Thin-Haul Aviation Operations Study

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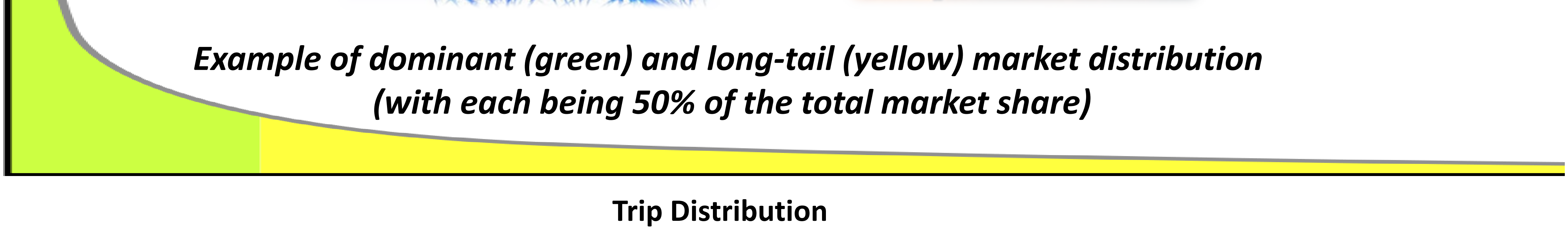
Outline

- Introduction to “thin-haul” operations
- Dramatic reductions in operating costs anticipated by Distributed Electric Propulsion (DEP) aircraft concepts
- Focus of our research in DEP-enabled thin-haul operations

What are Thin-Haul Operations?

Thin-Haul Commuters *provide Essential Air Services to small communities with 'thin' passenger trip distributions. New business models and technologies are developing across many industries to capture 'long-tail' markets instead of focusing only on dominant markets.*

(see The Long-Tail: Why the Future of Business is Selling Less of More)



This is a market valued by the U.S. Congress, which provided $263M in funding to Essential Air Services (EAS) in 2015 to assure aviation access to over 160 remote and underserved communities.

Thin-Haul: Many Business Models

- Scheduled Operations
  - Small capacity aircraft
    - < 10 seats
  - Short missions
    - <300 nm
  - Limited ground infrastructure
    - Limited TSA involvement
    - Small terminals / No gates

- On-Demand Operations
  - Taxi & charter operators
    - Piston aircraft
    - Multiengine jet aircraft
  - Regional to intercontinental ops.
  - Limited ground infrastructure
    - Usually operate from FBOs
    - No TSA involvement

