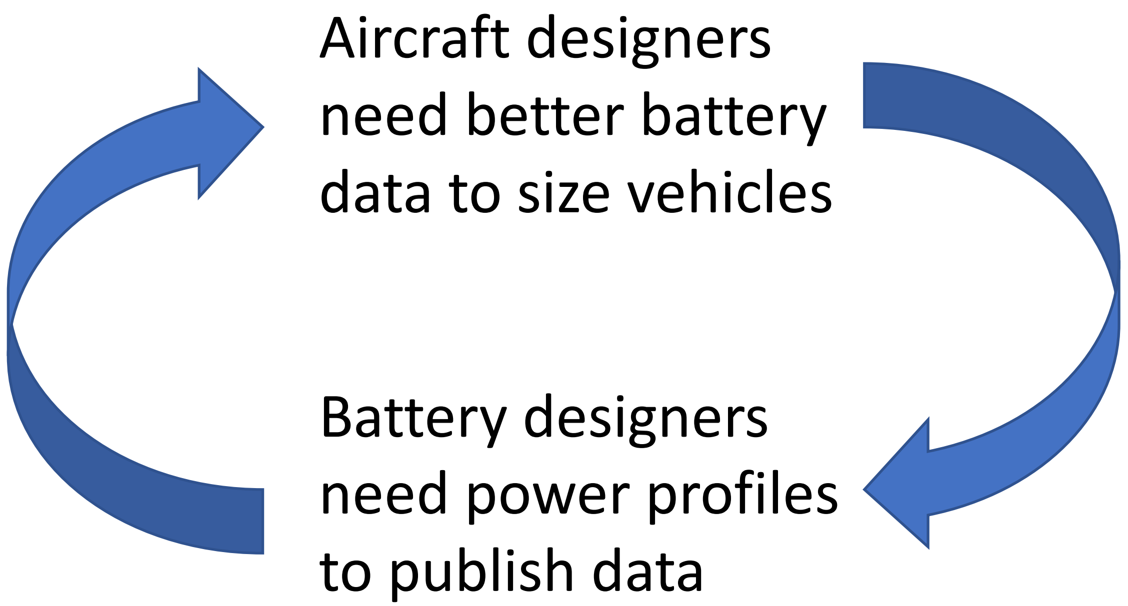
Battery Evaluation Profiles for X-57 and Future Urban Electric Aircraft

Jeffrey Chin
Eliot Aretskin-Hariton, Daniel Ingraham, Dustin Hall,
Sydney Schnulo, Justin Gray, Eric Hendricks
NASA Glenn Research Center
AIAA EATS 2020


Aircraft designers need better battery data to size vehicles
Battery designers need power profiles to publish data

Goals

- Facilitate better design coupling between battery and aircraft designers by highlighting multidisciplinary performance considerations

Overview

- Vehicle & Mission
- Optimization Environment
- Battery/Vehicle Coupling
- Results

