“The engineers had the firm belief that the hybrid was the answer to all these questions -- oil depletion, emissions, and the long-term future of the automobile society -- but the business people weren't in agreement.”

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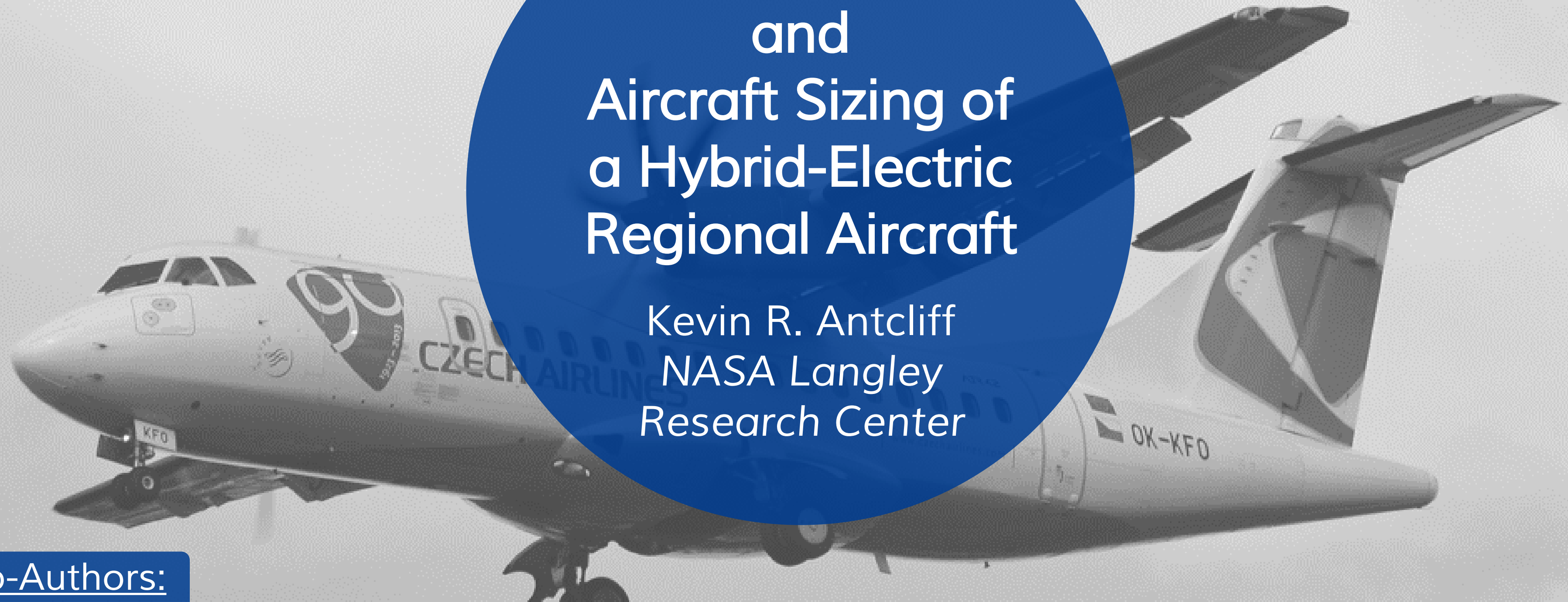
8,000,000
Worldwide Sales of Toyota Hybrids as of July 2015

Mission Analysis and Aircraft Sizing of a Hybrid-Electric Regional Aircraft

Kevin R. Antcliff
NASA Langley Research Center



Co-Authors:
Mark D. Guynn, Ty V. Marien, Douglas P. Wells
NASA Langley Research Center
Steven J. Schneider, Michael T. Tong
NASA Glenn Research Center

