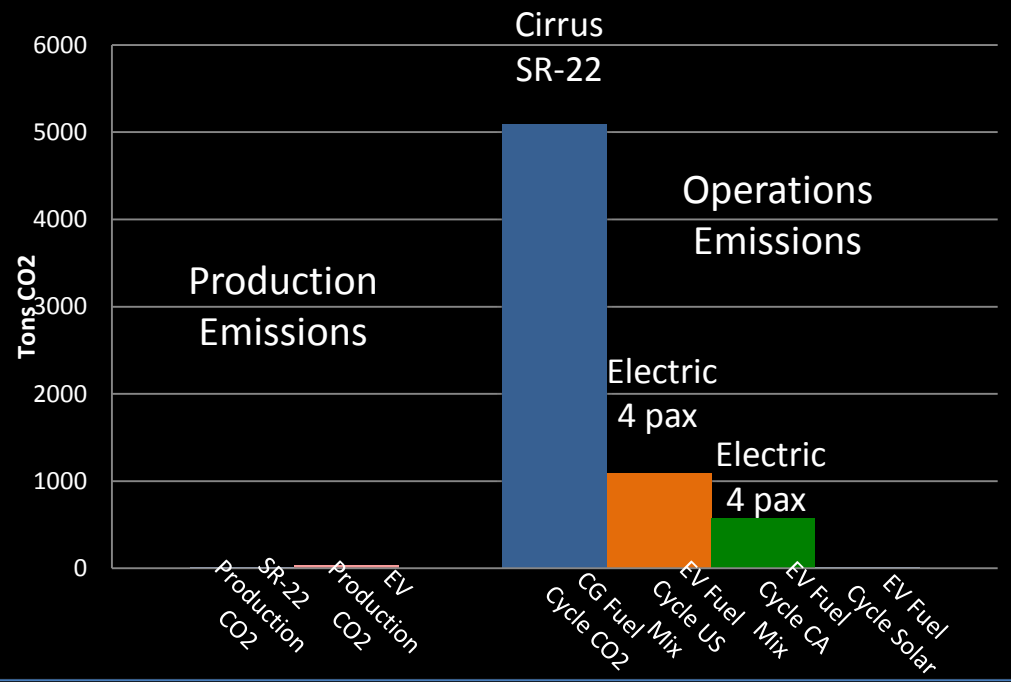
***DEP Enabling Characteristic*: Scale-free Propulsion**

High power to weight, efficiency, reliability, and compactness at any scale

GL-10 sUAS DEP Tilt-Wing Tilt-Tail Vertical Takeoff and Landing (VTOL) Demonstrator (Fully Redundant Vehicle Thrust Solution)

Electric Propulsion Offers a New Value Proposition

Production versus Operation emissions GREET analysis over the lifetime of the aircraft, including 8 batteries swaps over aircraft lifetime.



Electric not only provides 5 to 10 times reduction in greenhouse gas emissions with current electricity, and essentially zero emissions with renewable based electricity; it also provides a technology path to eliminate 100 Low Lead AvGas, which is the #1 contributor to current lead environmental emissions.

Electric Propulsion has been an active area for flight demonstration…

NASA SCEPTOR X-Plane

NASA Green Flight Challenge, 2011
Pipistrel G4 Taurus $1.5M Winner

Rui Xiang RX1E
China

FEATHER
JAXA

Electric Cri-Cri
Airbus

Pipistrel Watts Up
Slovenia
(Ready for Production)

