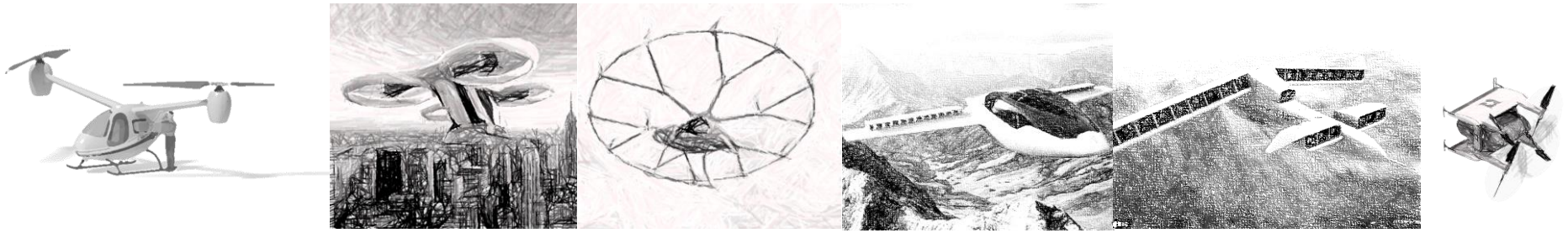
Designing eVTOL for Urban Air Mobility



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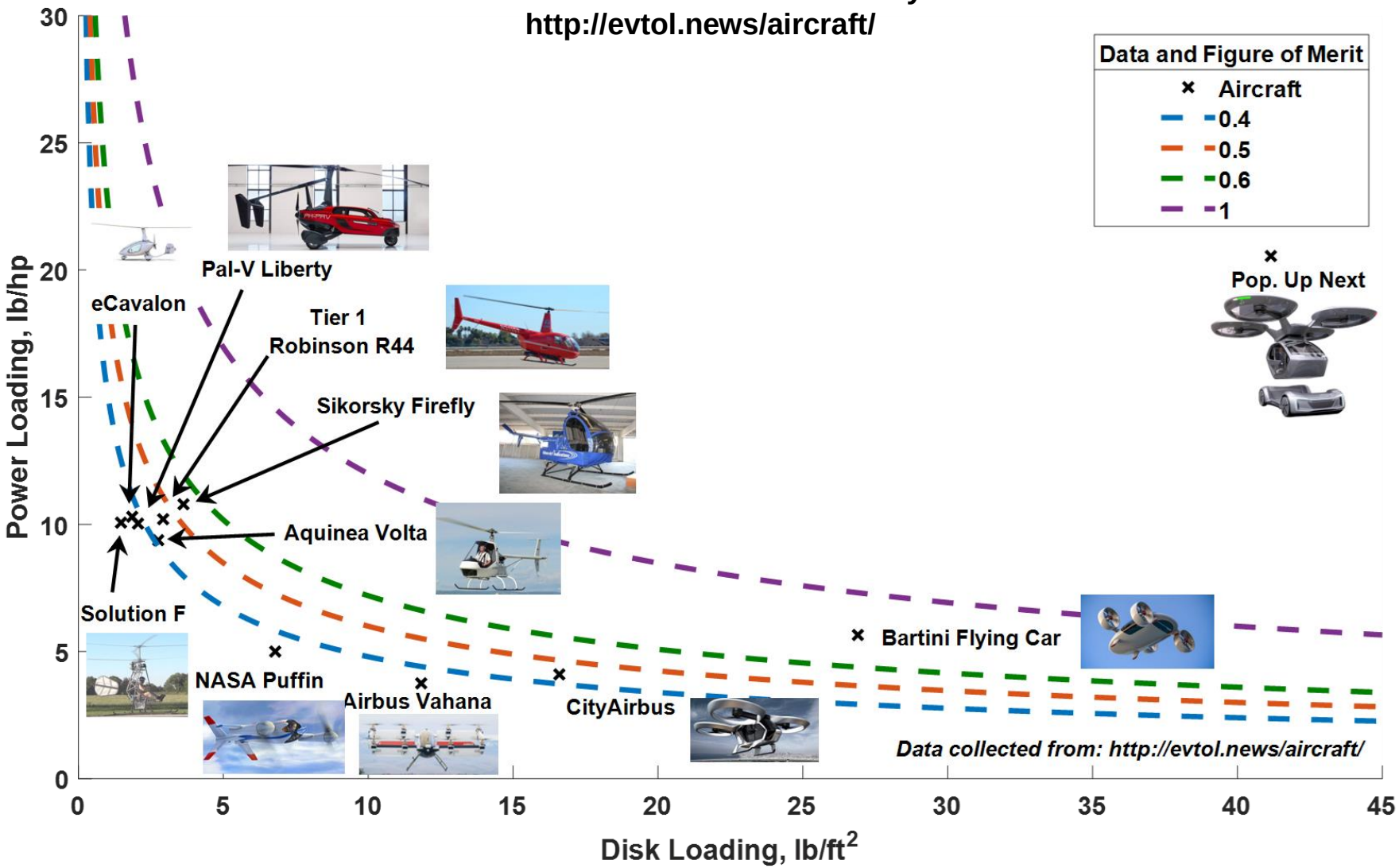
Objectives for Summer Internship

- **Learn about and analyze existing eVTOL vehicles**
- **Design a VTOL aircraft**
- **Test LiPo batteries**
- **Design an eVTOL aircraft using collected data**

Power and Disk Loading for Various eVTOL Aircraft

Source: World eVTOL Directory
http://evtol.news/aircraft/



Mission for My eVTOL

Range 14.7 miles, 12.8 nautical miles (25.6 round-trip)