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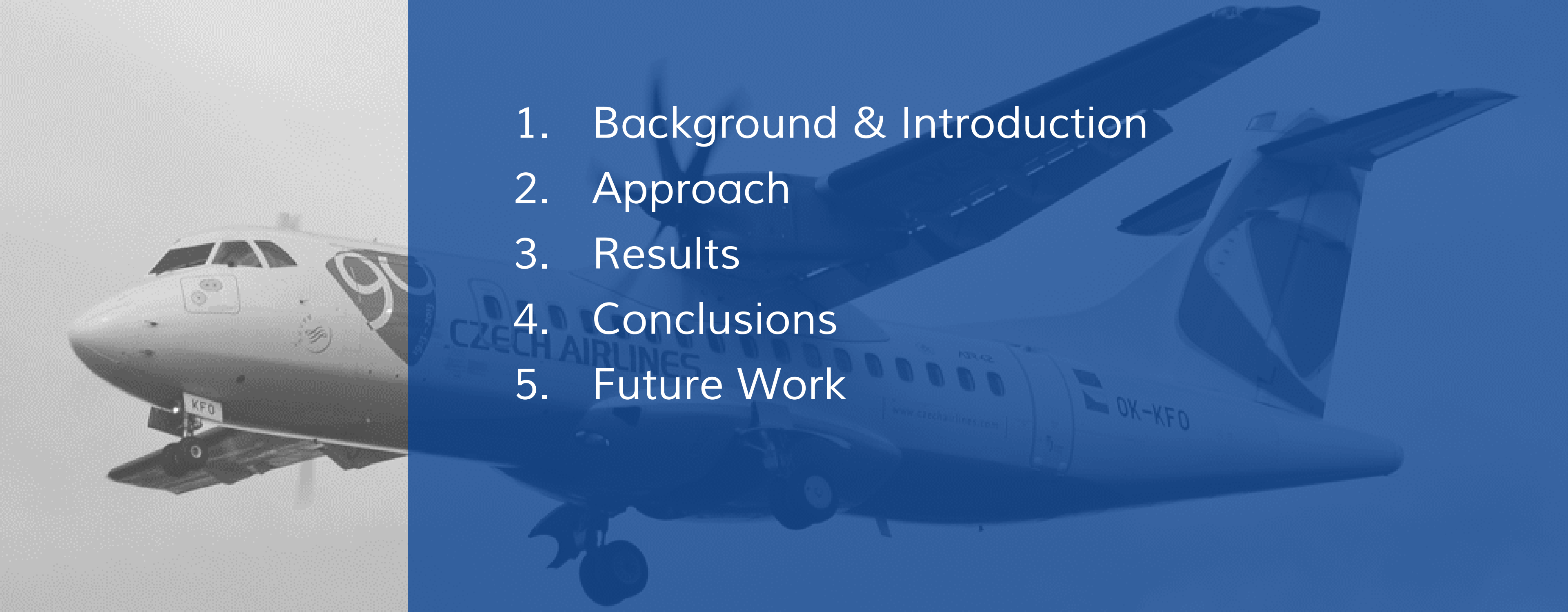
AIAA SciTech 2016, January 4-8, 2016
San Diego, California



Outline

1. Background & Introduction
2. Approach
3. Results
4. Conclusions
5. Future Work

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1. Background & Introduction

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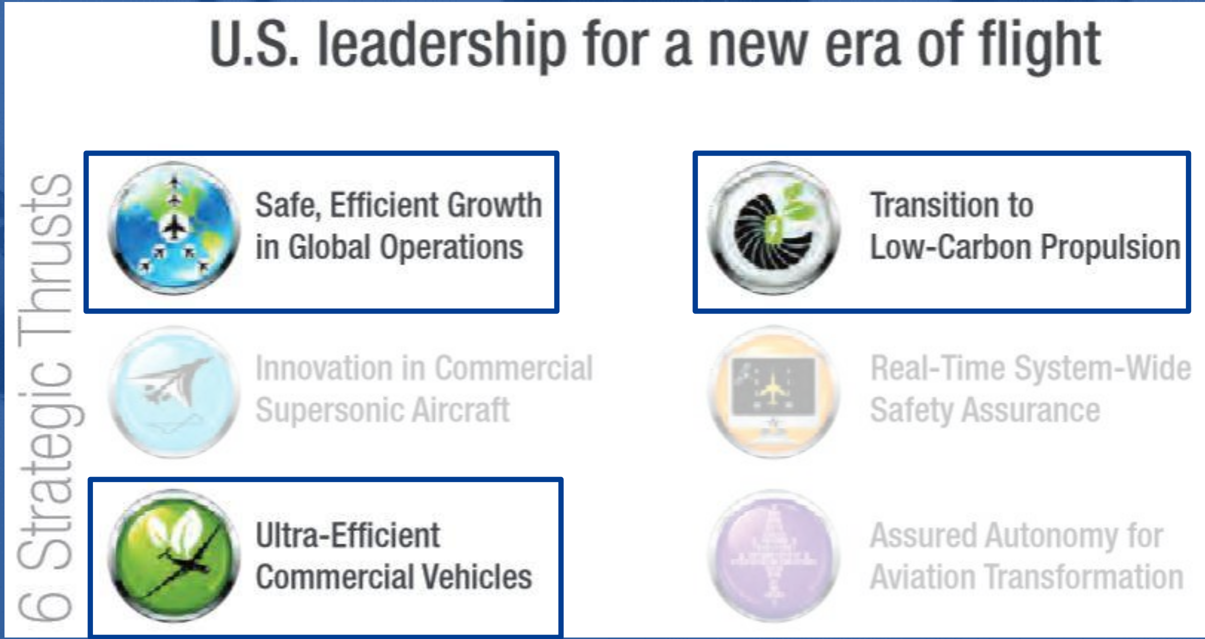
Short Haul Revitilization Study