Vehicle and Mission

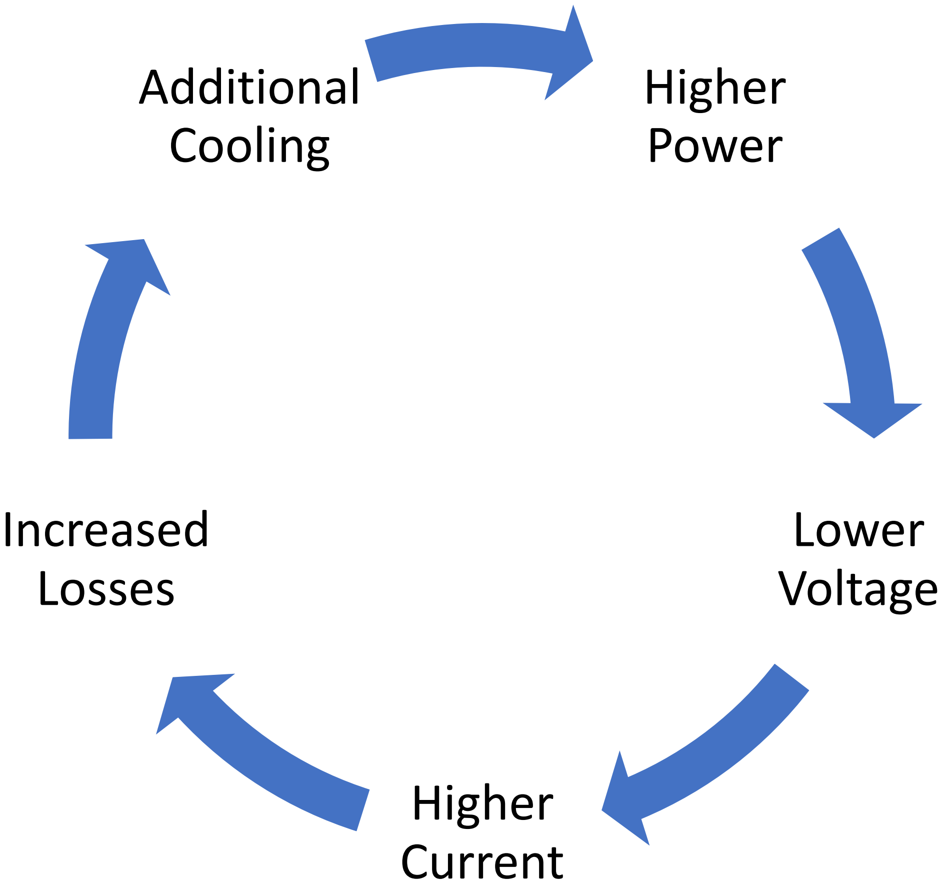
X-57

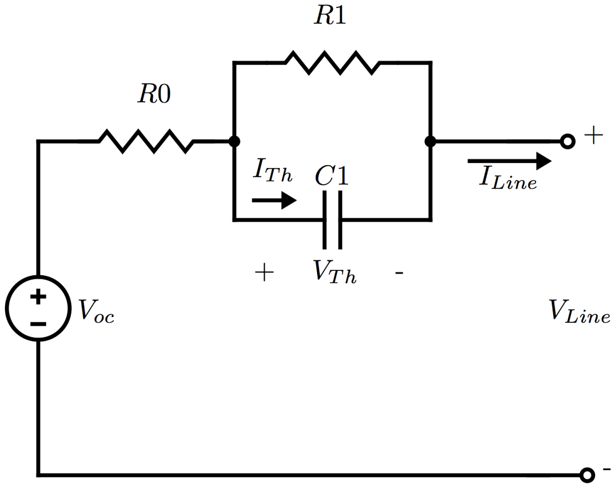
- Experimental Platform
  - 80 km
  - 120knot cruise speed
  - 6kft cruise altitude

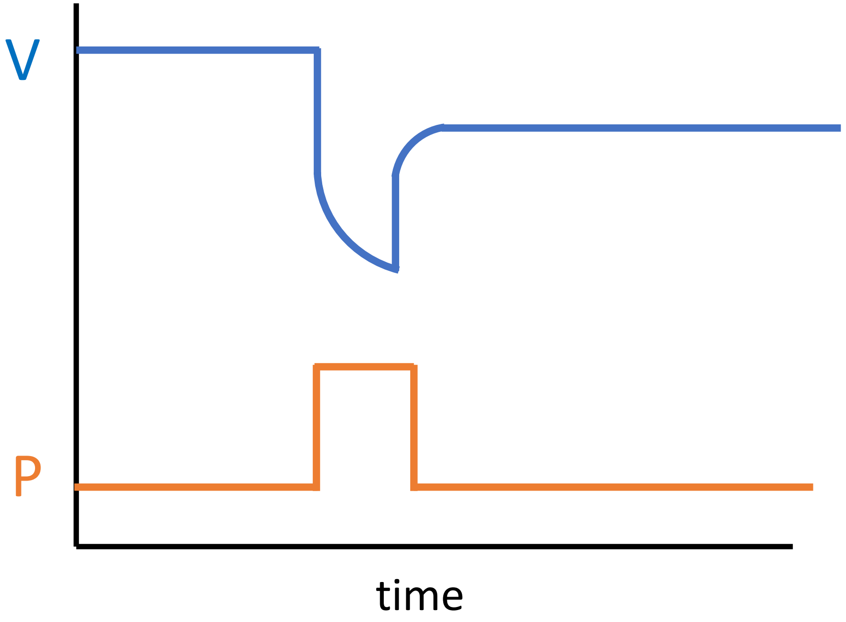
Quadrotor

- Single and Six Passenger Variants
- 30-120 km
- 1.5km altitude ceiling
- 200m minimum cruise altitude
- Subsystems: Propulsion, Thermal, Mass, Aero, Trajectory