E-Fan
Airbus

DA-36 E-Star
Airbus

E-Genius
Airbus

Transformational Aeronautic Concepts Program

SCEPTOR Project X-Plane

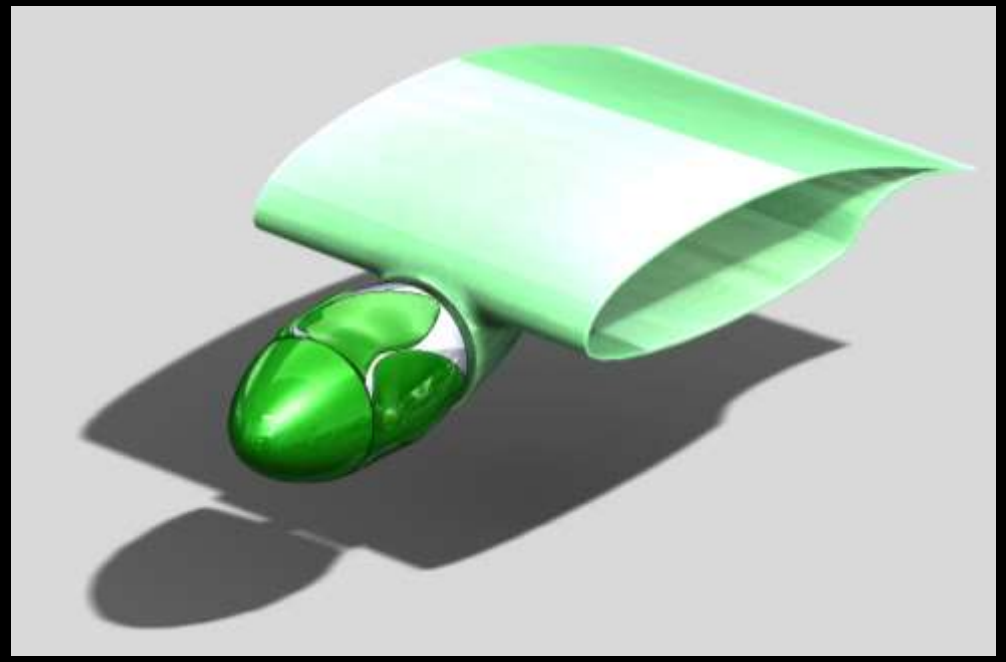
(Scalable Convergent Electric Propulsion Technology Operations Research)

Tecnam P2006T Light Twin General Aviation Aircraft

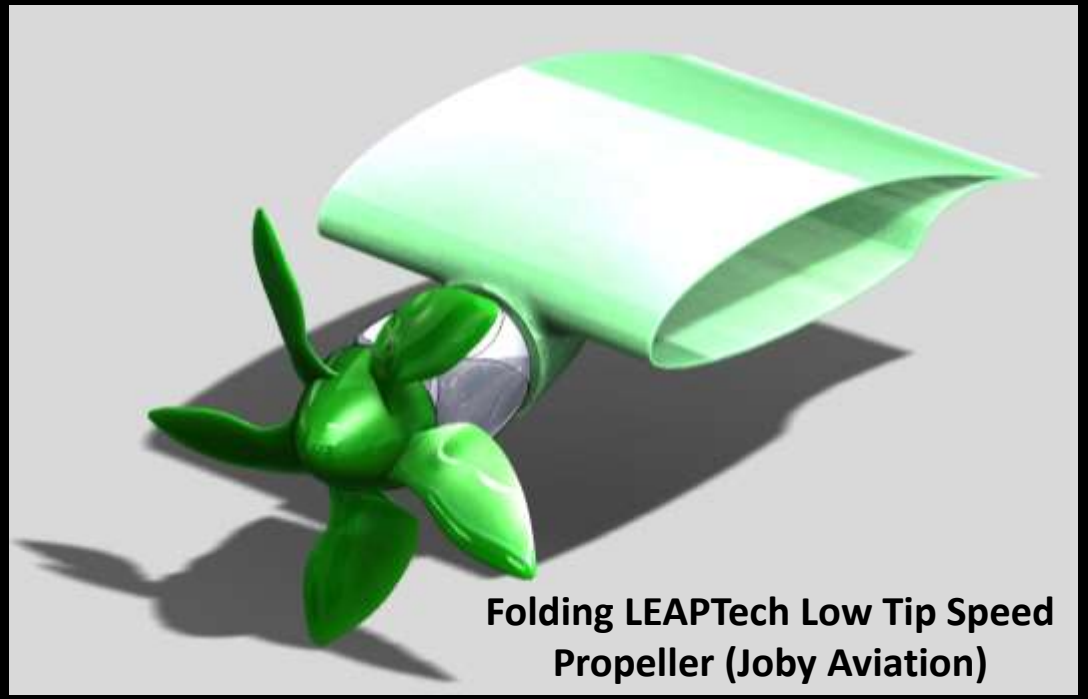
NASA Distributed Electric Propulsion (DEP) X-Plane