MOBILITY THROUGH THE AIR IS VITAL TO ECONOMIC STABILITY, GROWTH, AND SECURITY AS A NATION

National Plan for Aeronautics R&D and Related Infrastructure



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Many Experimental Aircraft...
...Even More to Come

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Top-Left: Adambro, available at https://commons.wikimedia.org/wiki/File:Boeing_Fuel_Cell_Demonstrator_AB1.JPG, licensed under CC BY-SA 3.0.

Middle-Left: Bernd Sieker, available at https://commons.wikimedia.org/wiki/File:Airbus_E-Fan_%2814088845198%29.jpg, licensed under CC BY-SA 2.0.

Objective

- Would a parallel hybrid-electric aircraft introduced in the 2030 time frame be competitive with conventional aircraft for a regional, short-haul mission?

Output

- Total energy consumption
- Total projected energy cost
- TOGW, OEW, Battery Weight, etc.

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2. Approach

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Study Decisions and Assumptions

- Year 2030 technology
- Parallel hybrid-electric propulsion
- Various levels of battery specific energy
- No deviation from propulsion airframe integration of baseline aircraft
- No change to airframe design parameters
- Fixed level of electrification for full mission
- Tools used include: OpenVSP, FLOPS, NPSS, WATE++, and ModelCenter

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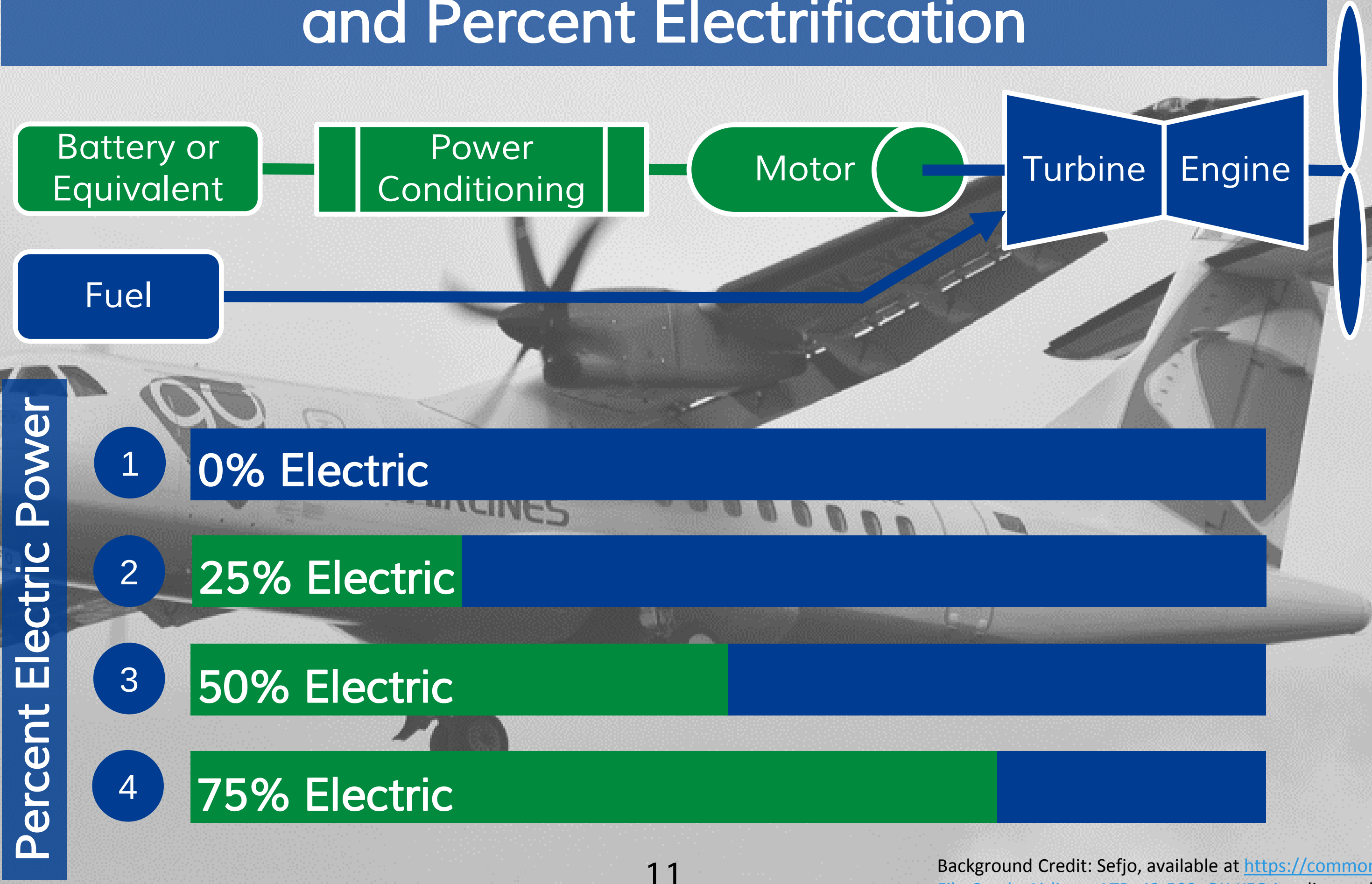
Parallel Hybrid-Electric Propulsion and Percent Electrification