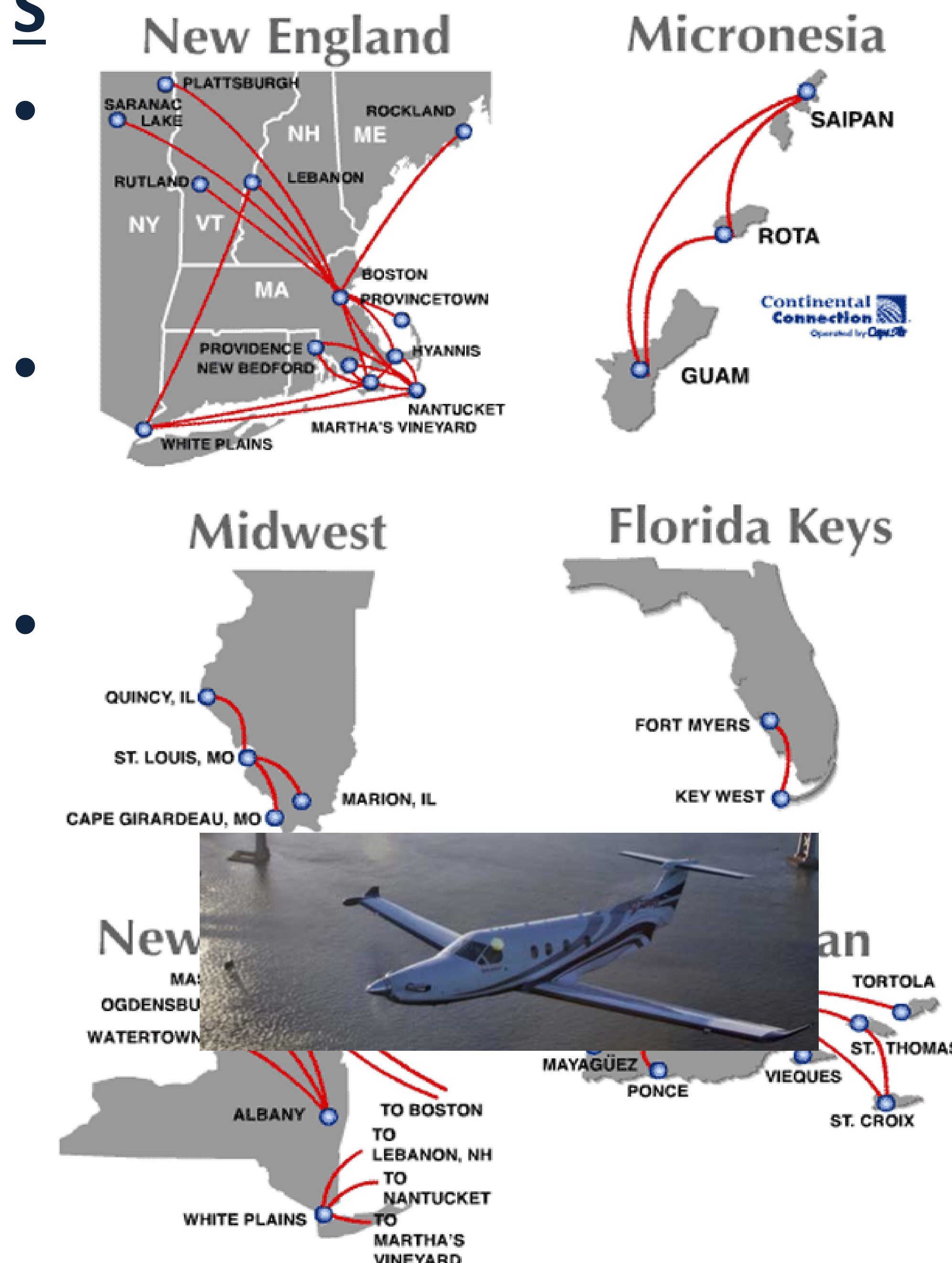
MOKULELE AIRLINES — Cape Air — SURFAIR — BOUTIQUE AIR — UBER — NETJETS — LINEAR air — IMAGINE Air — JETLINX

THE WALL STREET JOURNAL.

