Turboprop Electric Propulsion With and Without Synergistic Integration and Operations

Kevin R. Antcliff
NASA Langley Research Center

Background Credit: Sefjo, available at https://commons.wikimedia.org/wiki/File:Czech_Airlines_ATR_42-500_OK-KFO.jpg, licensed under CC BY-SA 3.0.

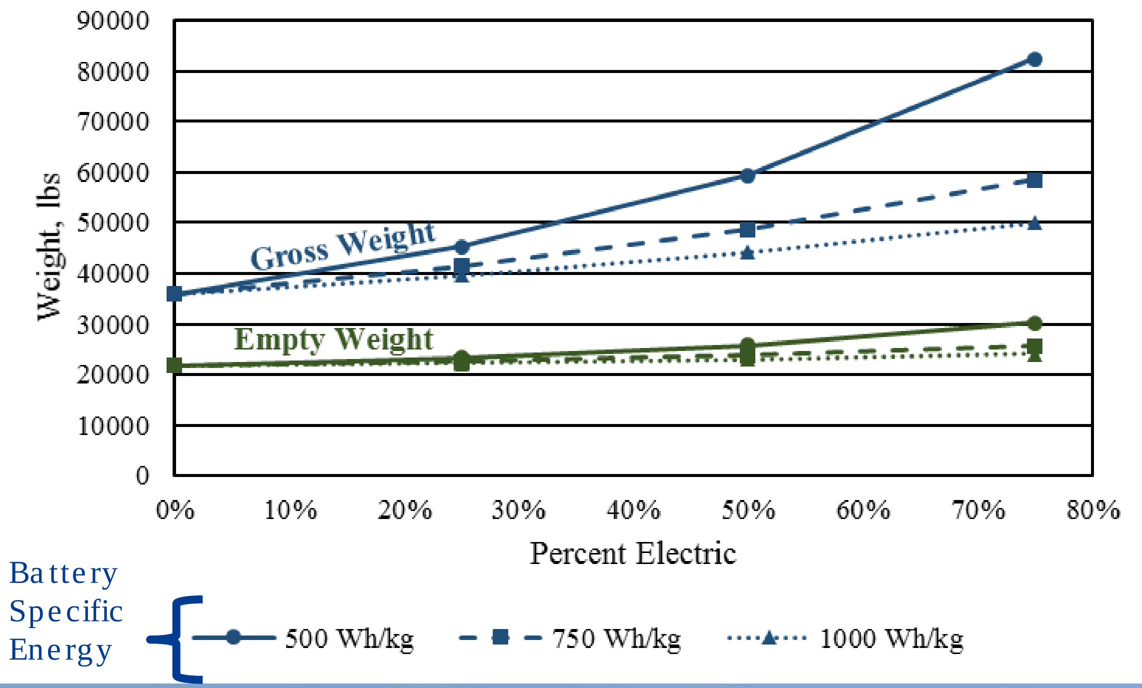
Turboprop Electric Propulsion
<u>Without</u>
Synergistic Integration or Operations

Determine if a hybrid-electric ATR-42-like 48 passenger aircraft introduced in the 2030 time frame would be competitive with conventional aircraft for a regional, short-haul mission.

Assumptions:

- Year 2030 airframe technology level
- Parallel hybrid-electric propulsion (with varying degrees of hybrid)
- Battery portion fixed at 25%, 50%, 75% power required
- Battery specific energy of 500, 750, and 1000 Wh/kg
- Identical propulsion-airframe integration as baseline
- Wing loading and thrust-to-weight optimized
- Range: 600 nm

Without Synergistic Integration or Operations



Gross Weight and Empty Weight versus Percent Electric

Comparing the advanced 75% electric to 0% electric:

At 500 Wh/kg:

- 2.3X heavier TOGW

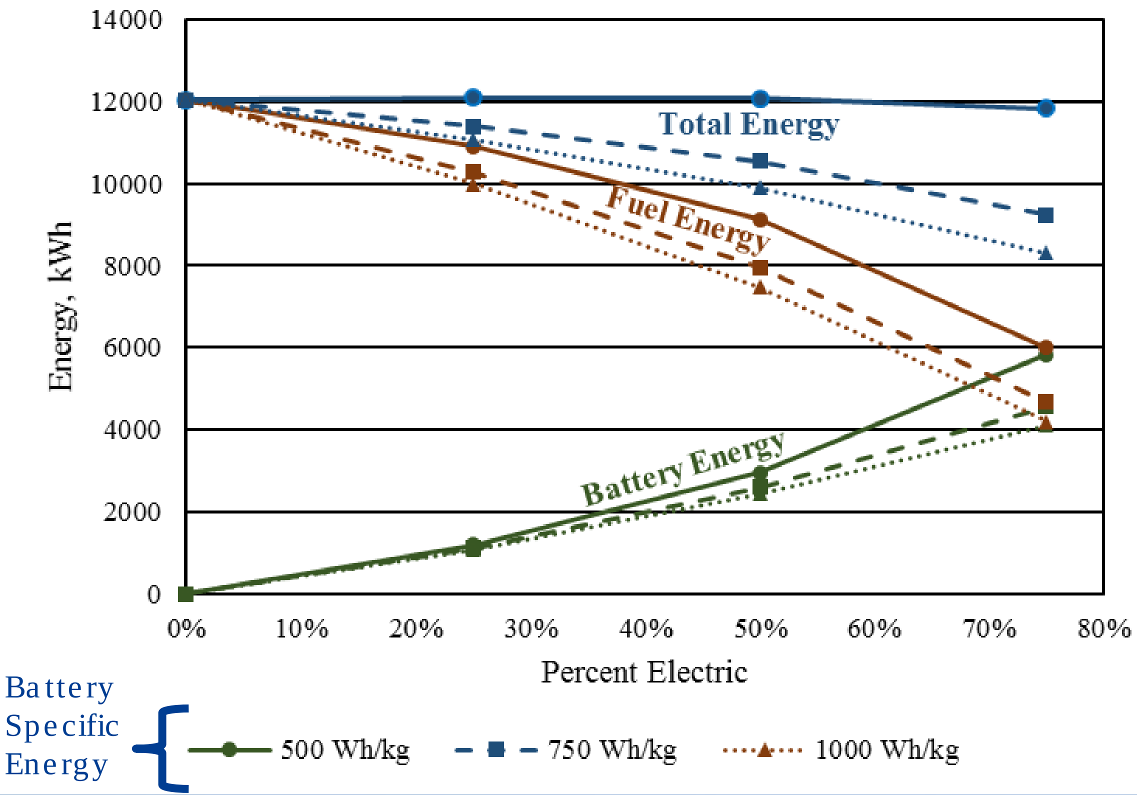
At 750 Wh/kg:

- 63% heavier TOGW

At 1000 Wh/kg:

- 39% heavier TOGW

Without Synergistic Integration or Operations

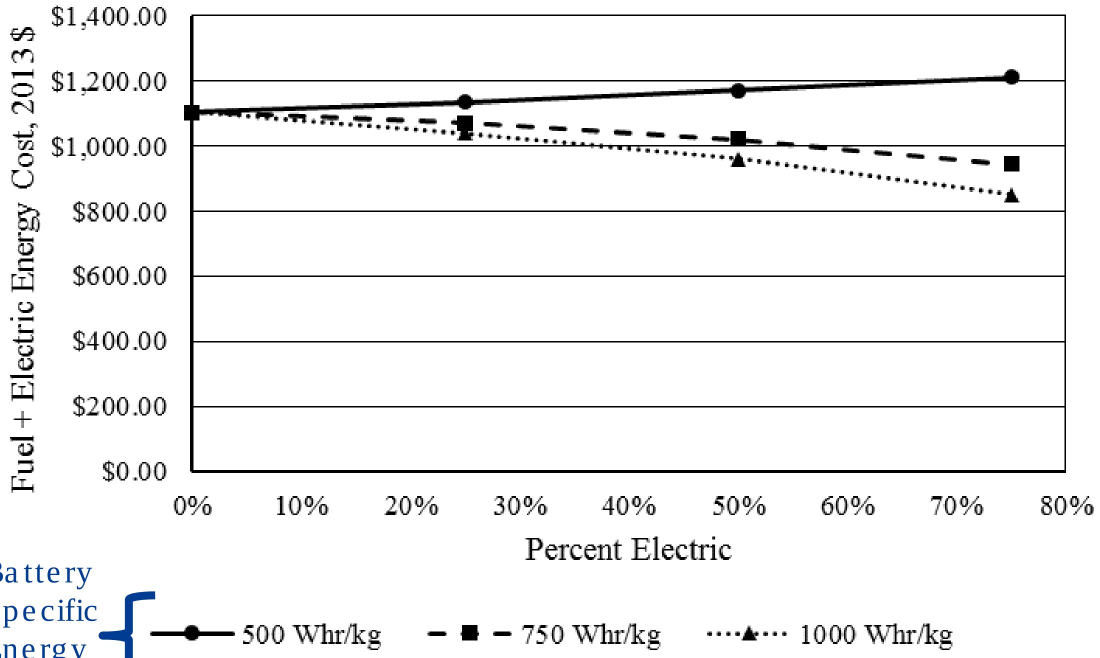


Battery, Fuel, and Total Energy versus Percent Electric

- Battery energy and fuel energy are equal at ~76% electric power
- At 500 Wh/kg, total energy remains relatively constant
- At 750 and 1000 Wh/kg, the total energy decreases significantly

Without Synergistic Integration or Operations

Total Energy Cost versus Percent Electric



Battery Specific Energy

- *$3.33 per gallon for Jet-A*
- *$0.11 per kWh for electricity*

Comparing advanced 75% electric to 0% elec.

At 500 Wh/kg:

- 10% more

At 750 Wh/kg:

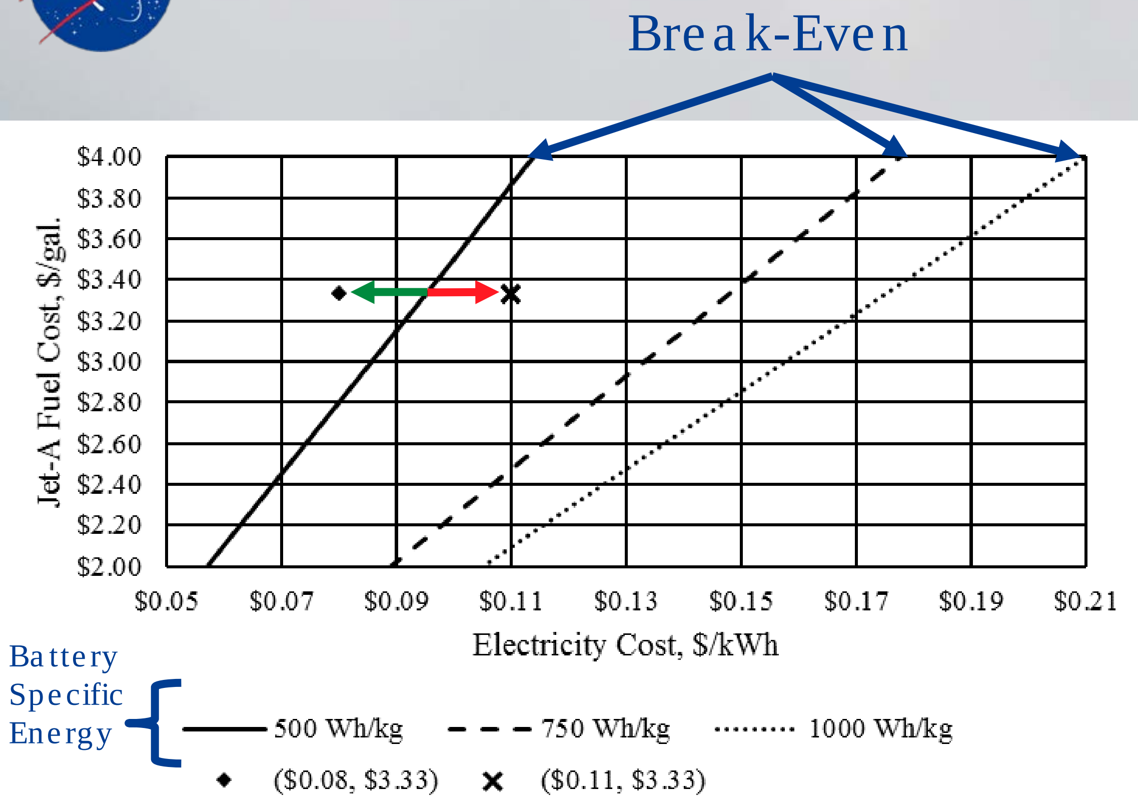
- 14% less

At 1000 Wh/kg:

- 23% less

Without Synergistic Integration or Operations

Break-Even Energy Cost for the 75% Electric Advanced Turboprop



Fuel cost constant at $3.33 per gallon of Jet-A

Break-Even at $0.11 per kWh:

- 9% increase in total energy cost

Break-Even at $0.08 per kWh:

- 14% decrease in total energy cost

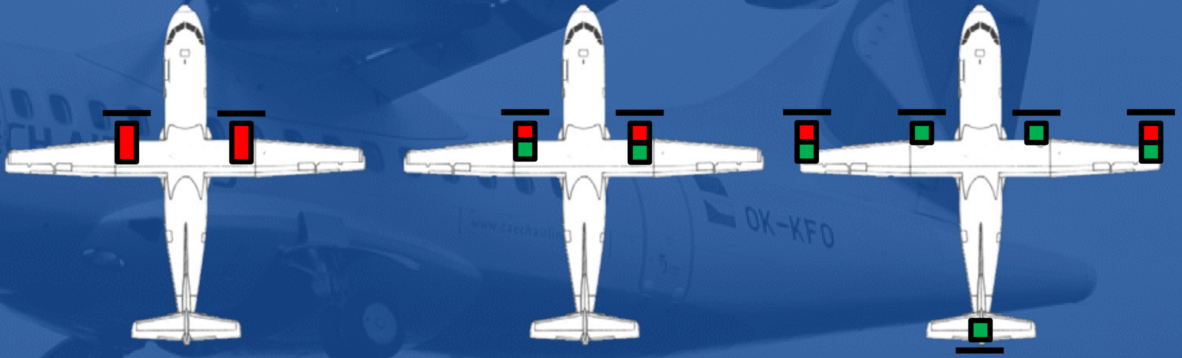
Design Range Sensitivity (500 Wh/kg)

% Electric	Units	0%	75%		0%	75%	
Range	nm	600	600		300	300	
Total Fuel Weight	lb	3,340	1,720		2,310	850	
Total Batt. Weight	lb	0	39,590		0	15,270	61%
OEW	lb	21,800	30,300		21,300	24,200	
TOGW	lb	35,900	82,400	130%	34,500	51,100	48%
Elec. Energy Cost	$	0	660		0	260	
Fuel Energy Cost	$	1,110	550		610	220	
Total Energy Cost	$	1,100	1,210	9%	610	480	21%

Turboprop Electric Propulsion
With
Synergistic Integration and Operations

Integration:

Electric propulsion enables increased freedom to locate the propulsors wherever a synergistic benefit can be achieved