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Baseline Aircraft

ATR 42-500

48 pax

840 nm

Mach 0.475

5% Reserve

87 nm Alternate Airport

45 min. hold

Ty V. Marien. *Seat Capacity Selection for an Advanced Short-Haul Aircraft Design* 3:30 – 4:00pm Today

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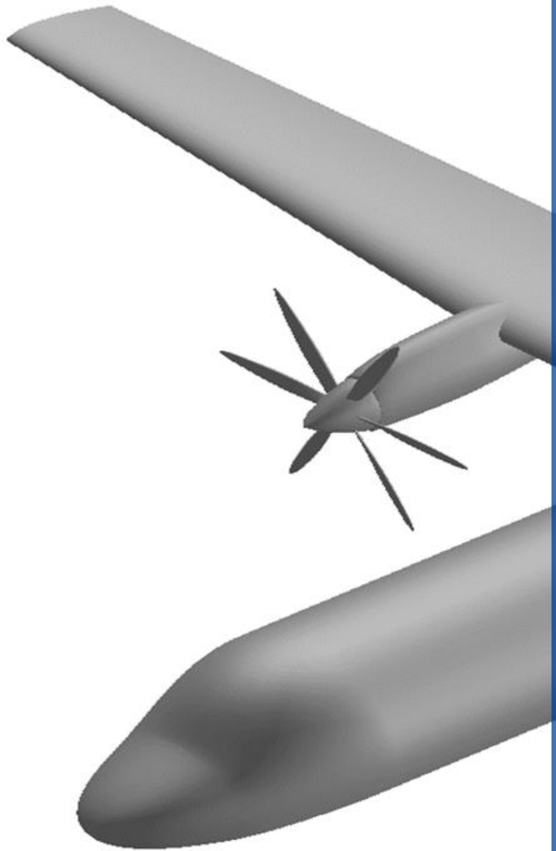
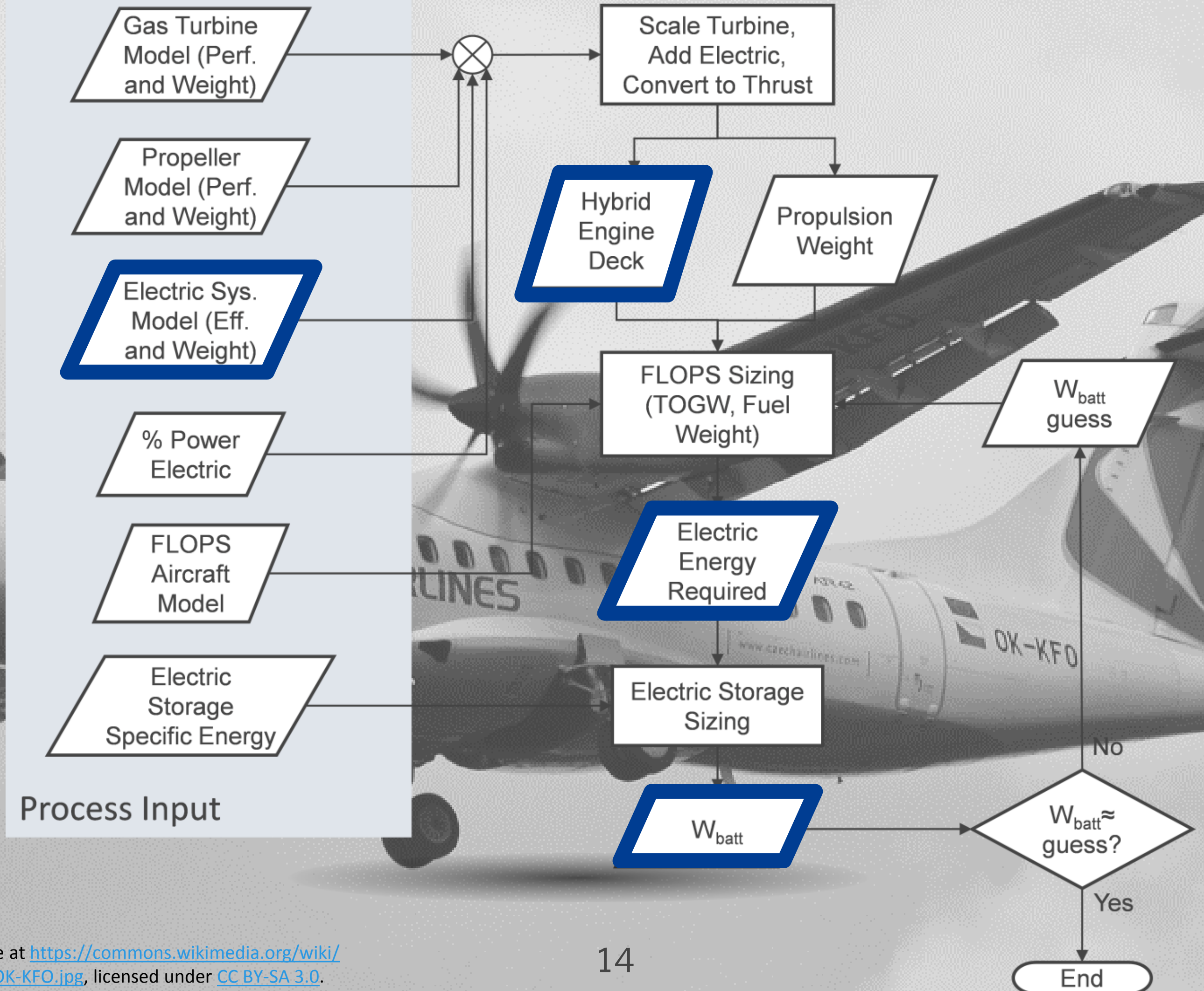