Airbus to Join Forces With Uber for On-Demand Helicopter Service, CEO Says

Updated Jan. 18, 2016 10:13 a.m. ET

Thin Haul: Two Successful Operators



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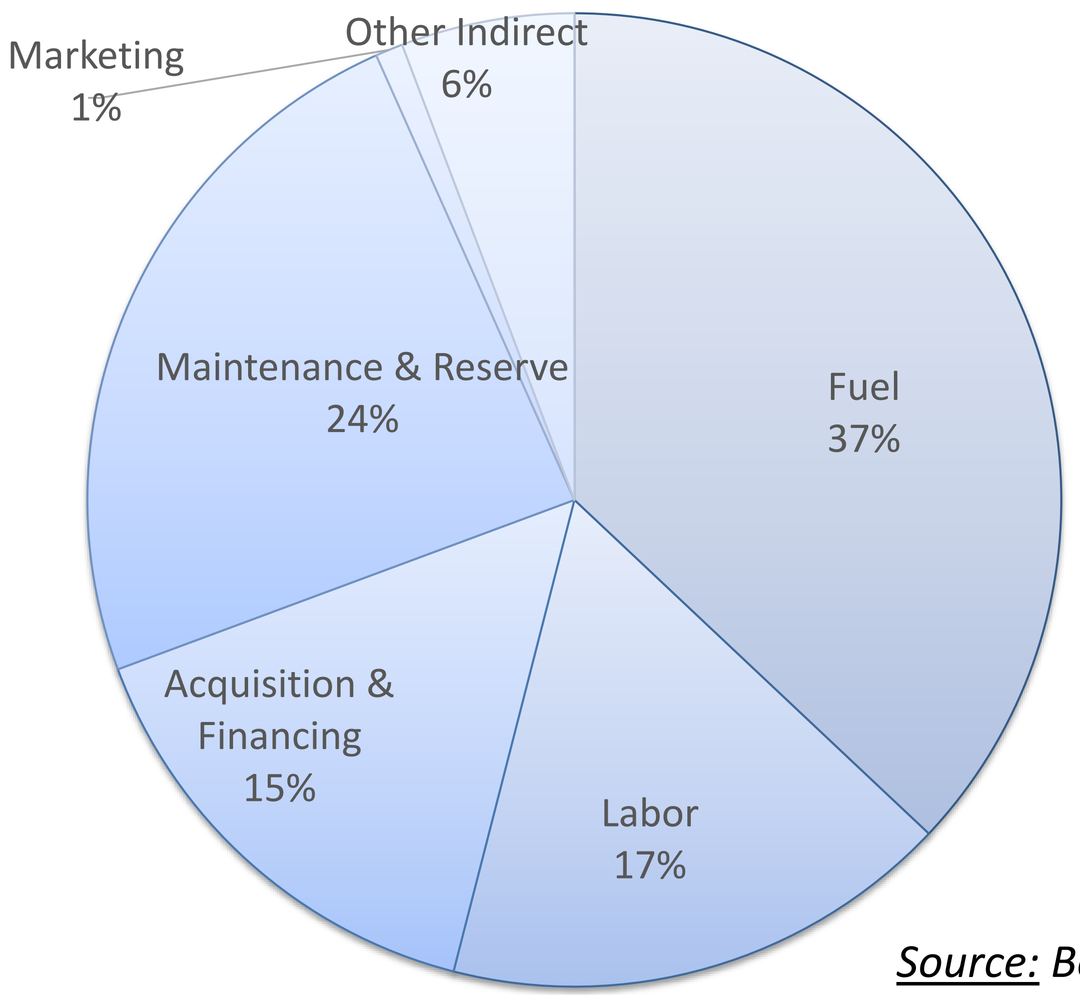
Thin-Haul Operating Costs



<u>Source:</u> BoutiqueAir EAS application, CNM-DFW, 367nm, 1hr08min, PC-12

Fuel is typically one of the largest cost components and its price is very volatile

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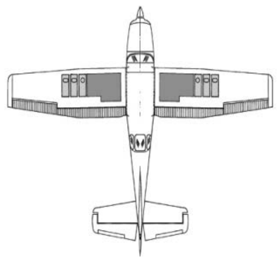
What Drives Fuel Burn?



Fuel Tank Energy Storage → ICE Shaft Horsepower → Propeller → Airframe Aero → **Specific Range = 1.03nm/lb → 0.19nm/kWh**

Thermal Efficiency = 28%

C402 with Teledyne Continental TSIO-501-E, 300Hp

Cruise 5,000ft, ISA, 148kt: 2 x 72 lb/hr @ 49.1% BHP

Shaft Power = 0.491*300hp*0.745kW/hp = 109 kW

Power from Fuel = 72lb/hr*5.48kWh/lb = 394 kW

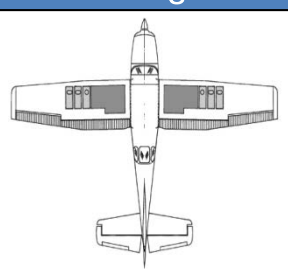
Thermal Efficiency = 109/394= 28%

Specific Range = (148nm/hr) / (144lb/hr) = 1.03 nm/lb

Specific Range = 148 / (144*5.39kWh/lb) = 0.19 nm/kWh

Fuel Tank Energy Storage → Turboprop Shaft Horsepower → Propeller → Airframe Aero → **Specific Range = 0.64nm/lb → 0.12nm/kWh**

Thermal Efficiency = 23%



PC-12 with Pratt & Whitney PT6A-67P, 1200Hp

Cruise 20,000ft, ISA, 205kt: 322lb/hr and 19psi @ 1,700rpm

(19psi indication converts to 1614ft.lb)