Battery Capacity is Discharge Profile Dependent



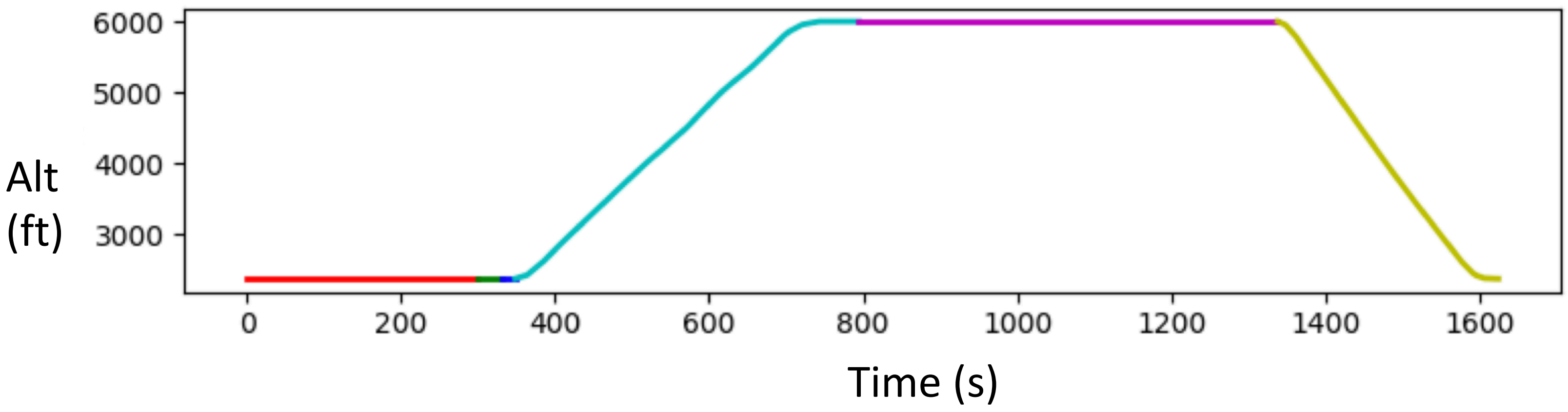




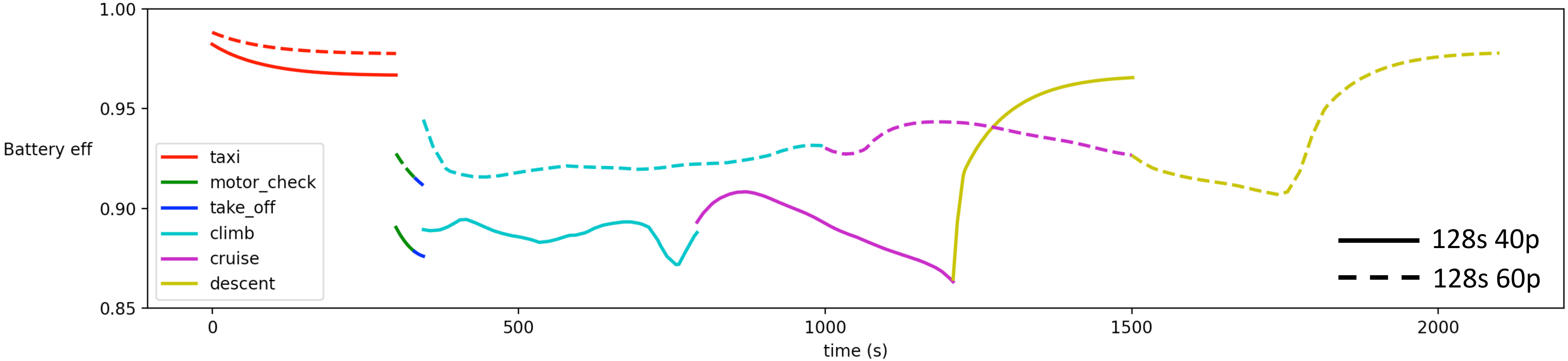
Battery knockdowns are significant

System	Knockdown	∈ (Wh/kg)
Cell	-	225
Pack	*0.663 (structure)	149
Vehicle	*0.8 (depth of discharge)	**119**

Component	η @ cruise
Propeller	76%
Motor	92%
Inverter	97.5%
Wire	99.9%
Battery	89.1%
Total	**60.7%**