$15 million, 3-year research project to achieve the first DEP manned flight demonstrator

Inboard Distributed Electric Propulsion Propeller Folding

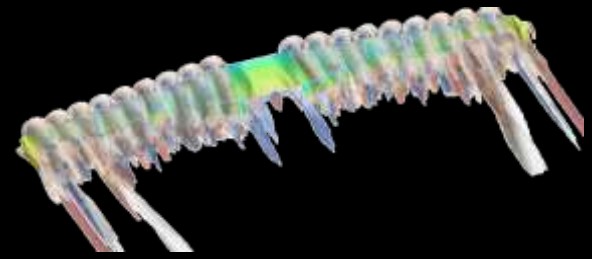


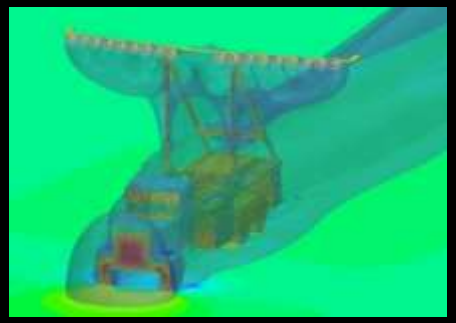
Alisport Slient-2 Motorglider
(flush storage in a proverse pressure gradient)



Folding LEAPTech Low Tip Speed Propeller (Joby Aviation)

NASA DEP research has moved to larger scale testing of DEP…





Distributed Electric Propulsion – What it Means… #3

***DEP Capability*: DEP can provide highly coupled aero-propulsive integration can provide significant lift augmentation, potentially without the typical high pitching moments associated with circulation augmentation due to aft loading of the wing airfoil.**

NASA SCEPTOR Distributed Electric Propulsion

Airbus E-fan: 46 miles in 37 minutes = 74 mph average speed

NASA SCEPTOR Primary Objective

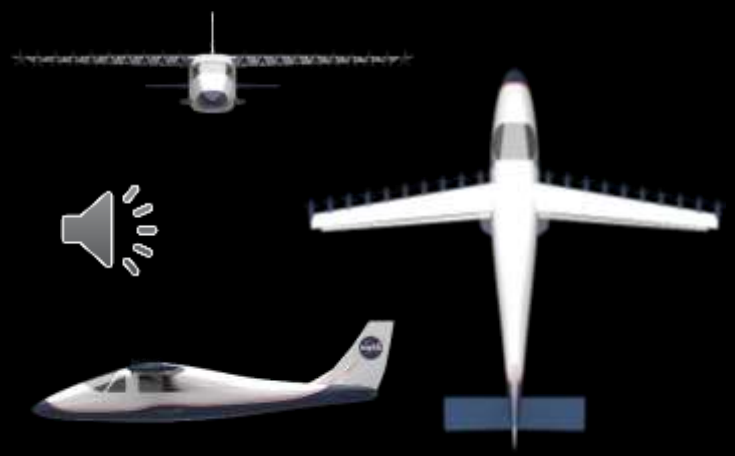
- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 kts)

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.
- Analytical scaling study to provide a basis for follow-on ARMD Hybrid-Electric Propulsion (HEP) commuter and regional turbo-prop research investments.