Shaft Power=1700rpm*1614ft.lb*0.000142kW.min/ft.lb=389kW

Power from Fuel = 322*5.39kWh/lb=1736 kW

Thermal Efficiency = 389/1736= 23%

Specific Range = (205nm/hr) / (322lb/hr) = 0.64 nm/lb

Specific Range = 205nm/hr / (322*5.39) = 0.12 nm/kWh

DEP: A Technology to Revolutionize Thin-Haul

Battery Energy Storage → DC/AC Inverter → Electric Motor → DEP- Enhanced Airframe Aero

Efficiency = 98%

Efficiency = 97%

Overall Efficiency = 95%

$$P_{req.} = \frac{1}{\eta} \cdot \frac{W \cdot V}{(L/D)} \qquad \left(L/D\right)_{MAX} = \frac{1}{2} \cdot \sqrt{\frac{\epsilon \cdot \pi \cdot AR}{C_{D,0}}}$$

"Specific Range" = 0.71nm/kWh

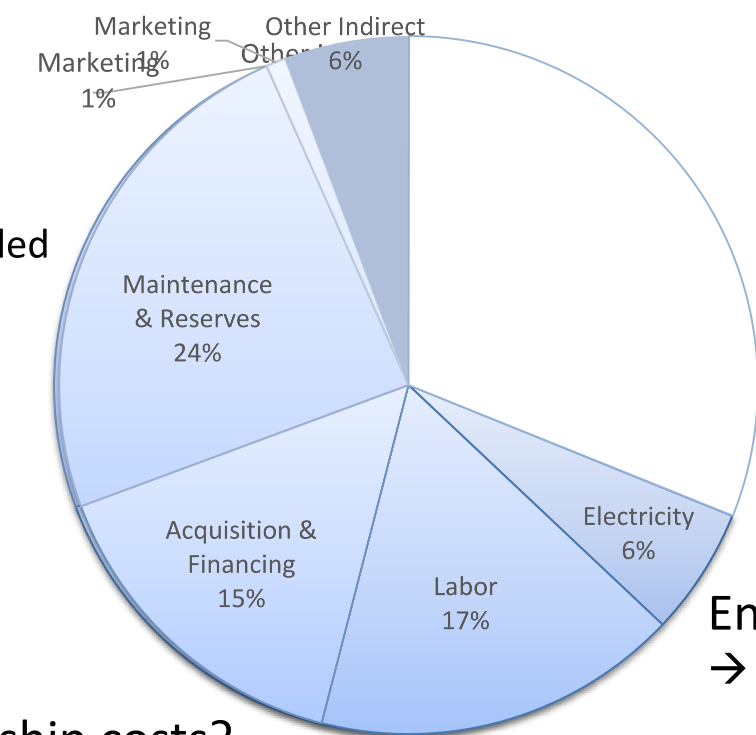
(Initial Distributed Electric Propulsion concept studies)

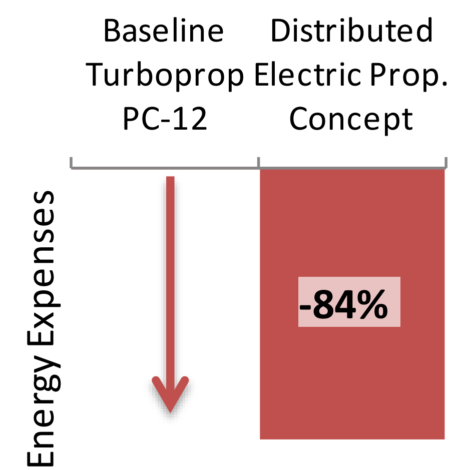
	Best Case Scenario (New England Area)	**Likely Scenario** (New England Area)	**Worst Case Scenario** (New England Area)
AVGAS 100LL (US$/gal)	4.04	5.00	8.99
Jet A-1 (US$/gal)	2.80	4.45	7.95
Industrial Electricity (US$/kWh)	0.38	0.12	0.16
C402 Piston with AVGAS-100LL	0.65 $/nm	0.81 $/nm	1.45 $/nm
PC12 Turboprop with Jet A1	0.80 $/nm	1.03 $/nm	1.84 $/nm
Initial DEP Concept Studies	0.03 $/nm	0.16 $/nm	0.19 $/nm

Dramatic improvements in energy conversion efficiency and higher L/D significantly decreases energy costs

Impacts of DEP on Operating Costs

<u>Baseline:</u> BoutiqueAir EAS application, CNM-DFW, 367nm, 1hr08min, PC-12





Maintenance & Reserves costs?