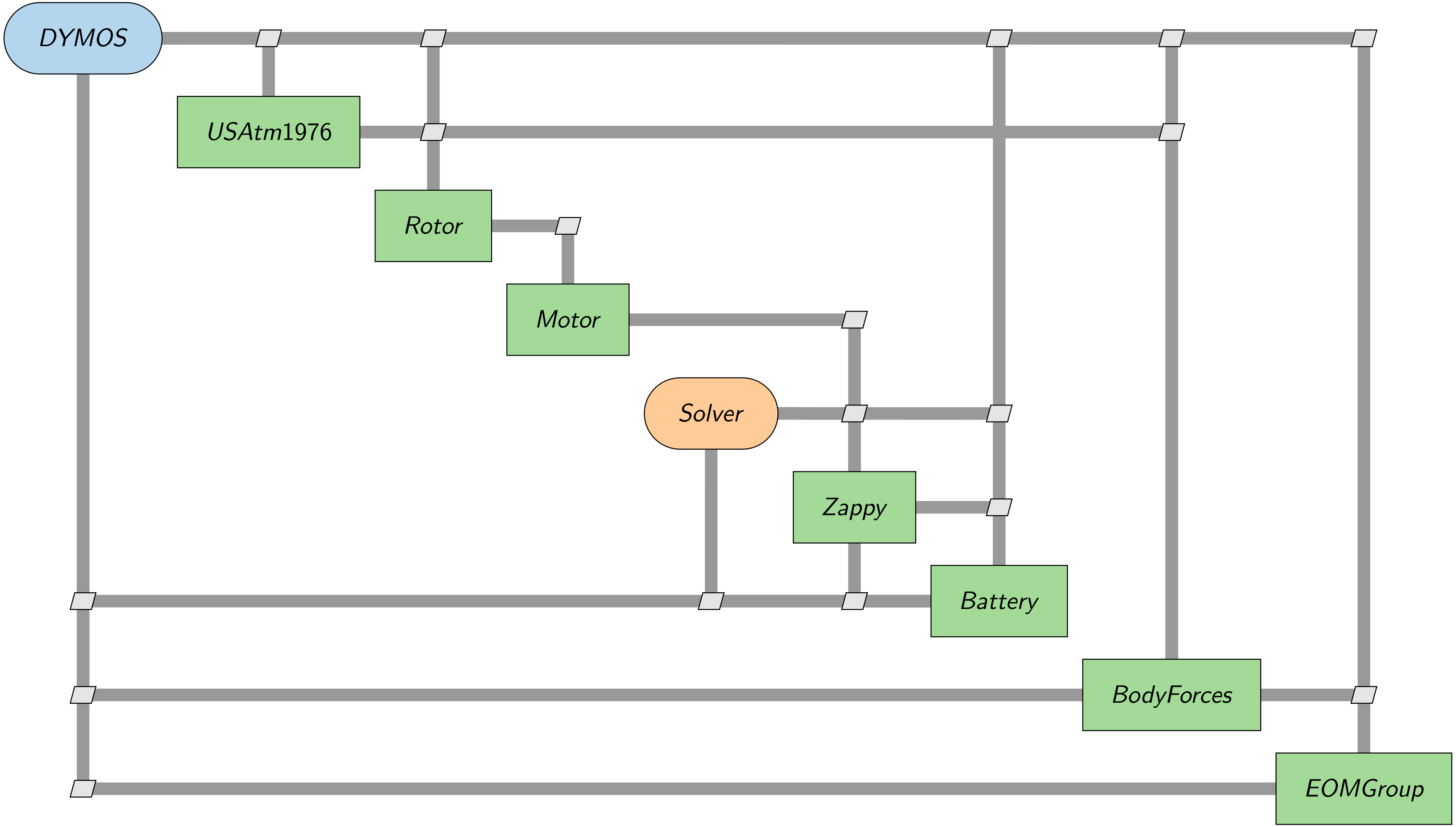


Battery Discharge Efficiency Varies with Pack Size



Phase	Batt. Power	Duration	Batt. η	Drive η*	Batt. to Shaft η
Taxi	34.0 kW	300s	97.0%	79.4%	77.0%
Motor Check	187.8 kW	30s	88.3%	89.1%	78.7%
Take-Off	189.3 kW	15s	87.6%	89.2%	78.1%
Climb	156.8 kW	446s	88.6%	88.8%	78.7%
Cruise	141.6 kW	417s	89.1%	88.4%	78.8%
Descent	31.4 kW	293s	95.1%	77.2%	73.4%