Baseline Without Synergy With Synergy

: Turbine : Turbine-Electric Motor : Electric Motor

Assumption: Consistent payload, fuselage parameters, & design constraints

Turboprop Electric Propulsion
With
Synergistic Integration and Operations

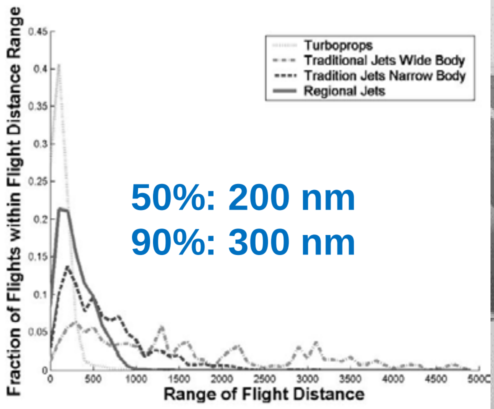
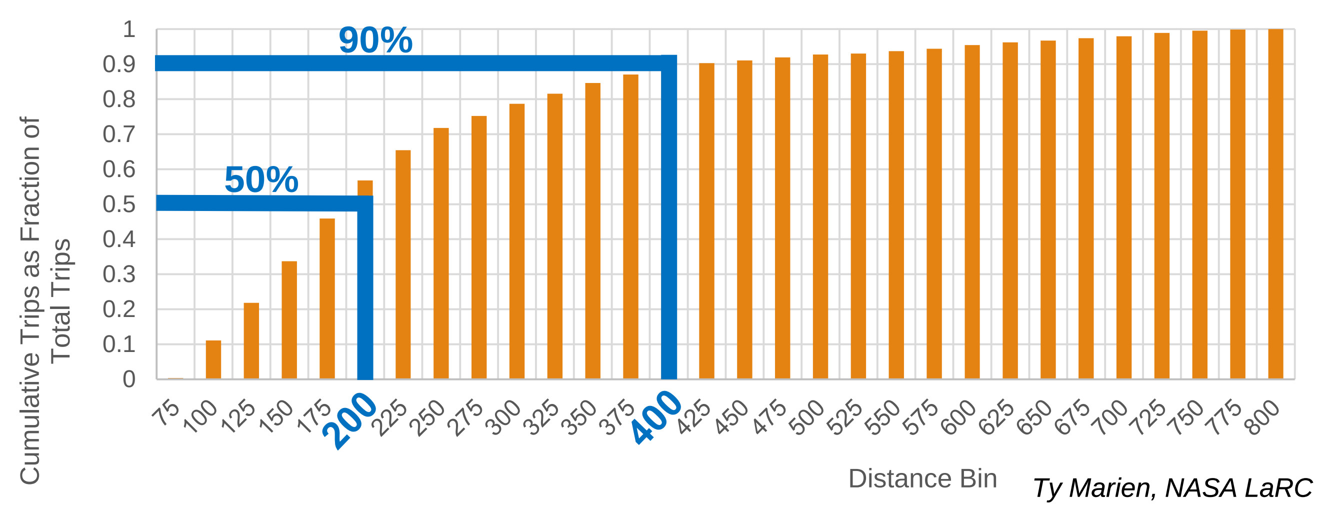


Fig. 6 January 2003 distance histogram.

Growth and Operating Patterns of Regional Jets in the U.S.
Mozdzanowska, Hansman

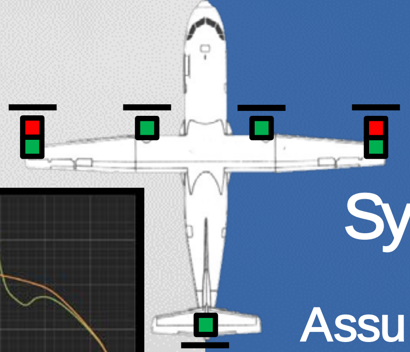
Operations:

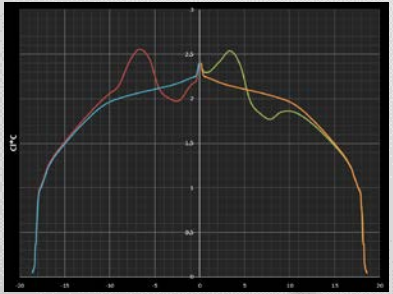
Sizing a hybrid-electric propulsion system should be based on the distribution of trip range required.