→Do long lives of motors decrease needed reserves and routine maintenance?

→Do short lives of batteries necessitate increased reserves?

Ownership costs?

→How do we design the operation to maintain aircraft utilization while considering battery charging?

Energy costs?

→ Can optimization of charging strategies further reduce electricity expenses? (peak/day/night rates)

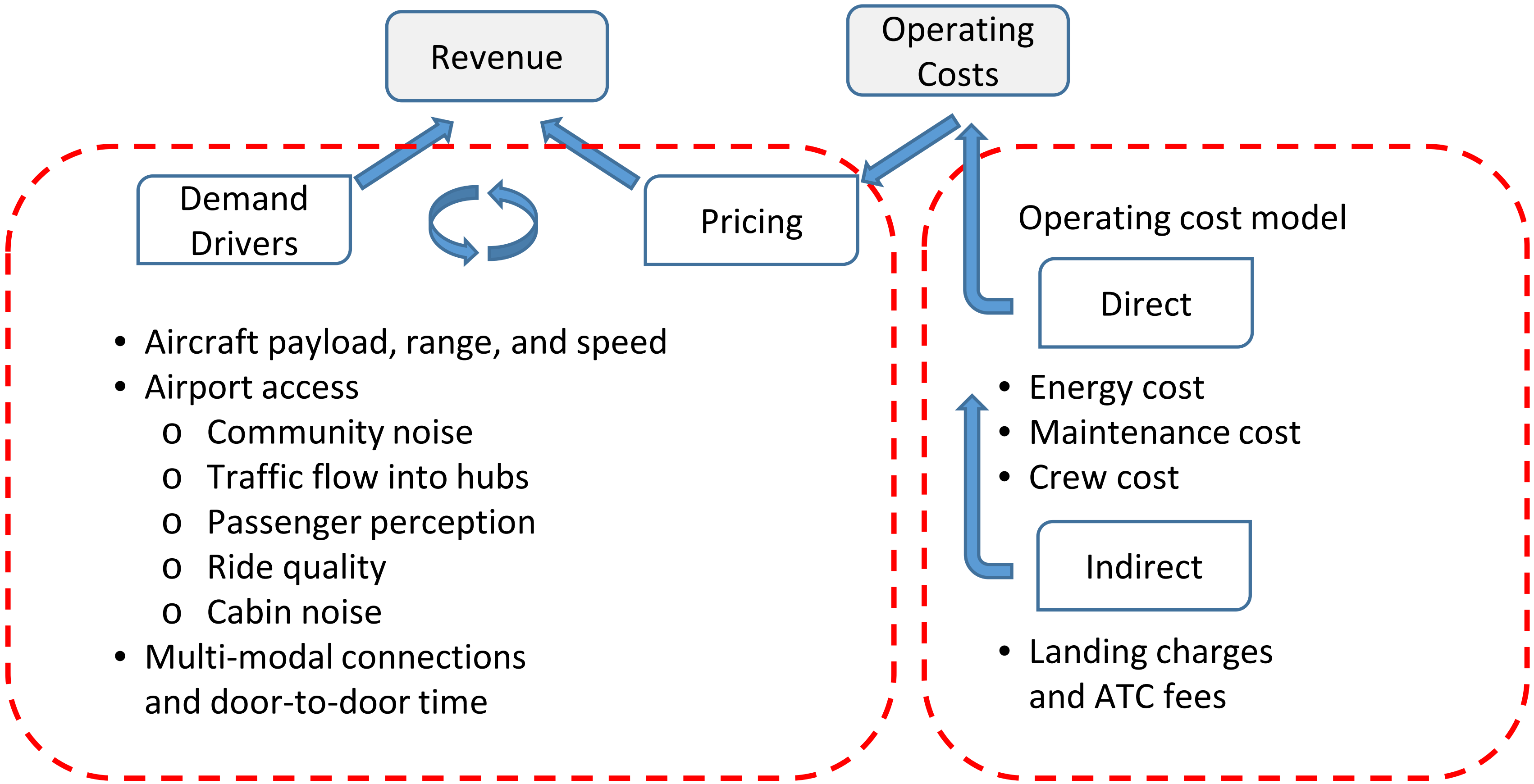
Labor costs?