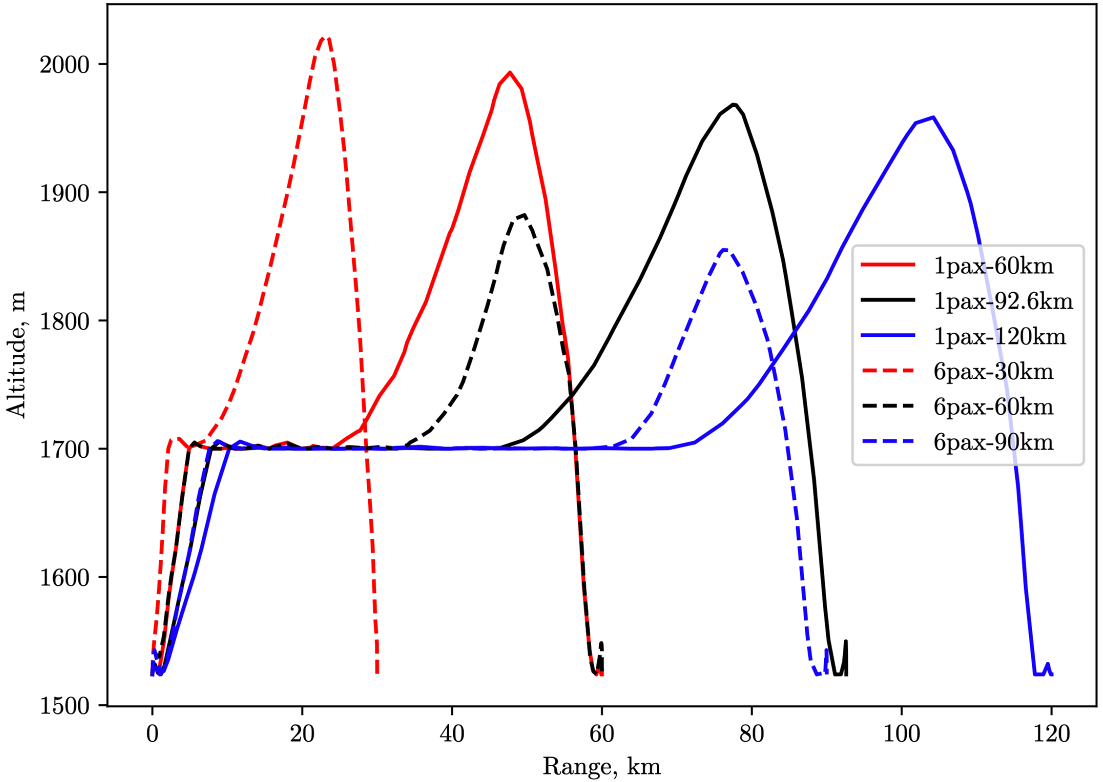
Optimization Environment



Thermal Management Adds Additional Efficiency Penalty

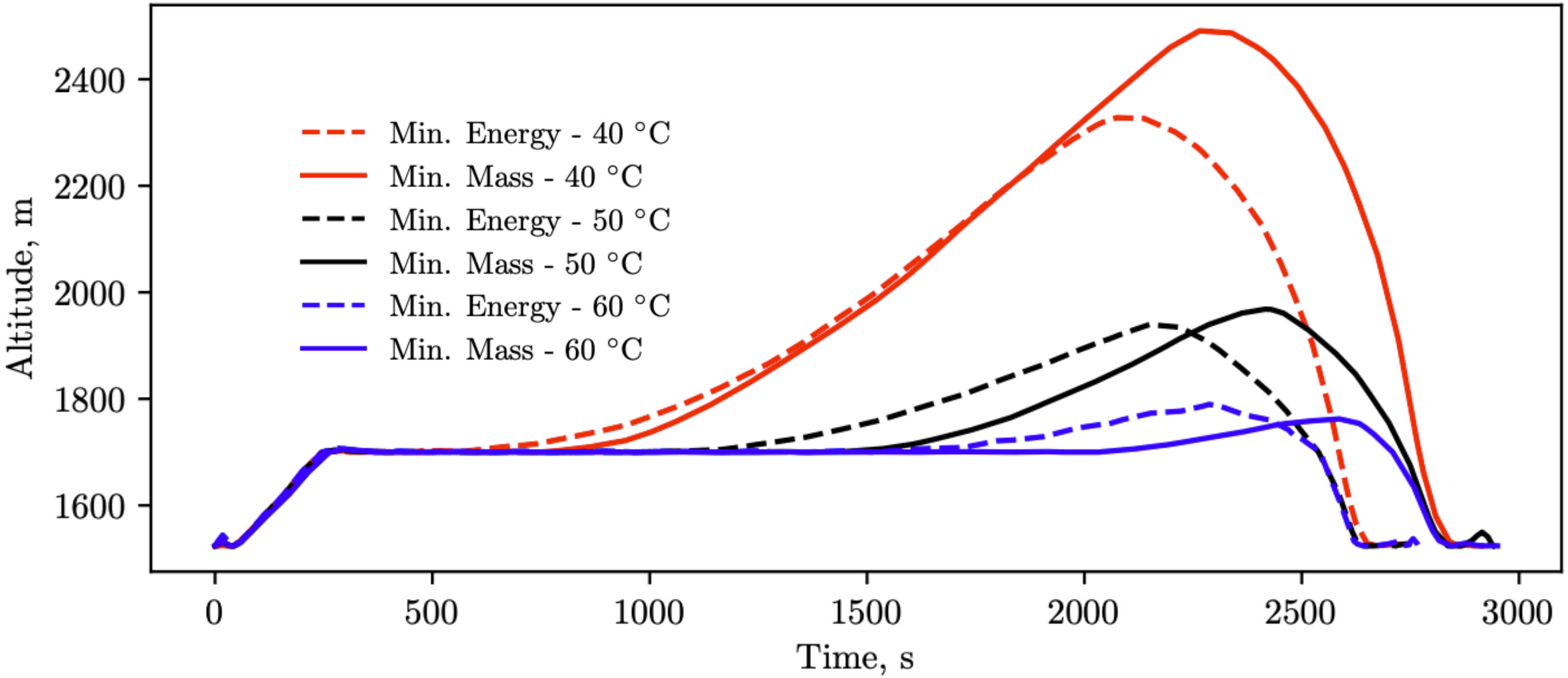
Component	*η* @ cruise*
Propeller	76%
Gearbox	99%
Motor	97.4%
Inverter	98%
Wire	99.9%
TMS	97.3%
Battery	89.7%
Total	**62.6%**

System	Knockdown	∈ (Wh/kg)
Cell	-	488
Pack	*0.769 (structure)	375
Vehicle	*0.8 (depth of discharge)	**300**