Distributed Electric Propulsion provides high peak power without sensitivities

Ryan Verti-Plane

+

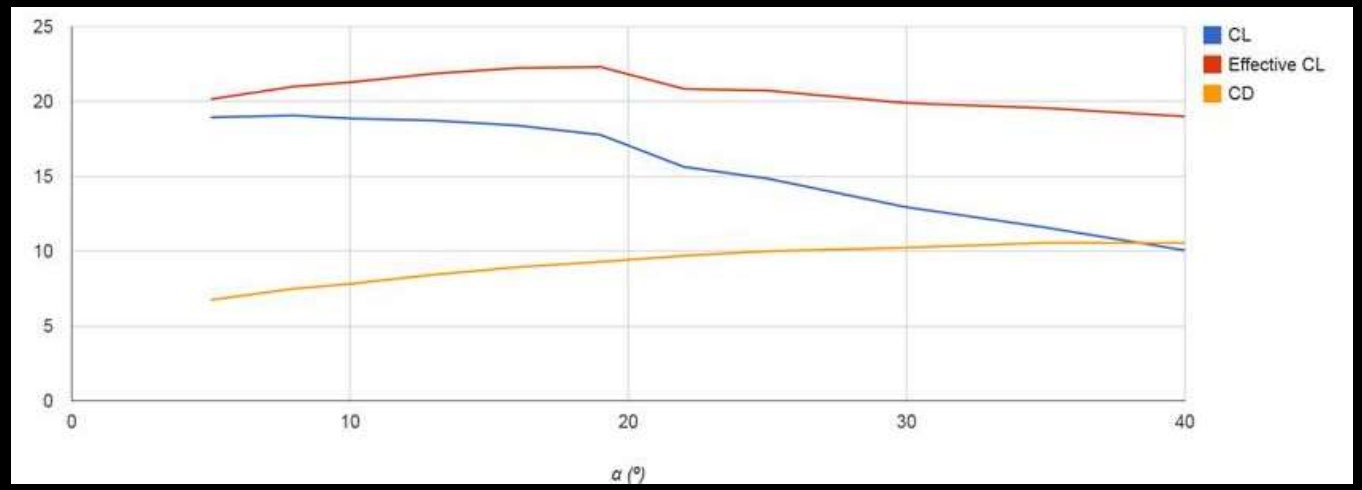
DEP Technologies

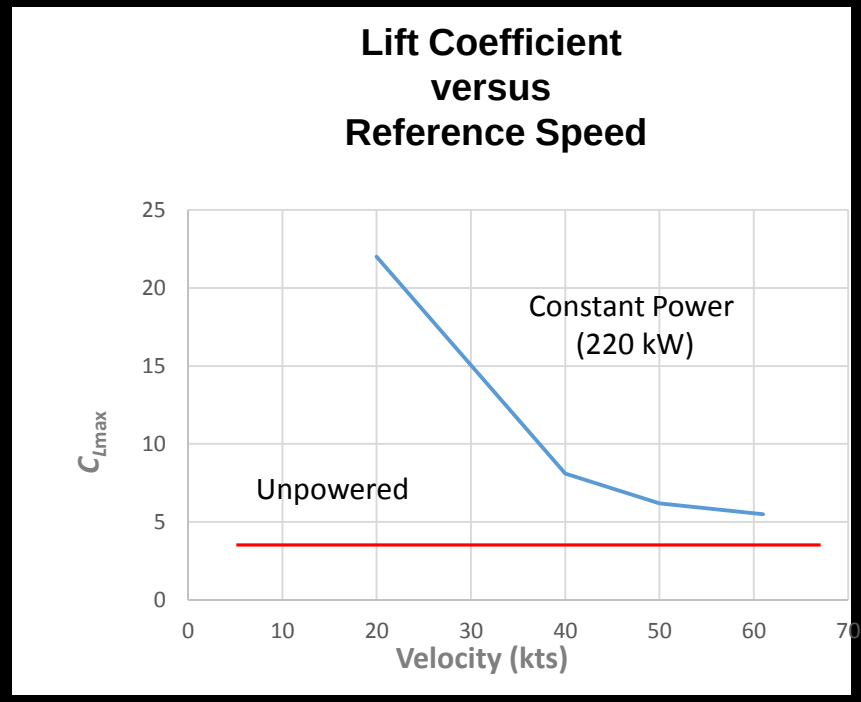