Additional 5 minute hover

Mission Criteria

Maximum weight (gross takeoff weight) 2000 lbs

Payload (weight of people and cargo) 400 lbs

Edgewise rotor

Lift/drag ratio = 5

structure factor 0.24

Cruise velocity 70 kt

Tiltrotor

Lift/drag ratio = 9

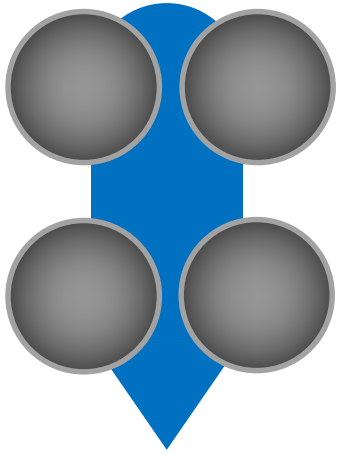
structure factor 0.3

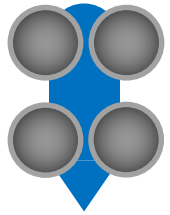
Cruise velocity 150 kt

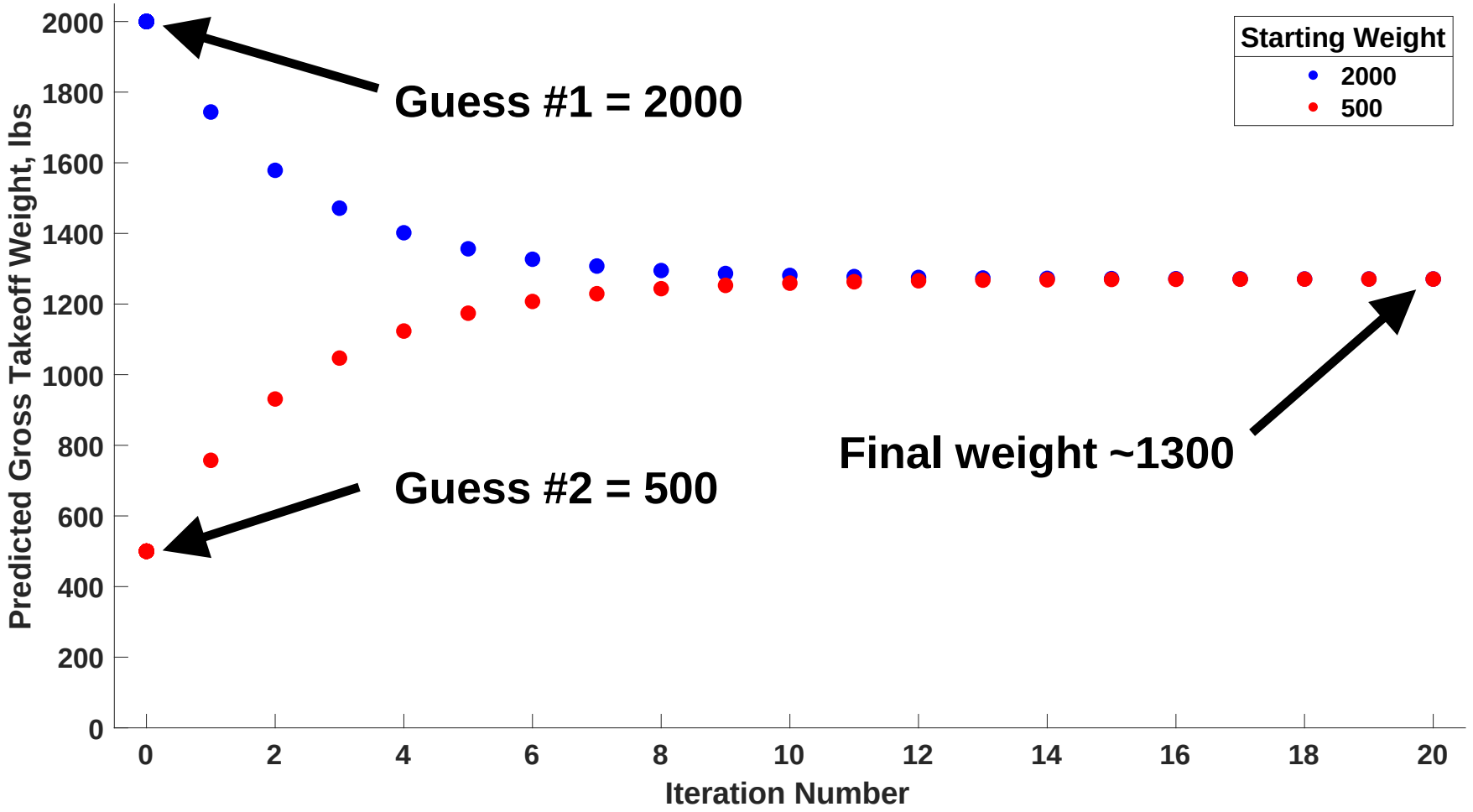
Design Process

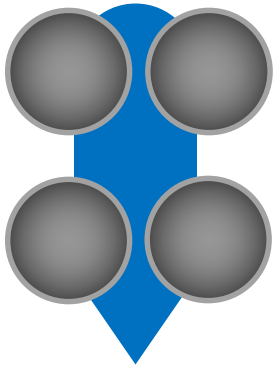
1. Objective and criteria
2. **Conventional (turboshaft) design**
3. Battery testing
4. Conversion to electric power