Advanced Aircraft (Year 2030)

1. Baseline aircraft modeled
2. Calibrated to match ATR 42-500
3. Decreased to the study mission range of 600 nm
4. Advanced technology factors introduced
5. Advanced aircraft sized for minimum gross weight to meet study mission
6. Hybrid-electric engine deck introduced
7. Optimized with hybrid-electric propulsion and additional battery weight

Multi-Disciplinary Optimization Framework



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3. Results

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Modified NASA PW127E-like Performance: Current and Advanced

	Units	2015	2030
Mach		0	0
Altitude	ft	0	0
Throttle	%	100	100
Power	hp	2,400	2,400
Jet Thrust	lbf	287	287
SFC	lbm/hr/hp	0.474	0.427
Mass Flow	lbm/s	12.15	10.65
OPR		14.7	14.7

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Modified NASA PW127E-like Weights: Current and Advanced

Component Weights (lb)	Current 2400 SHP	Advanced 2400 SHP	Advanced Hybrid-Electric Gas Turbine + Electric Motor		
			1800 + 600 SHP	1200 + 1200 SHP	600 + 1800 SHP
Turbine Engine + Gearbox	1054	1010	819	626	410
Propeller System + Nacelle	782	781	766	752	737
Electrical System	-	-	135	270	405
Total System	1836	1791	1720	1648	1552