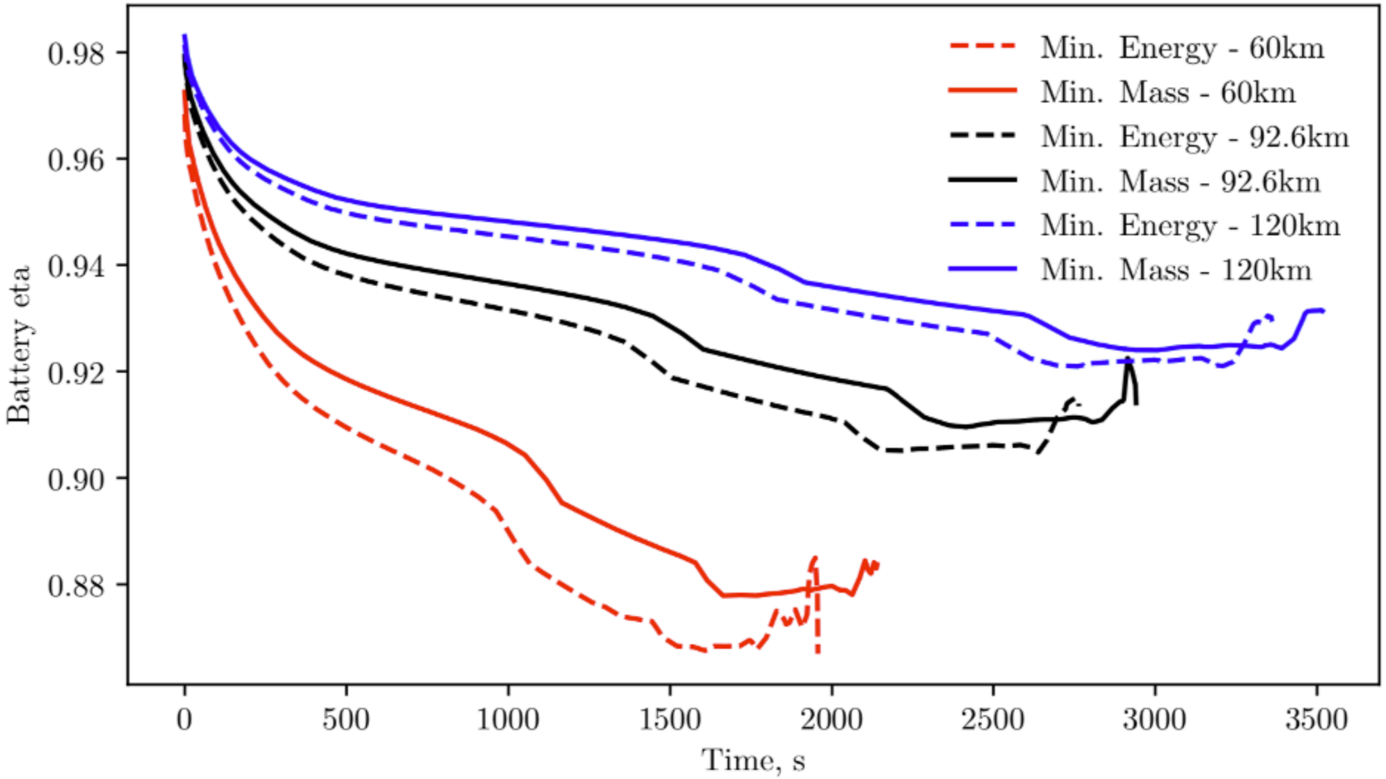


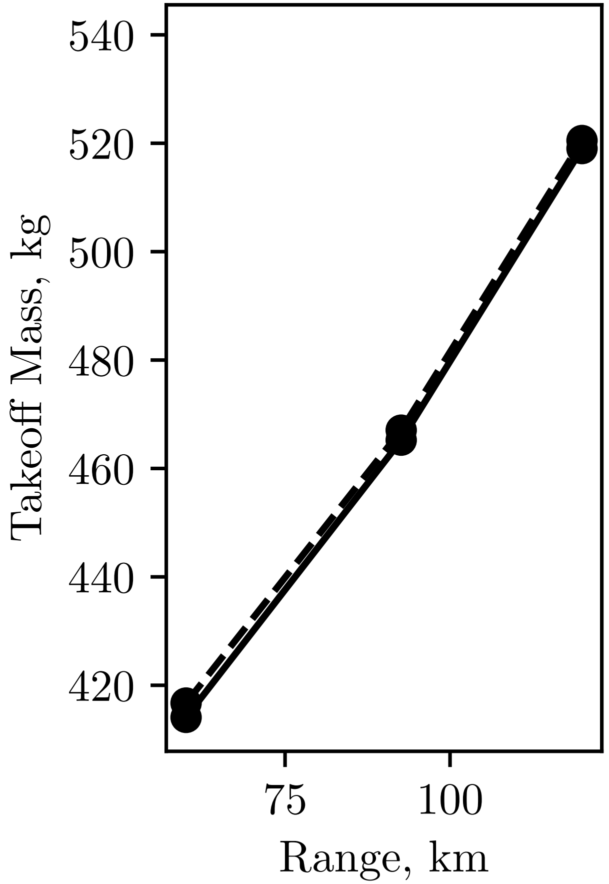
*1pax – 92.6km

Optimal Trajectories are Driven by Battery Temperature