Convergence of Design



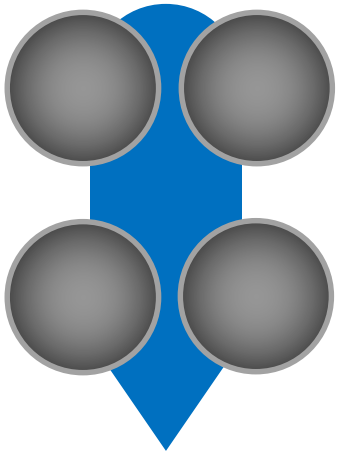






Disk loading = 8 lb/sqft
Structure weight = 0.24 GTOW

Disk Loading



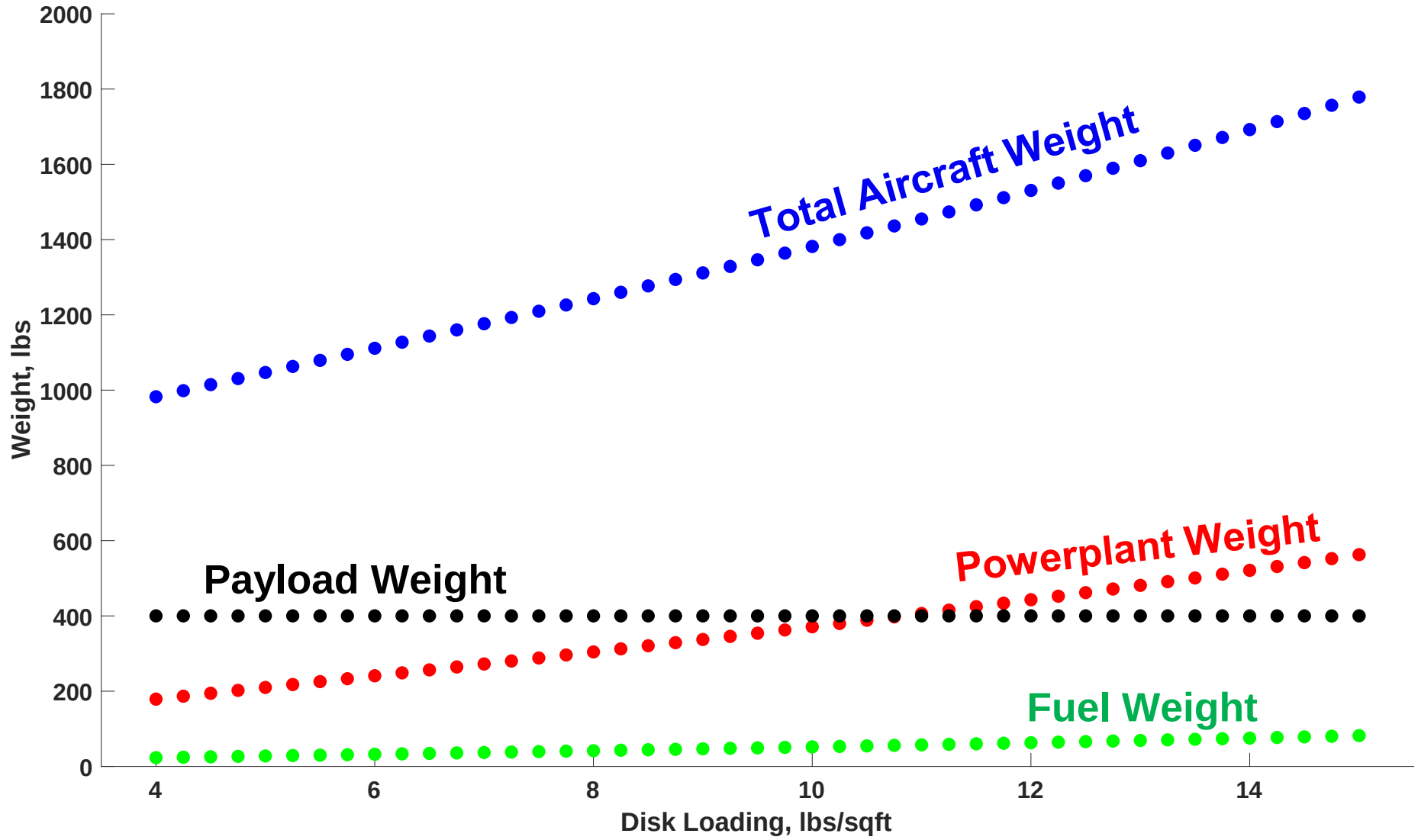
Surface area of 4 rotors

$$DL = \frac{weight}{total\ rotor\ area}$$

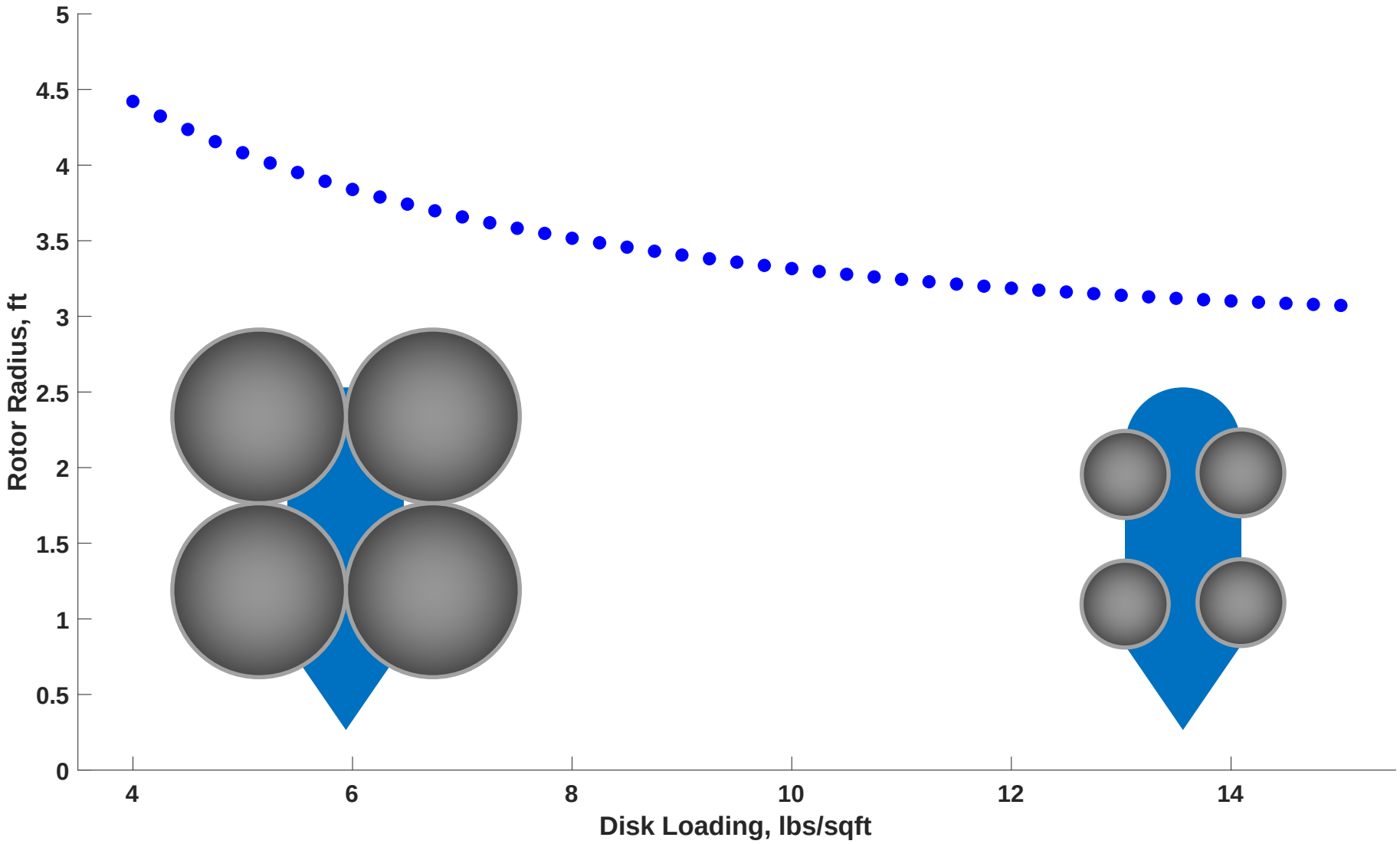
$$Area = \#\ rotors\ \times\ \pi\ \times\ radius^2$$

$$DL = \frac{weight}{\#\ rotors\ \times\ \pi\ \times\ radius^2}$$

Weight Predictions



Rotor Radius



Design Method

1. Objective and criteria
2. Conventional (turboshaft) design
3. **Battery testing**
4. Conversion to electric power

Battery Basics

Voltage
(Volts)

The force pushing electricity through a circuit

Charge
(Coulomb, Ampere hour)

The total energy in a battery

Current
(Ampere)

The amount of electricity moving through a circuit

Charge (how full the water gun is)

Current (how fast water flows through the nozzle)

Voltage (the force put on the trigger)

Battery Discharge

Power
(Watts)

The rate at which electrical force is applied

C-Rate
(Ampere hour)

The rate at which a battery is discharged

Inversely effects discharge time: if a battery takes 1 hour to discharge at 1 C, it will take 30 minutes at 2C

$$\text{C–rate} = \frac{\text{Power}}{\text{Energy}}$$

Energy
(Watt hours)