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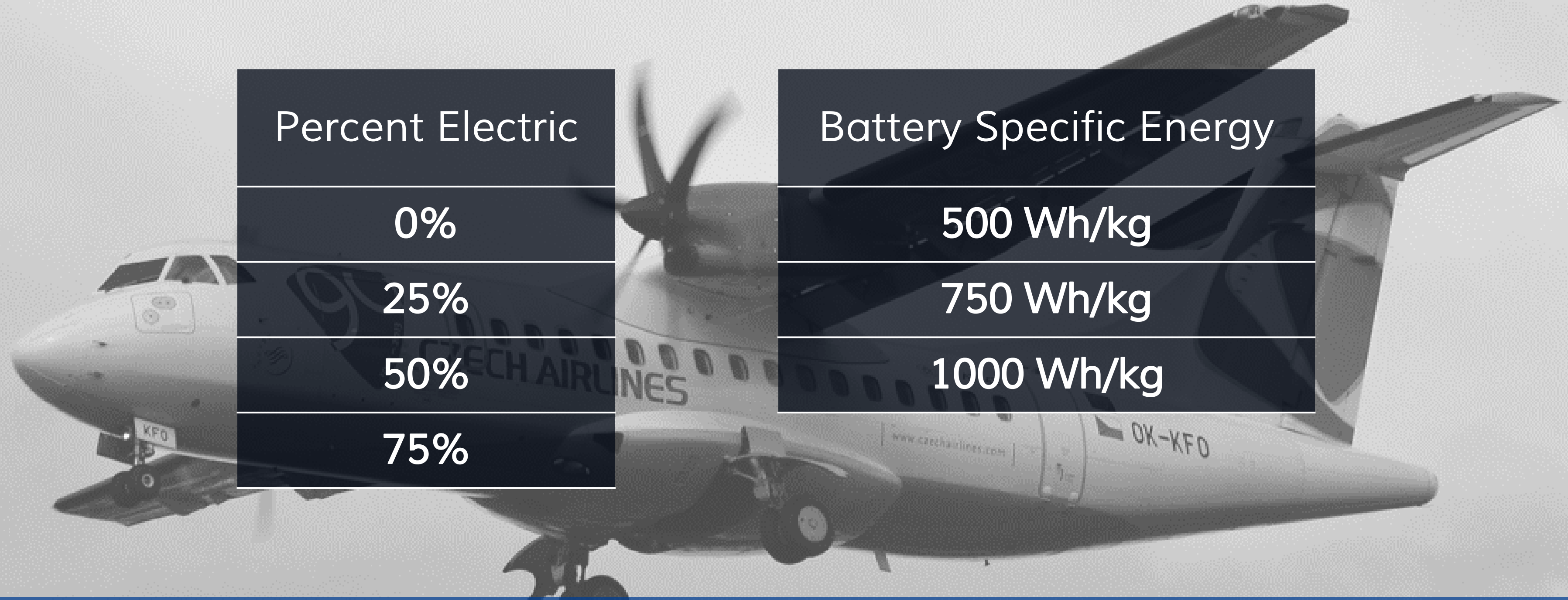
Study Cases at 600 nm



Percent Electric
0%
25%
50%
75%

Battery Specific Energy
500 Wh/kg
750 Wh/kg
1000 Wh/kg

Battery Specific Energy = BSE in the following slides

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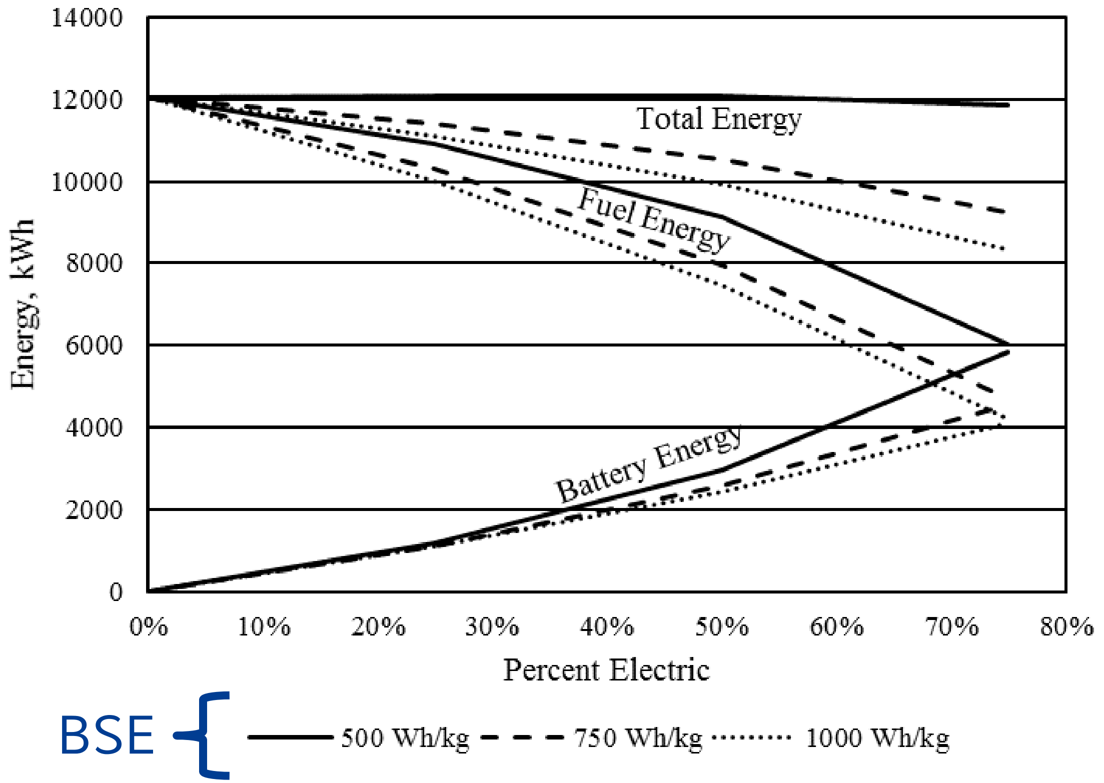
Battery, Fuel, and Total Energy versus Percent Electric