=

DEP VTOL Concept

***DEP Enabling Characteristic:* +50% Power for ~60 Seconds**

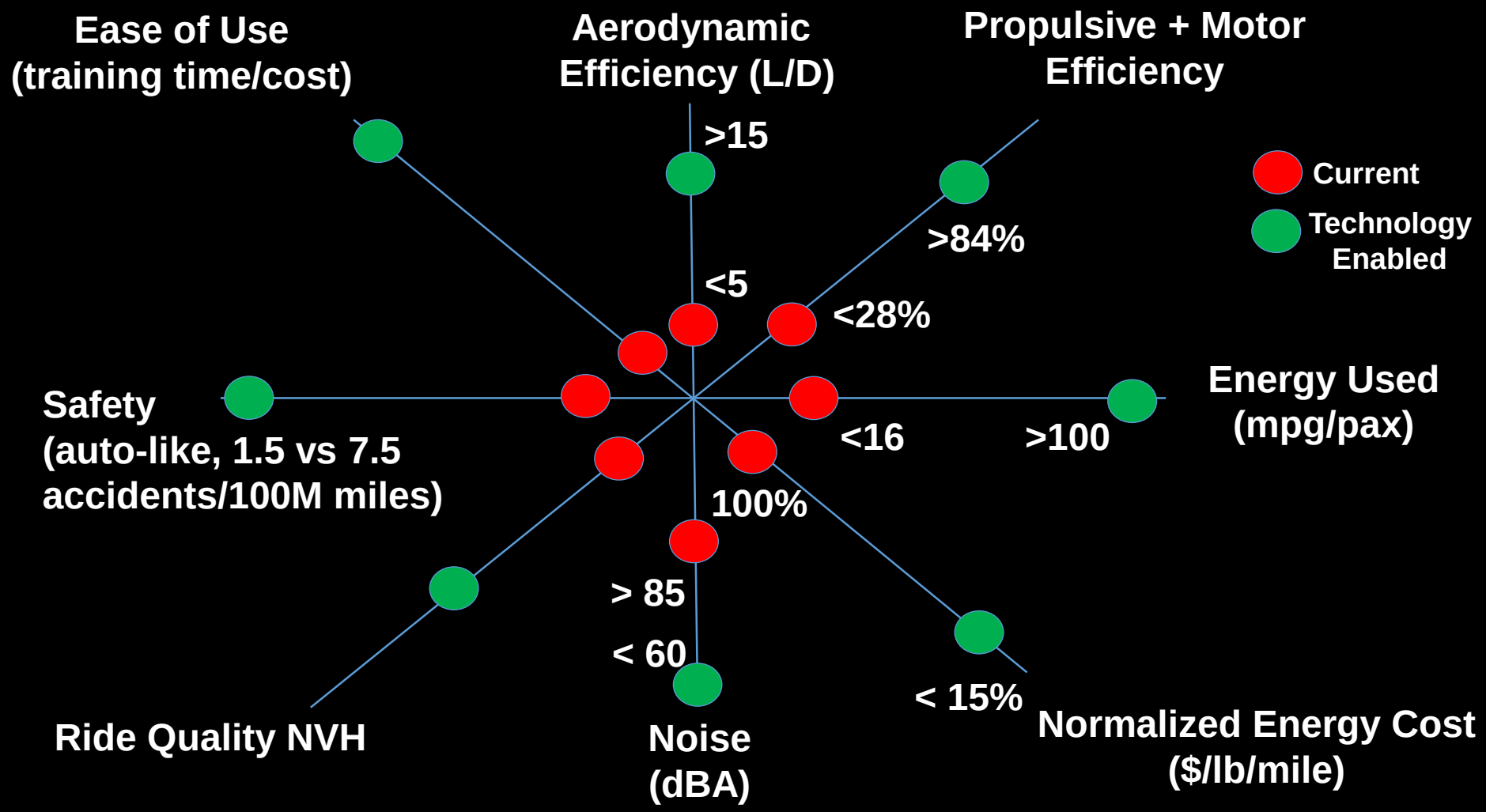
(without motor power lapse with altitude or temperature)