The total electrical force applied over time, usually kilowatt hours

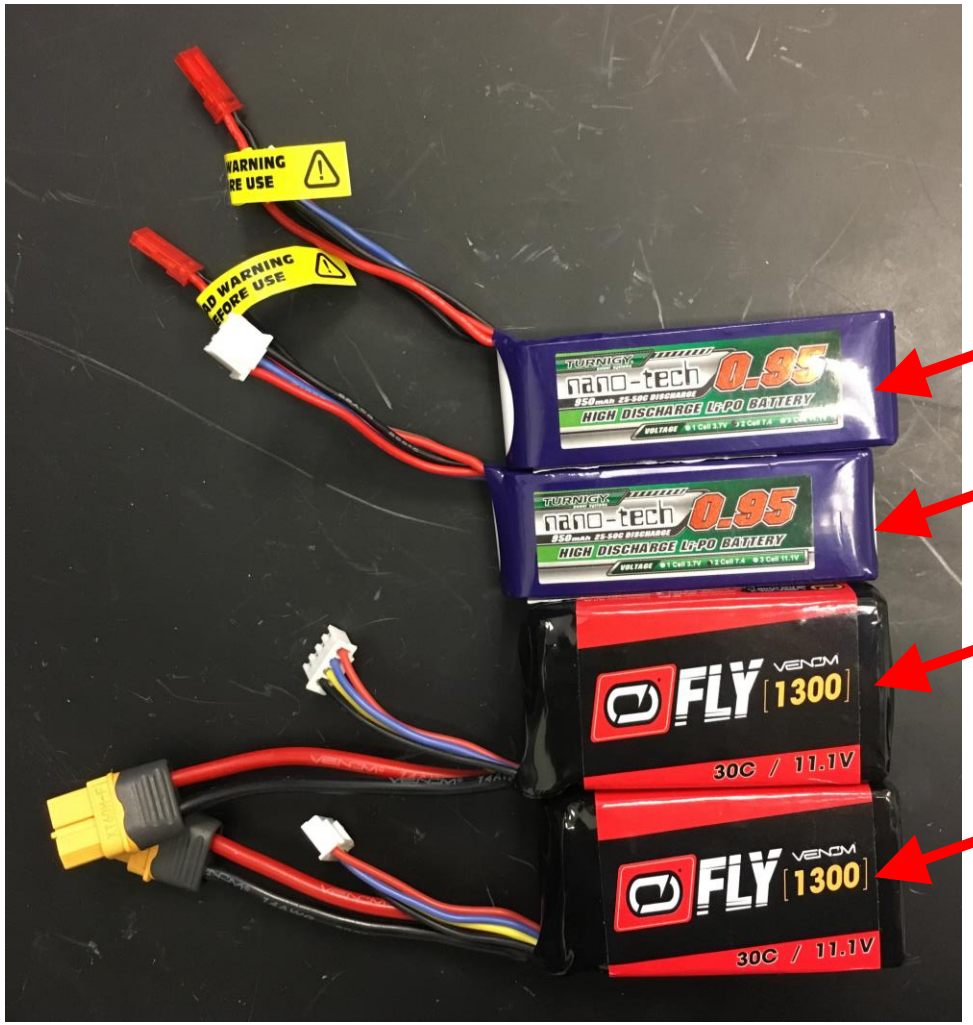
$$Coulomb = \frac{ampere}{second}$$

$$Volt = Amps * resistance$$

$$Watts = Volts * Amps$$

$$Watt\ hours = Watts * hour$$

Batteries



Lithium Polymer Batteries (LiPo)

3

4

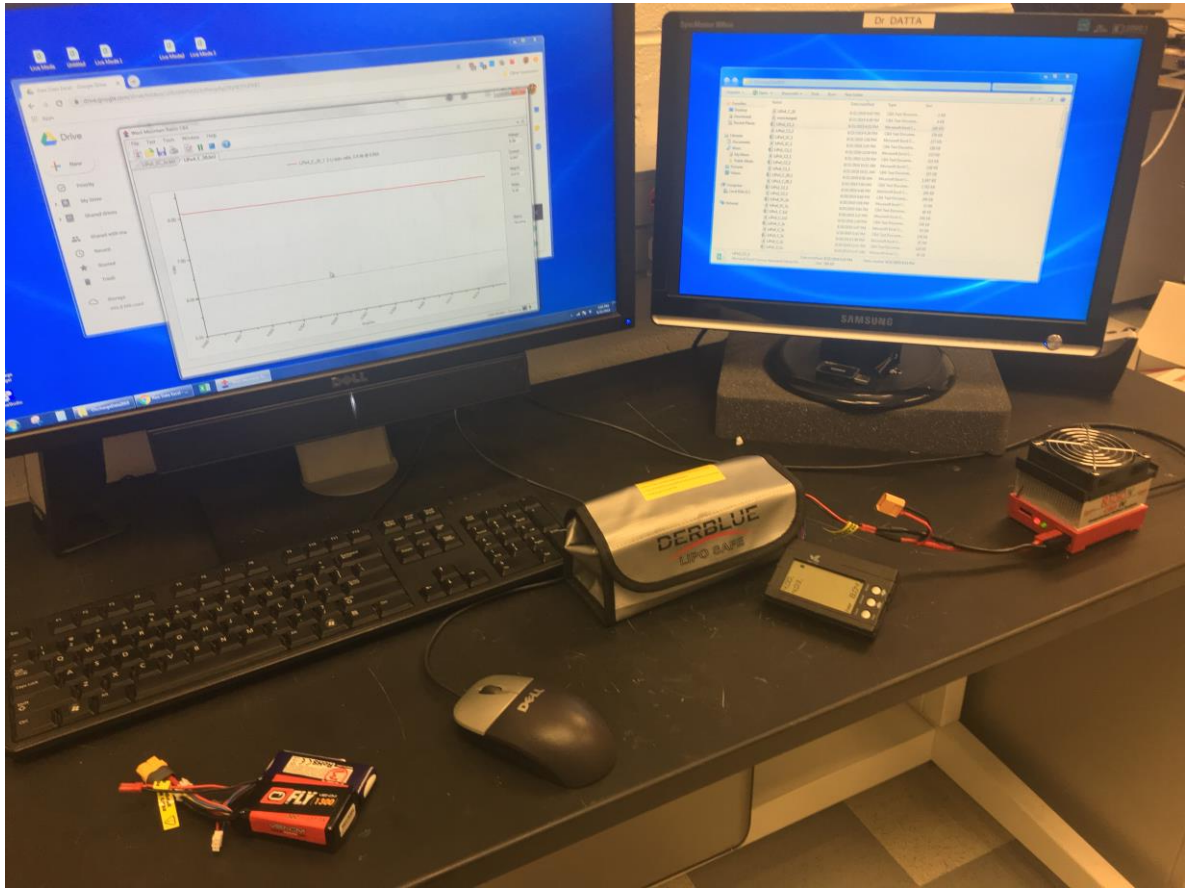
950 milliamp hours (0.95 Ah)
7.4 Volts
2 cells