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

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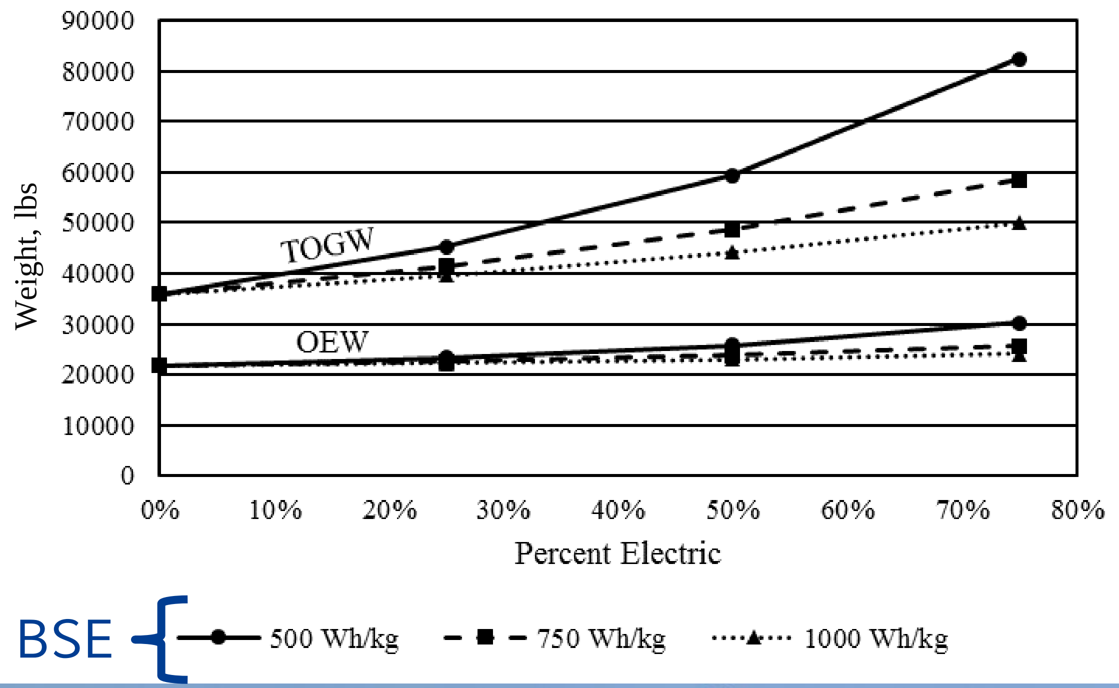
TOGW and OEW versus Percent Electric



Comparing our 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

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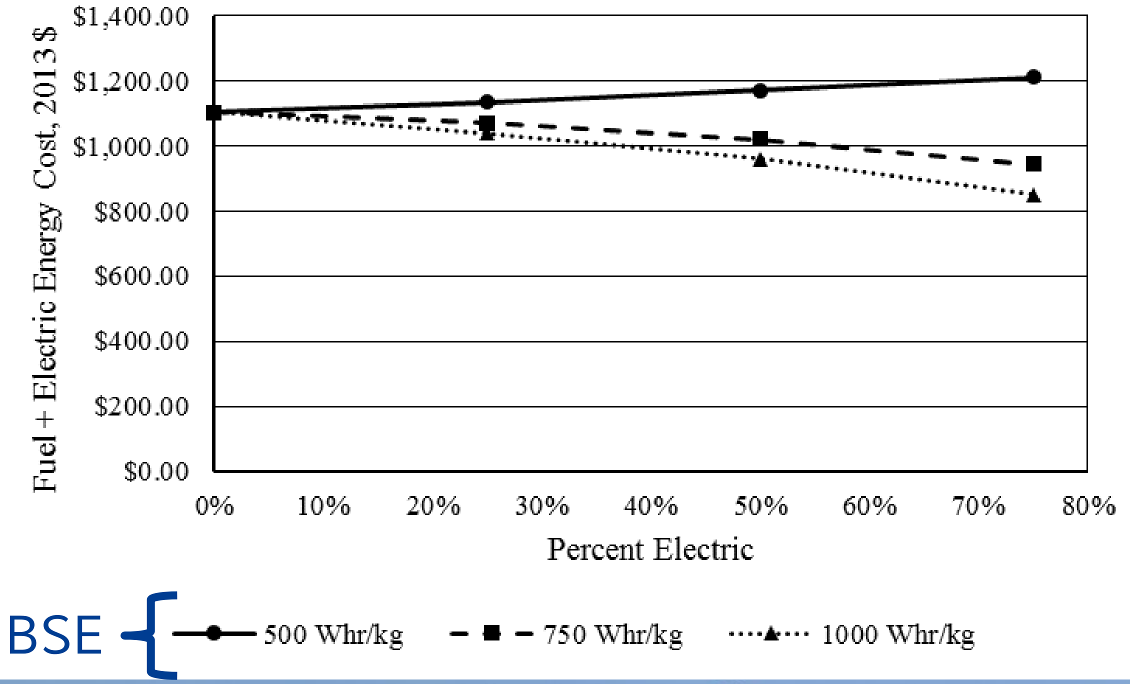
Total Energy Cost verus Percent Electric