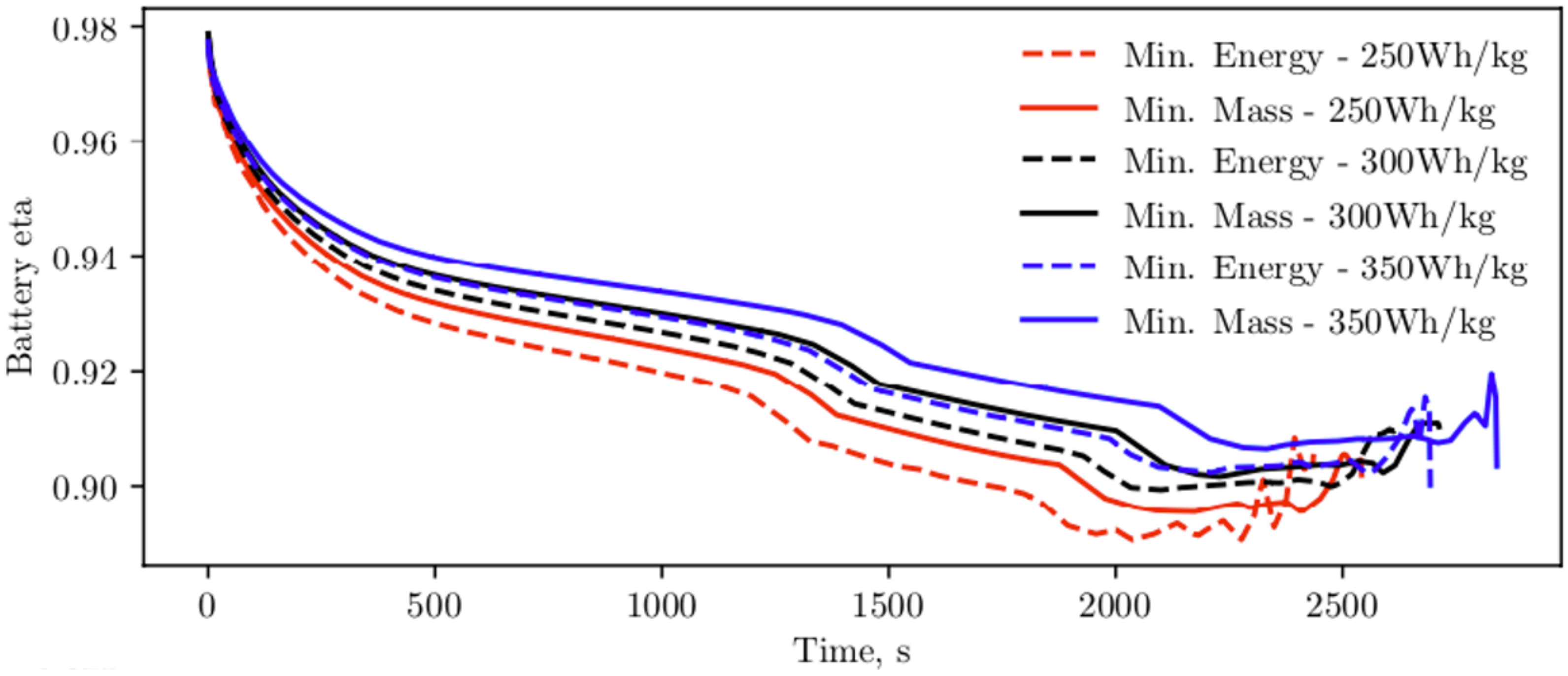


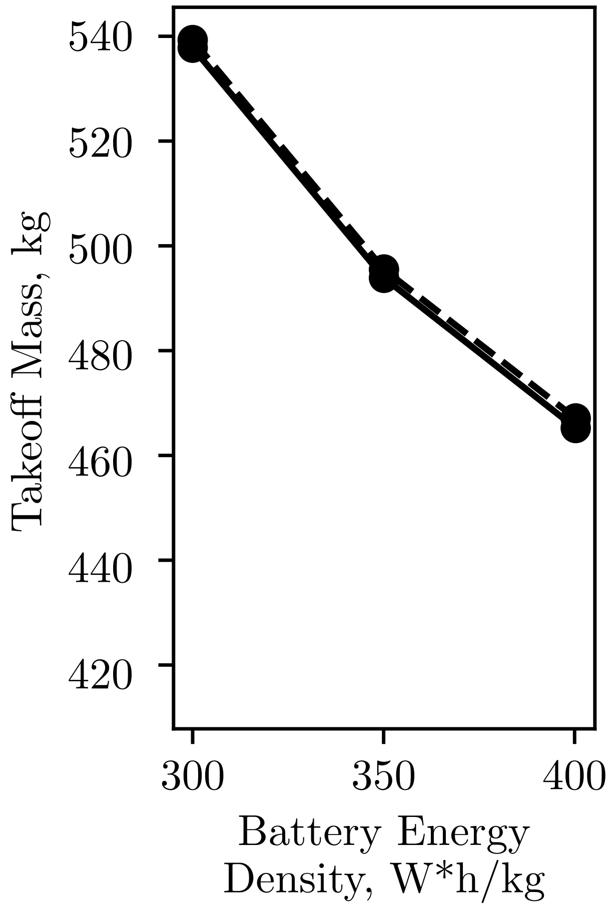
Range impacts both the proportions and scale