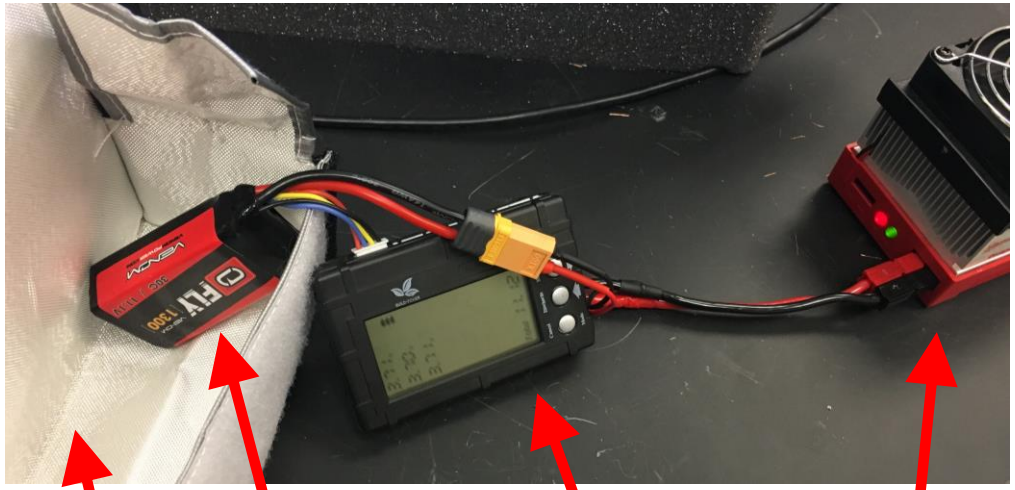
1

2

1300 milliamp hours (1.3 Ah)
11.1 Volts
2 cells

Experiment Setup





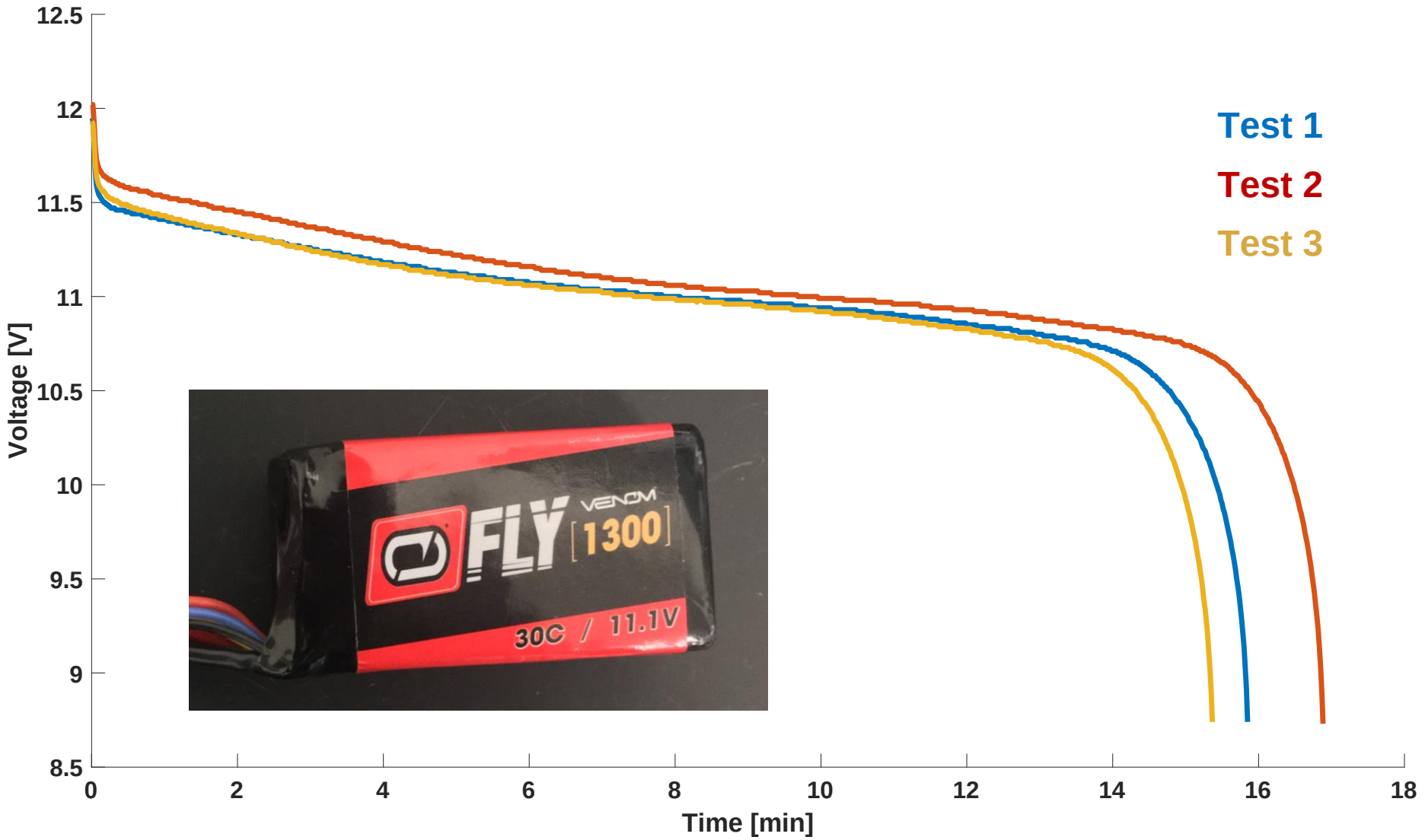
LiPo battery

Discharge unit

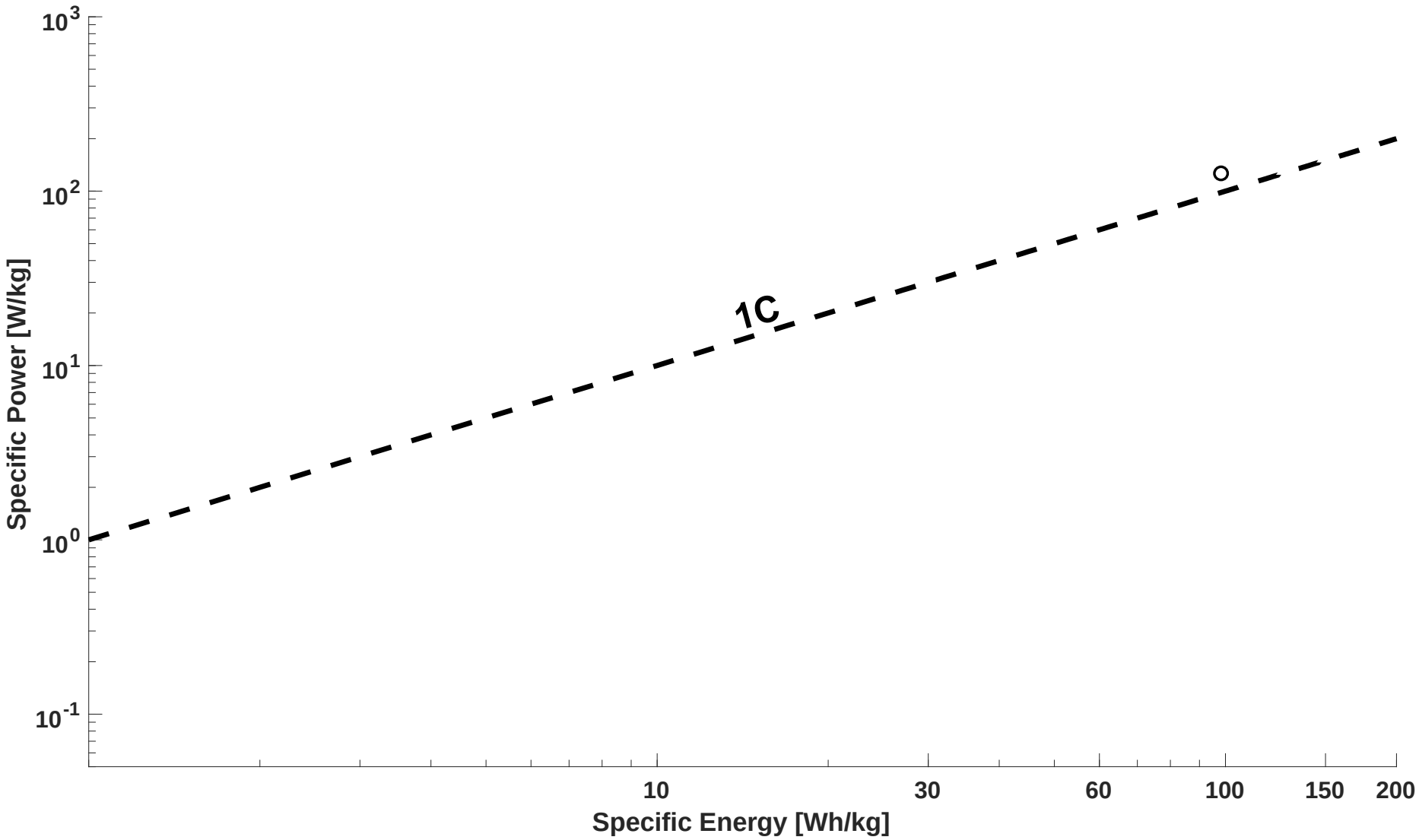