→ How much can single pilot operations decrease labor costs?

→ Can battery charging strategies be devised to manage turn around times and prevent idling crews at out-stations?

Many possibilities for reducing overall operating expenses by design of DEP aircraft and associated operating paradigms

Reducing Operating Costs Drives Demand



Pricing, demand, and operating costs are strongly coupled:

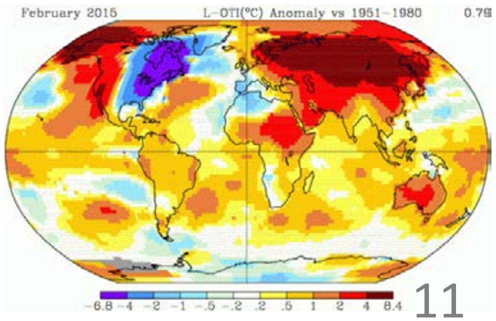
- Route level elasticity / Short haul ops. / North America : ~ -1.5, e.g. a 10% decrease in price results in an increase in demand by more than 15% (IATA Air Travel Demand – April 2008)
- Thin-haul operations even more elastic due to modal substitution on very short routes

Strong incentive to decrease operating costs in order to lower ticket prices and stimulate demand…

Focus of Our Research

- Model existing thin-haul commuter networks
  - Cape Air, Surf Air, and ImagineAir as case studies

- Model the impact of DEP aircraft concepts developed by Joby Aviation on operations in these thin-haul networks
  - Operations infrastructure & schedule
  - Operator economics (DOC & IOC)
  - Emissions (lowering aviation CO_2)