***DEP Capability:* Short duration hoover capability with sustained T/W ratios of <1.0**

Distributed Electric Propulsion – What it Means… #4

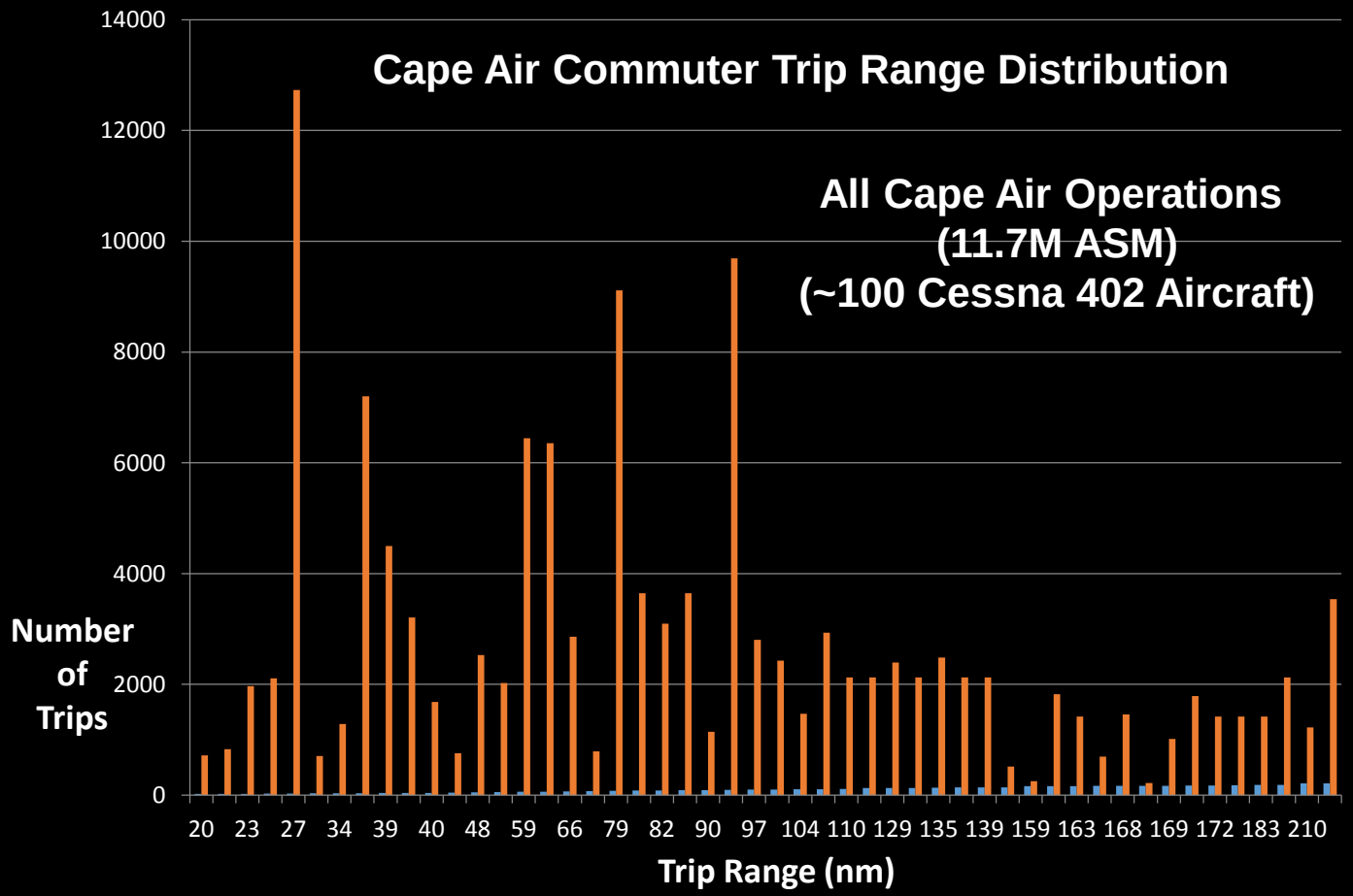


DEP Capability: **Coupled with autonomy are strong enablers of the civil VTOL transportation**

Distrubuted Electric Propulsion Early Adopter Opportunities

Ability to develop technology and certification standards at GA scale with low cost and rapid pace