Fireproof battery safe bag

Battery monitor

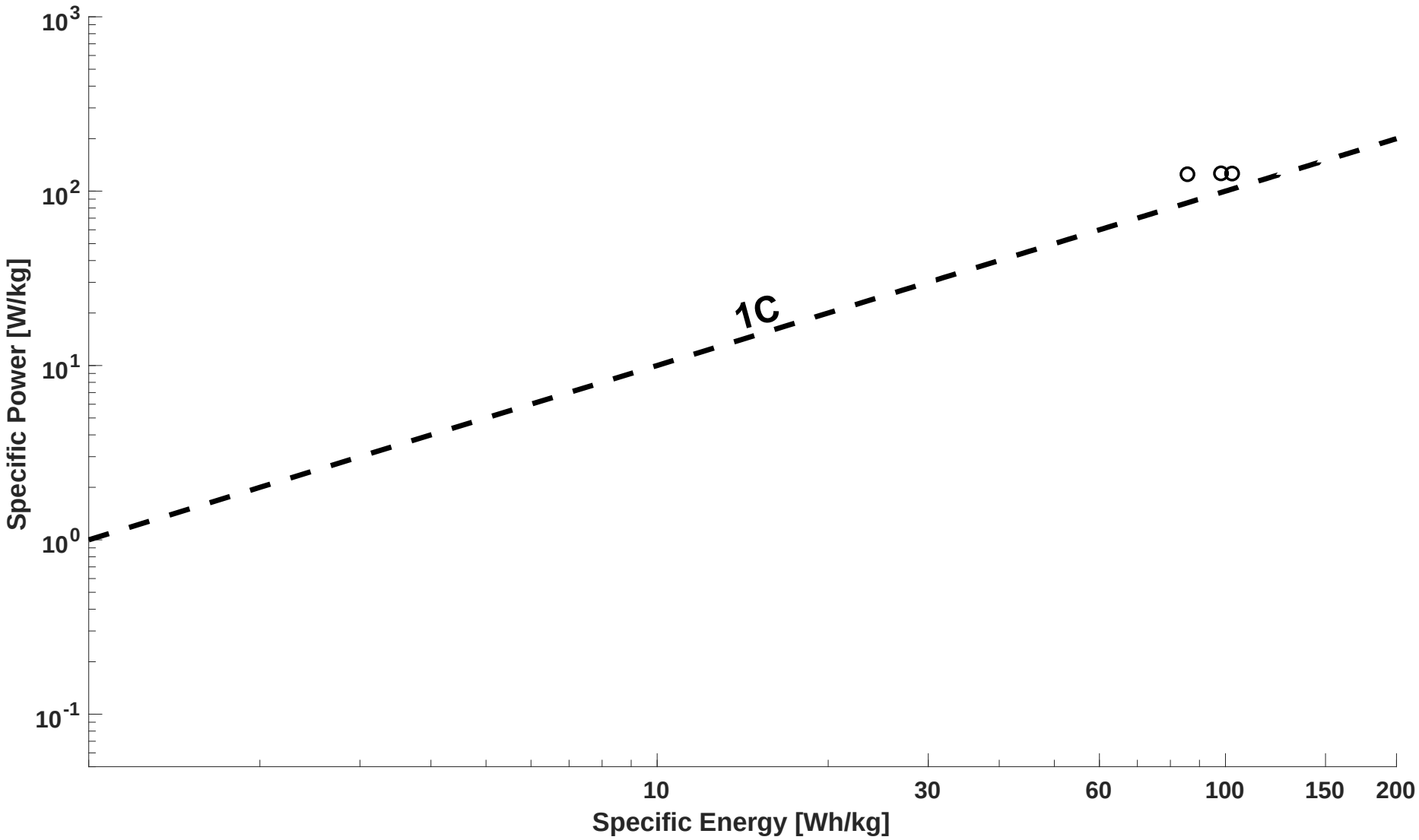
Raw Data


12.5
12
11.5
11
10.5
10
9.5
9
8.5
Voltage [V]
0
2
4
6
8
10
12
14
16
18
Time [min]
Test 1
Test 2
Test 3
VENOM
FLY
1300
30C / 11.1V