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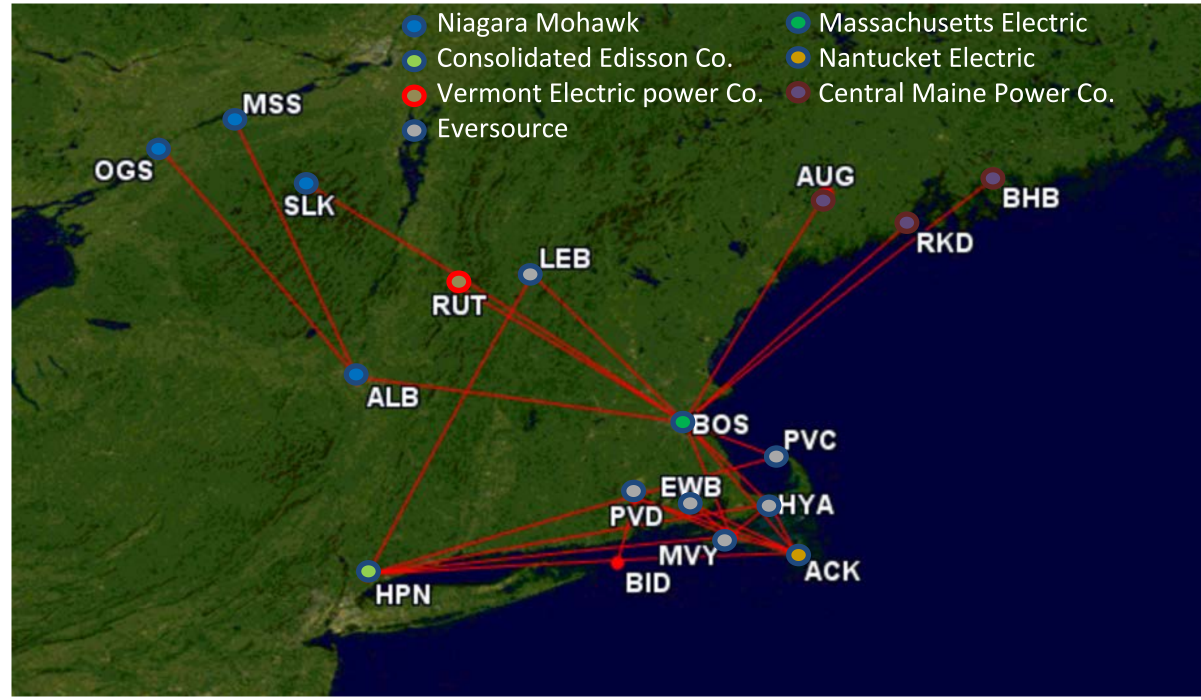
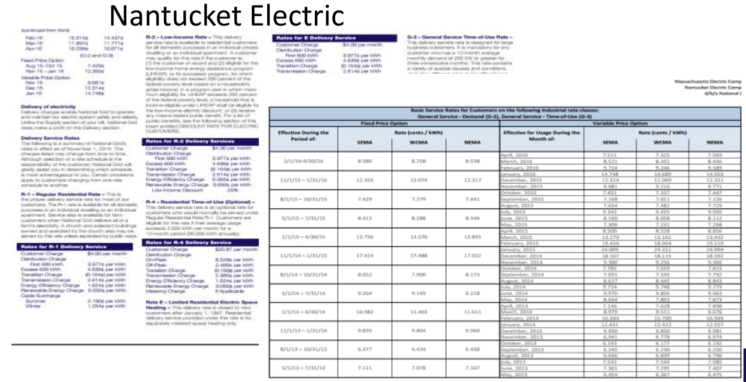
Electrical Usage Study for Cape Air-like Network

- To estimate electrical energy expenses, data such as the following are required:
  - Utility provider
  - Electricity price schedule
  - Peak power
  - Energy need



- Airports in the Cape Air network are served by many different utility providers
  - Eversource
  - Niagara Mohawk
  - …

Nantucket Electric



- Each provider has its own electricity price schedule
  - Ex: Nantucket Electric

G-3 – General Service Time-of-Use Rate – This delivery service rate is designed for large business customers. It is mandatory for any customer who has a 12-month average monthly demand of 200 kW or greater for three consecutive months. This rate contains a variety of special clauses and conditions, including different rates during "Peak" and "Off-Peak" hours, which are defined later in this document.

Rates for G-3 Delivery Service	
Customer Charge	$200.00 per month
Distribution Charge	
Demand	$3.92 per kW
Energy On-Peak	1.347¢ per kWh
Energy Off-Peak	0.594¢ per kWh
Transition Charge	(0.157)¢ per kWh
Transmission Charge	2.040¢ per kWh
Energy Efficiency Charge	0.987¢ per kWh
Renewable Energy Charge	0.050¢ per kWh
Cable Surcharge	
Summer	2.518¢ per kWh
Winter	2.027¢ per kWh

- Nantucket Electric rates depend on peak power and total energy draw:
  - Estimating peak power ⇔ Estimating number of chargers required
  - Number of chargers ⇔ Number of aircraft that can be recharged simultaneously

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Way Forward and Collaboration…

- Extend computation of energy prices to each airport in case study networks:
  - Estimate peak power at each airport per day
  - Estimate total energy need at each airport per day

→ **Requires collaboration with operators to analyze network schedules, track aircraft tail-numbers, estimate turn around times, and estimate number of simultaneous battery charges**

- Analyze impact of DEP aircraft on operations:
  - Impact on turn around time
  - Impact on rotations of crews
  - Impact on maintenance reserves

→ **Requires collaboration with operators to fully understand multi-faceted operational considerations and constraints**

- Optimize and refine DEP thin-haul concept of operations to improve operating costs, e.g. optimization of battery charge strategies to mitigate impact on utilization and to reduce electricity rates

Questions?