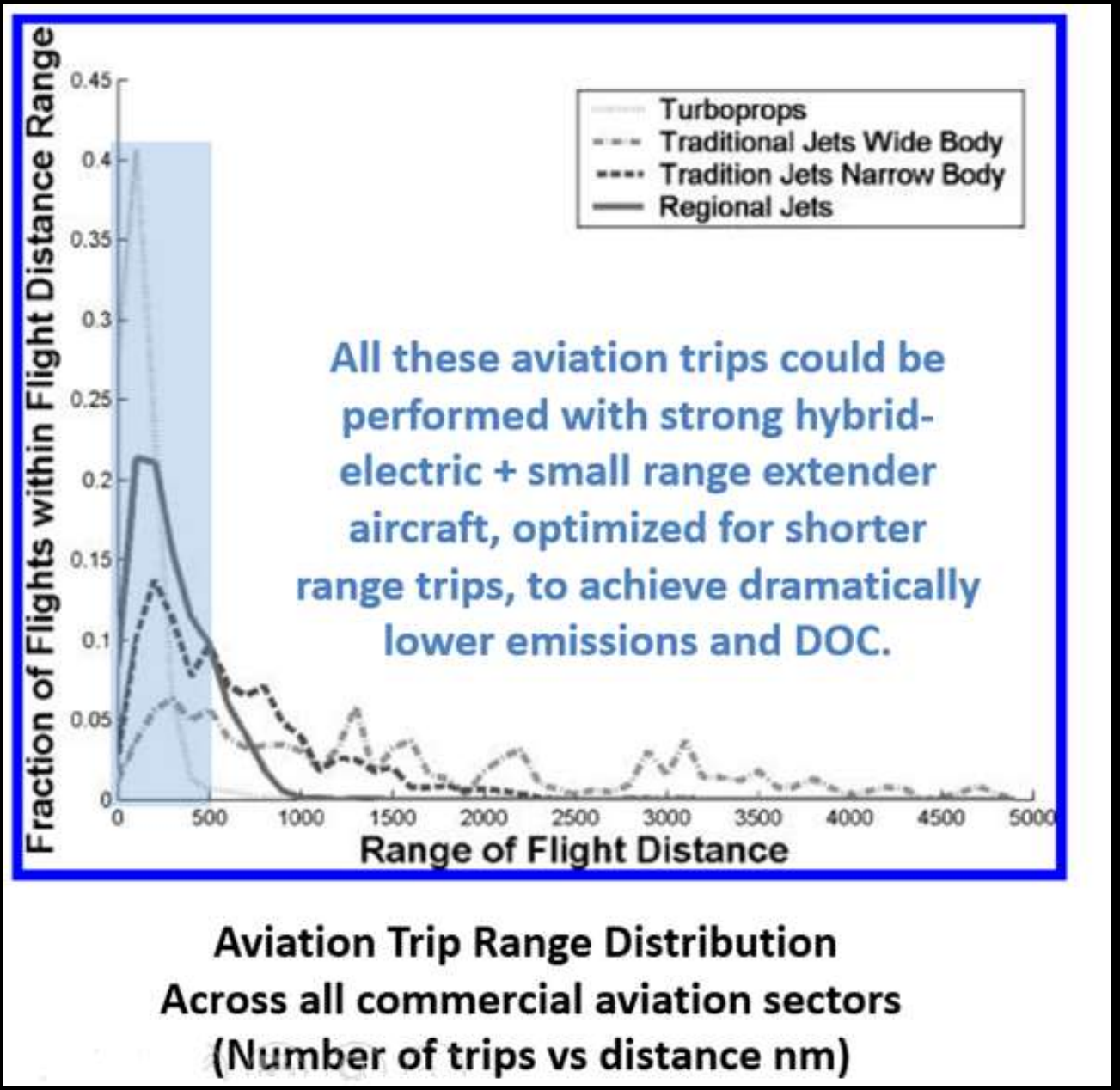
With early adopter market opportunities



Cape Air Based in Hyannis, MA with 1.4 MW solar farm at the airport

Cape Air Operations 750K pax/year using ~100 Cessna 9 passenger aircraft

Distributed Electric Propulsion evolutionary path forward across sectors



Aviation Trip Range Distribution
Across all commercial aviation sectors
(Number of trips vs distance nm)