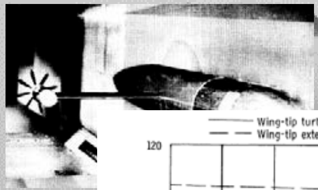


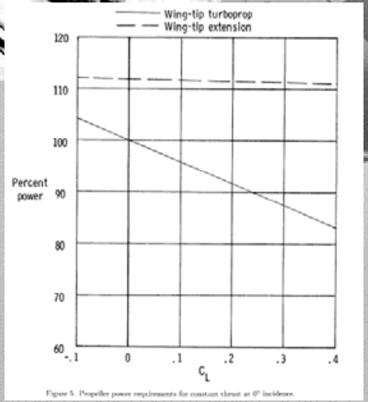
Assumption: Capturing 90% of total trips is an acceptable market strategy

Turboprop Electric Propulsion
With
Synergistic Integration and Operations









NASA TP-2739

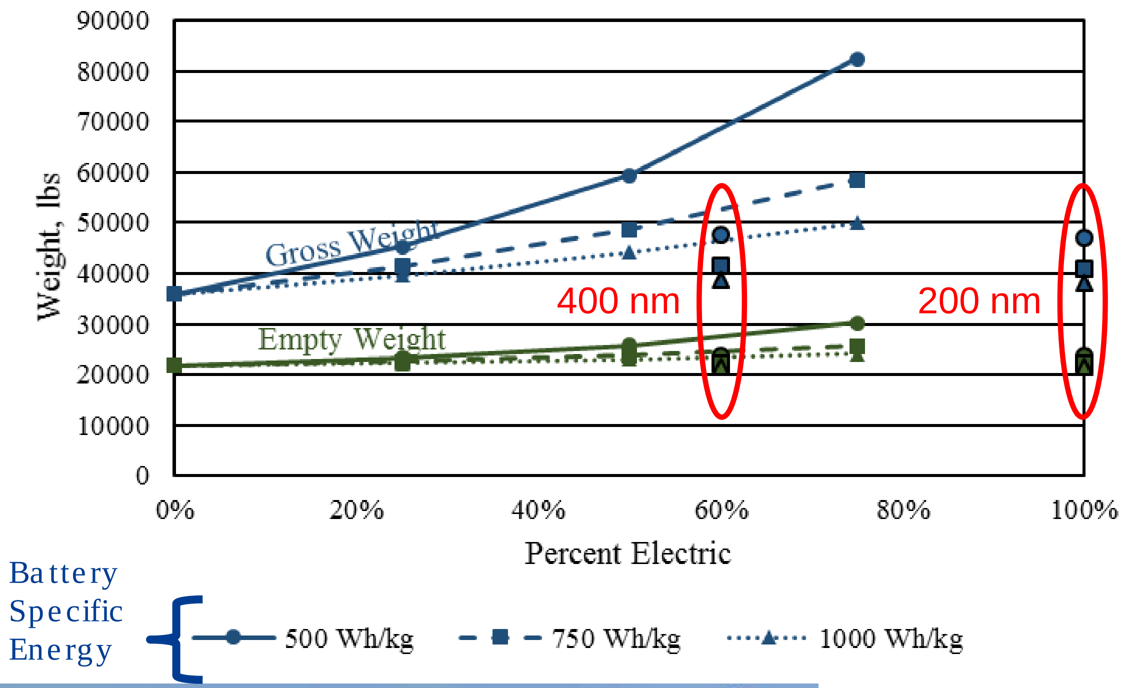
Assumptions:

- Removal of the inboard turboprop propulsion effects results in a **10% improvement in the induced drag** (non-optimal spanwise lift loading caused by propeller swirl, engine wing blockage effects, lift losses)

- Wingtip propulsion integration to take advantage of the vortex flow field results in a **18% increase in effective propulsive efficiency** (induced drag reduction).