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

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

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Design Range Sensitivity (500 Wh/kg)

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

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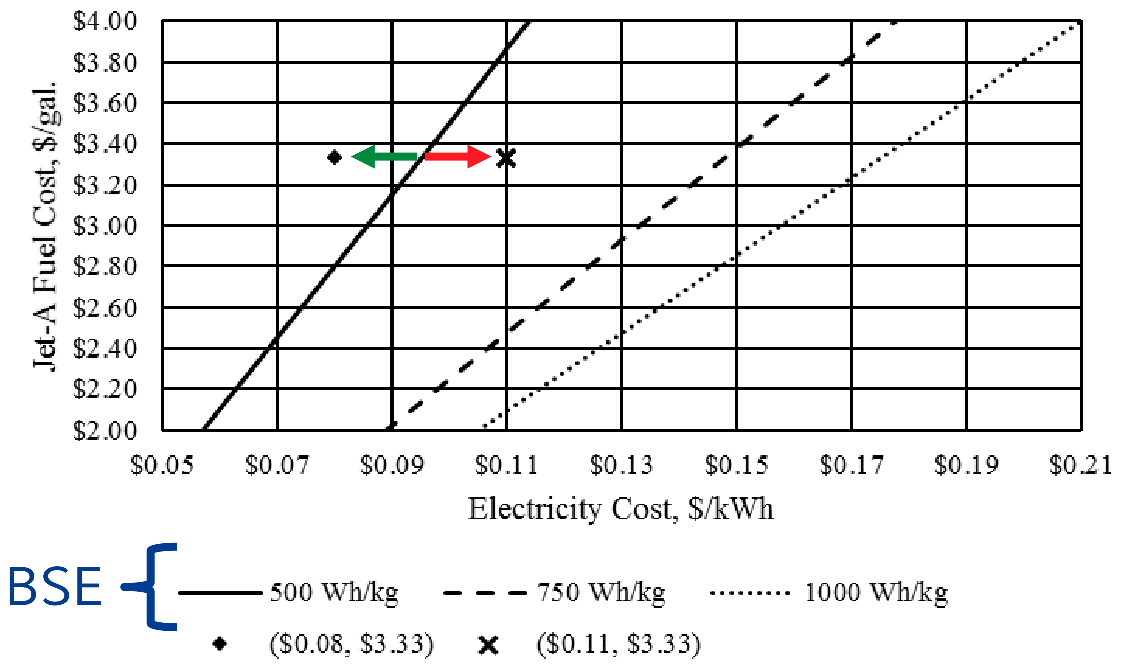
Break-Even Energy Cost for the 75% Electric Advanced Turboprop



Prediction 1:

- $3.33 per gallon of Jet-A
- $0.11 per kWh for elec.
- 9% increase in total energy cost →

Prediction 2:

- $3.33 per gallon of Jet-A
- $0.08 per kWh for elec.
- 14% decrease in total energy cost ←

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4. Conclusions

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Conclusions

- At 600 nm, BSE must be greater than 500 Wh/kg to yield energy consumption parity
- At 300 nm, BSE can be less than 500 Wh/kg for energy consumption parity
- The economics for a parallel hybrid vehicle at 600 nm and 500 Wh/kg is less attractive than for a conventional unless the electricity to fuel cost ratio decreases
- The 75% electric advanced turboprop needs a BSE of 600 Wh/kg to operate in total energy cost parity

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5.
Future Work

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Future Work

- Explore additional comparison metrics (life cycle emissions, noise, etc.) for hybrid and conventional aircraft
- Determining the BSE needed at a given design range to achieve a given objective
- Alternative propulsion-airframe integration that takes advantage of additional flexibilities provided by electric propulsion (distributed electric propulsion, series-hybrid, etc.)
- Optimize additional airframe design parameters to ensure a match between airframe and propulsion

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Thanks!

Any questions?

Acknowledgements:
This work was funded by NASA's Advanced Air Transport Technologies project.

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