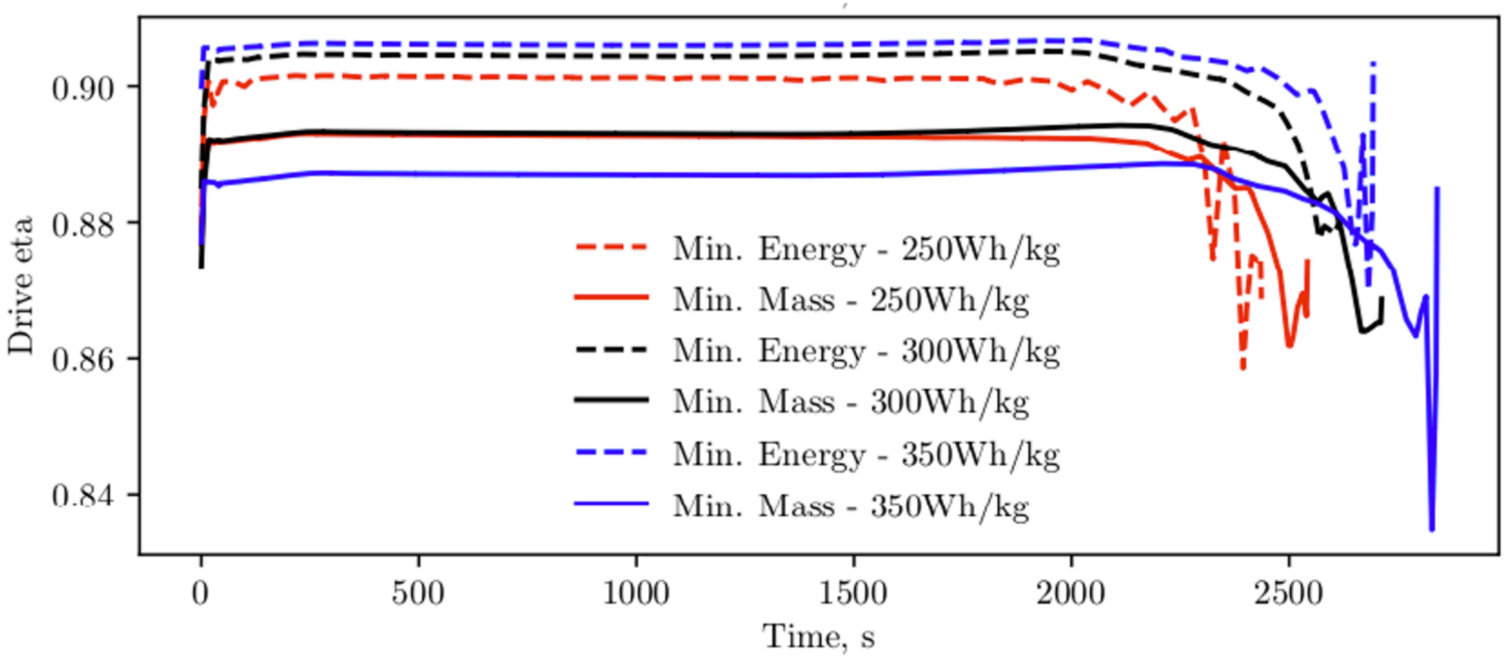


Energy density mostly impacts the scale





Energy density impacts thermal efficiency



<u>Minimized Energy vs Minimized Weight</u>

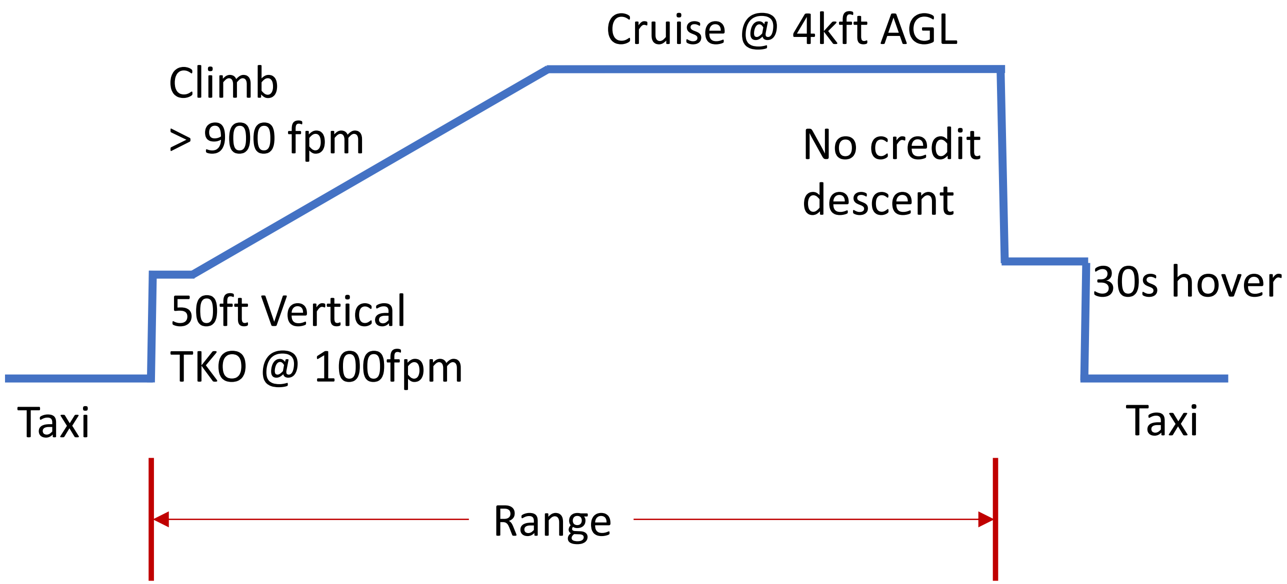
0.3% increase in vehicle weight,

15% increase in TMS weight

Summary

- Cell-to-air efficiencies of 60-65% are realistic (compared to 25-40% for combustion)
- Optimal trajectories are dictated by battery thermal constraints
- Regressions developed for range, passenger count, energy density have been established
- Range impacts optimal vehicle proportions more than energy density, both impact scale
- Higher energy density batteries create large differences between minimum energy and minimum weight vehicle designs

Forward Work



Investigate more constrained trajectories

- UAM Reference Mission*
- Back-to-back flights
- Additional Vehicle Types
  - Lift+Cruise
  - Tiltrotor/wing
- More generalized battery
- Additional thermal architectures
- Improved pack-level modeling

Develop comprehensive surrogate models to better inform battery development

*Silva, Johnson, Antcliff, Patterson

Thank You!

Transformative Tools and Technologies Project
Flight Demonstration Capabilities Project