- Fuselage BLI Propulsion results in a **10% increase in effective propulsive efficiency** (wake filling, inviscid effects)

With Synergistic Integration and Operations



Unlabeled data: 600 nm

Gross Weight and Empty Weight versus Percent Electric

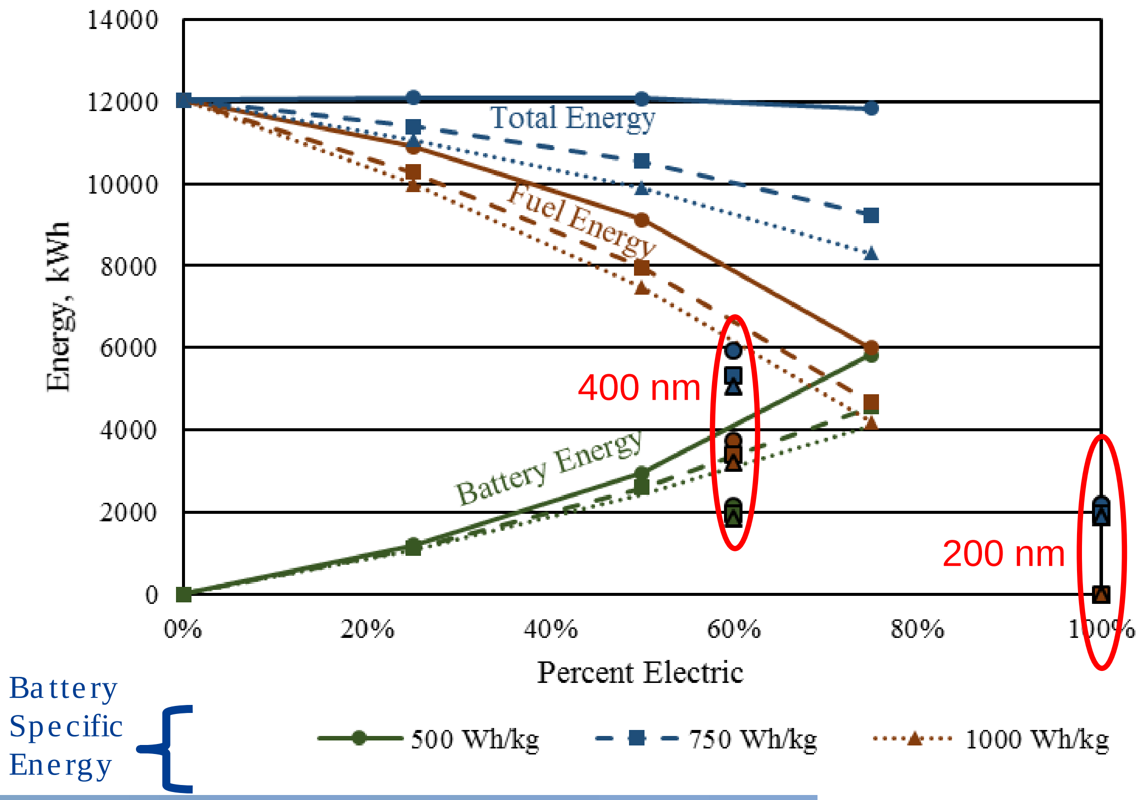
Comparing the non-synergistic 75% electric to the synergistic hybrid and all-electric models:

At 500 Wh/kg:
- 72, 75% heavier TOGW

At 750 Wh/kg:
- 41, 43% heavier TOGW

At 1000 Wh/kg:
- 29, 31% heavier TOGW

Battery, Fuel, and Total Energy versus Percent Electric



Unlabeled data: 600 nm

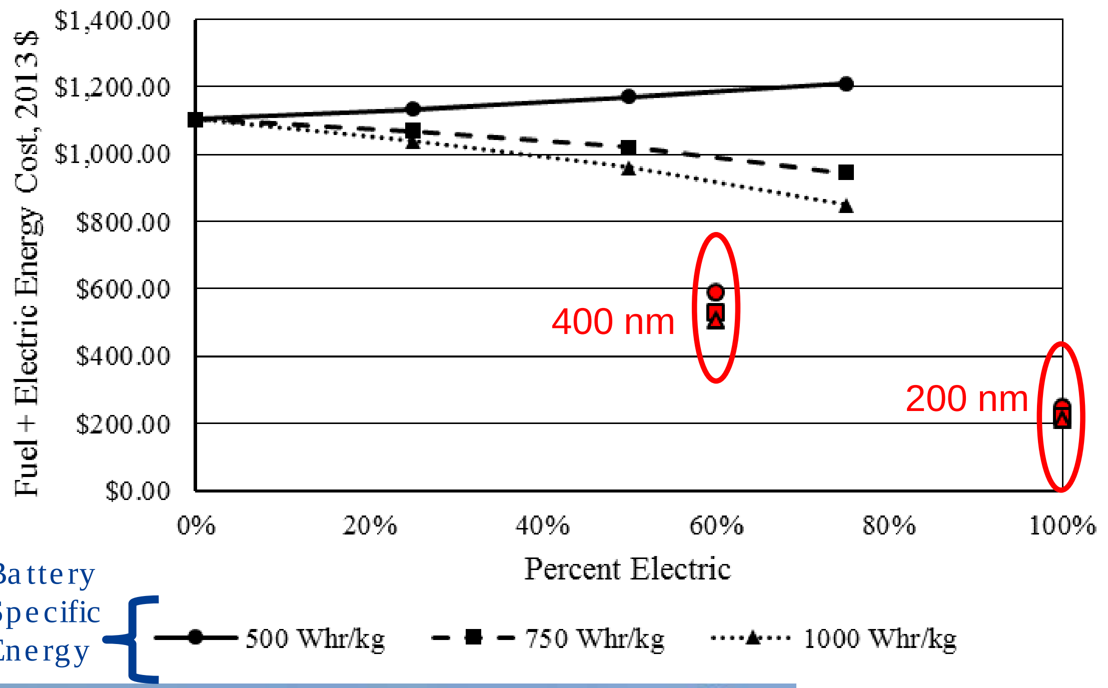
Total energy decrease from non-synergistic approach at 500 Wh/kg:

- 400 nm: 50% decrease
- 200 nm: 82% decrease

Synergistic integration yields a low sensitivity to changing battery specific energy

With Synergistic Integration and Operations

Total Energy Cost verus Percent Electric



Unlabeled data: 600 nm

- *$3.33 per gallon for Jet-A*
- *$0.11 per kWh for elec.*

*Comparing non-synergistic 75% electric a*t 500 Wh/kg to:

- 400 nm: 51% decrease
- 200 nm: 80% decrease

Concluding Remarks

- Designing with a reduced range and a propulsion integration strategy that is synergistic to electric propulsion dramatically improves the economics
- Relatively near-term batteries are as compelling of an economic proposition as long-term batteries

Caveats

- Battery amortization was not included in these costs (however, the economics are still quite compelling)
- This study hinges of operators who will accept an aircraft capable of only flying a 400 nm distance
- Current regulations do not allow an aircraft to start a gas turbine during flight- this would have to be altered for this concept

Thank You!

Any Questions?

Acknowledgements:

→ Mark Guynn
→ Mark Moore
→ Michael Patterson