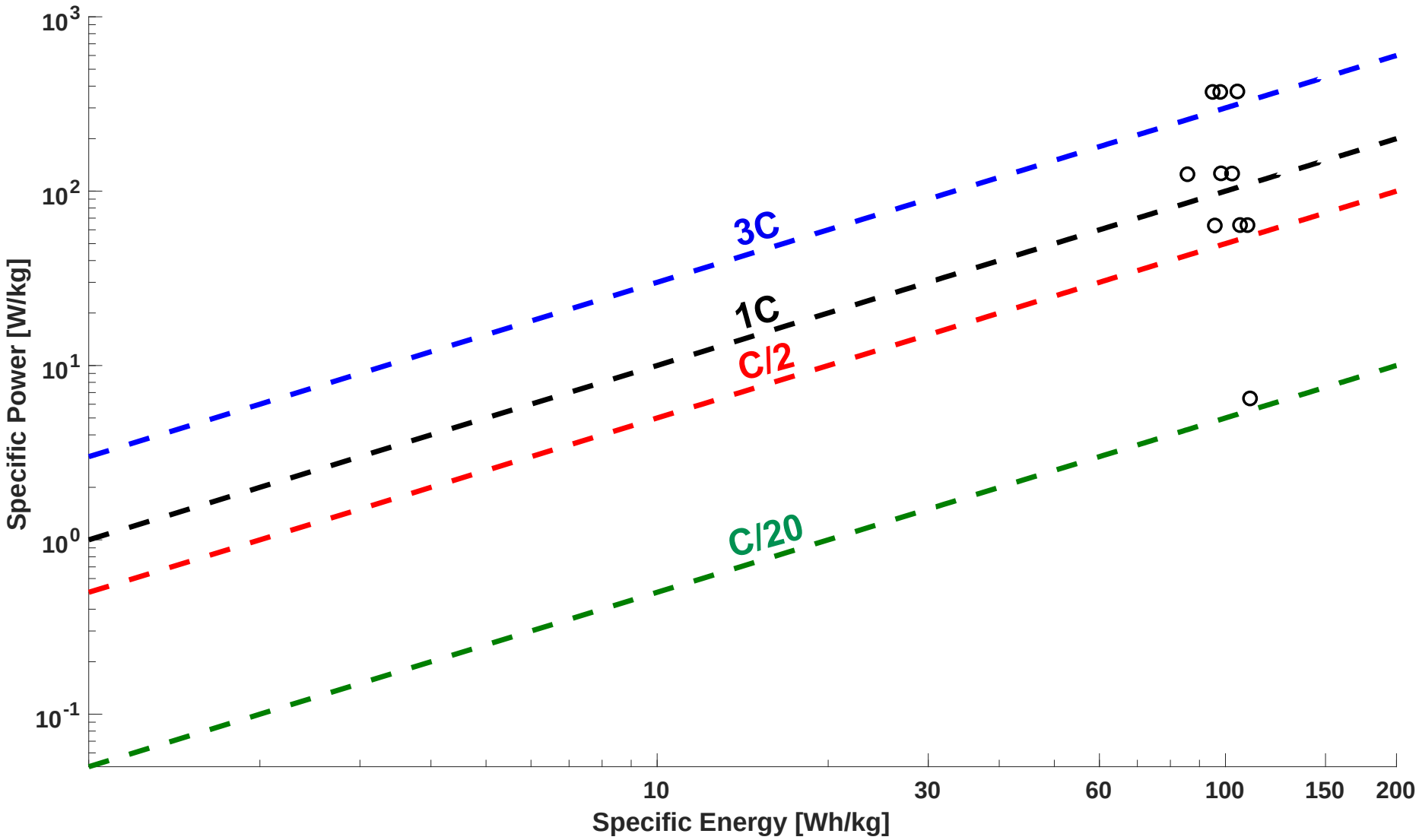
Data from Battery 1



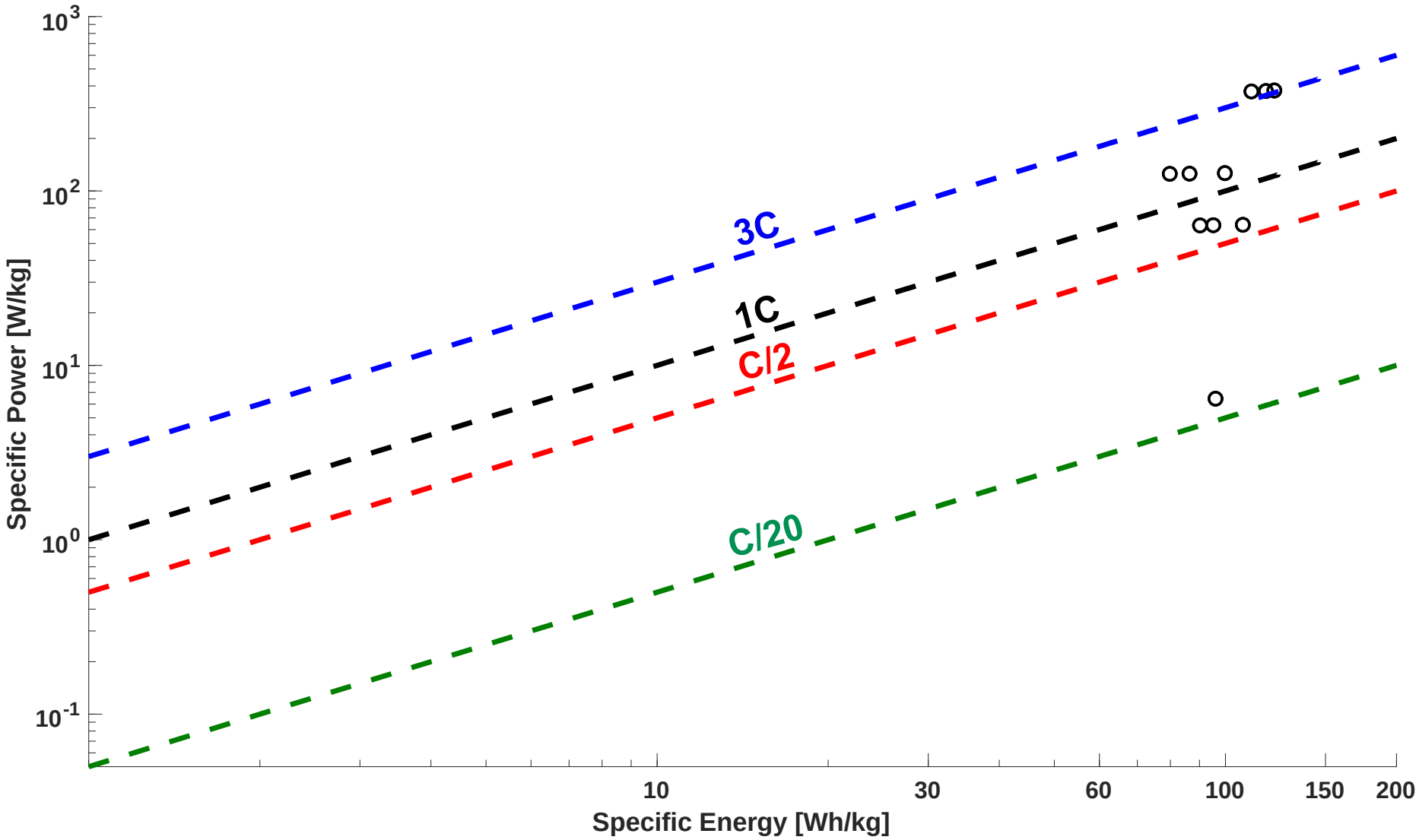
Data from Battery 1



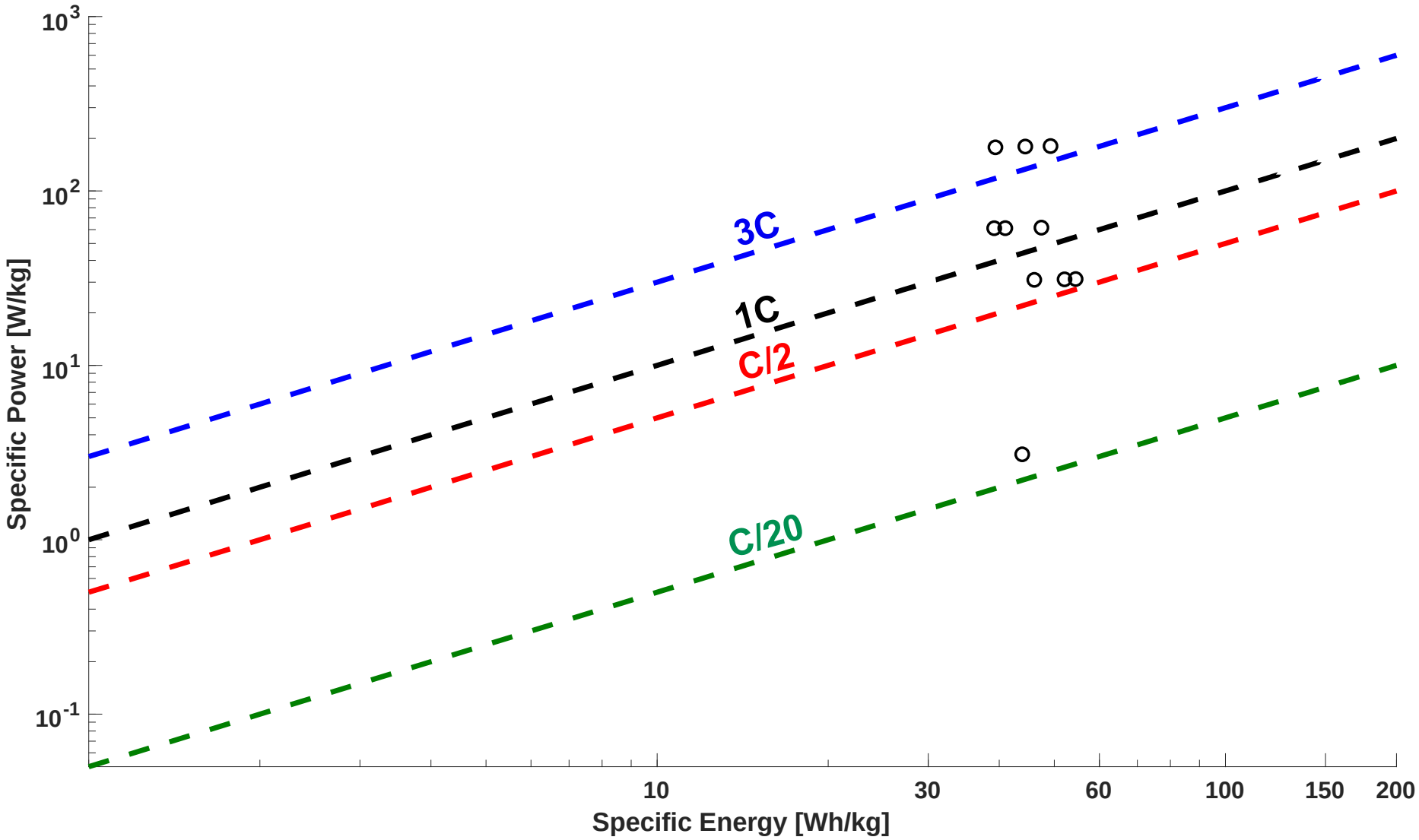
Data from Battery 1



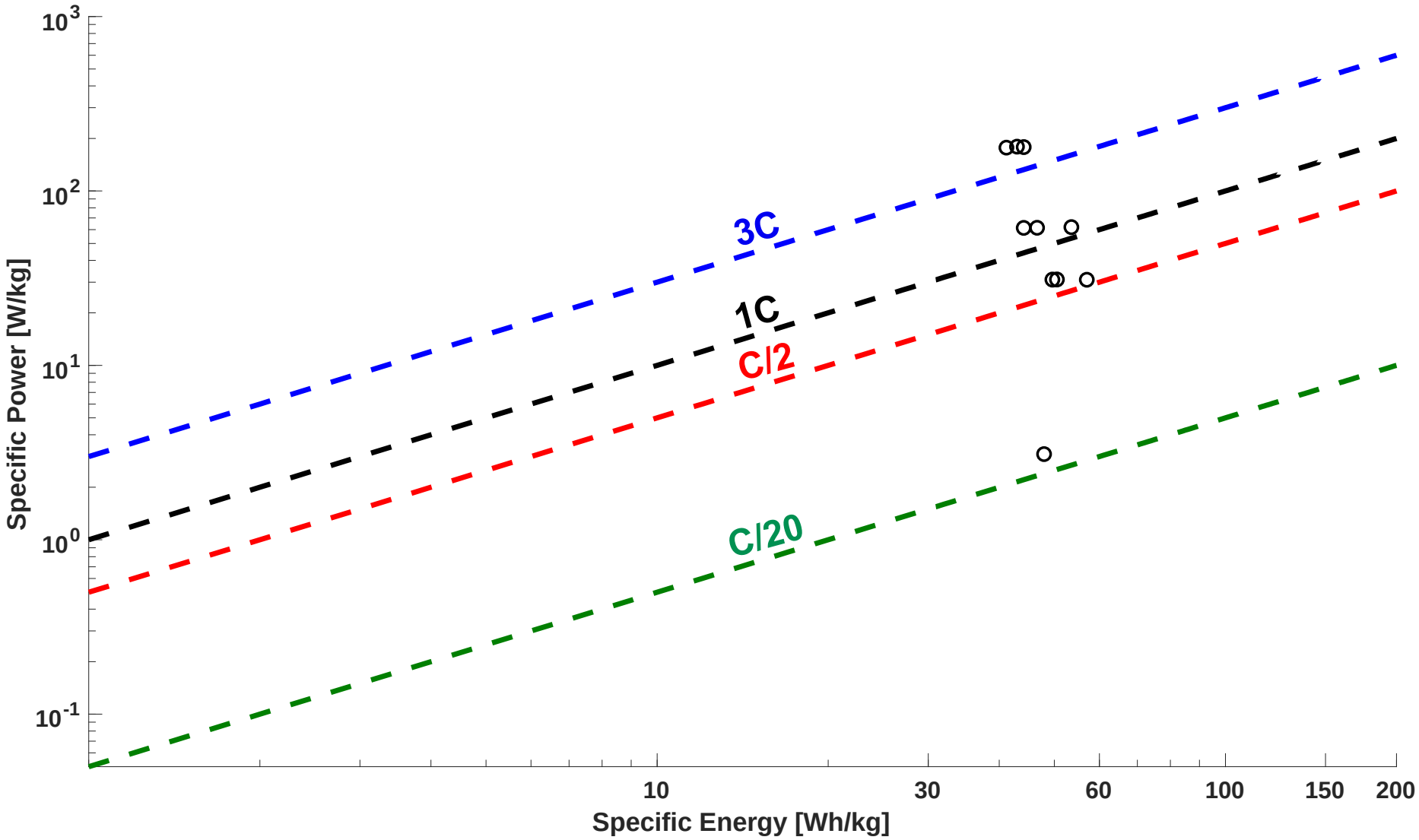
Data from Battery 2



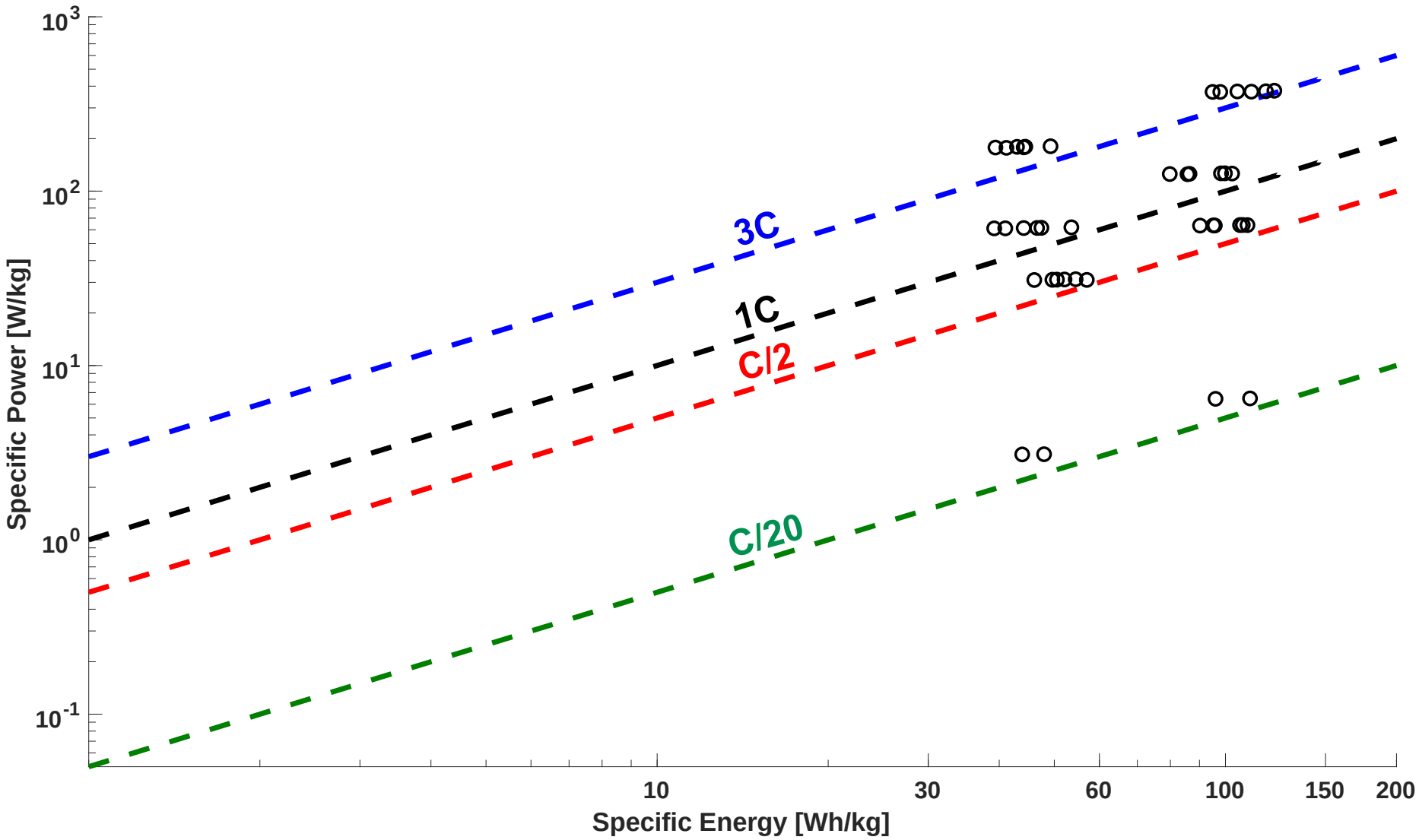
Data from Battery 3



Data from Battery 4



Final Data


Specific Power [W/kg]
10^3
10^2
10^1
10^0
10^{-1}
3C
1C
C/2
C/20
10
30
60
100
150
200
Specific Energy [Wh/kg]

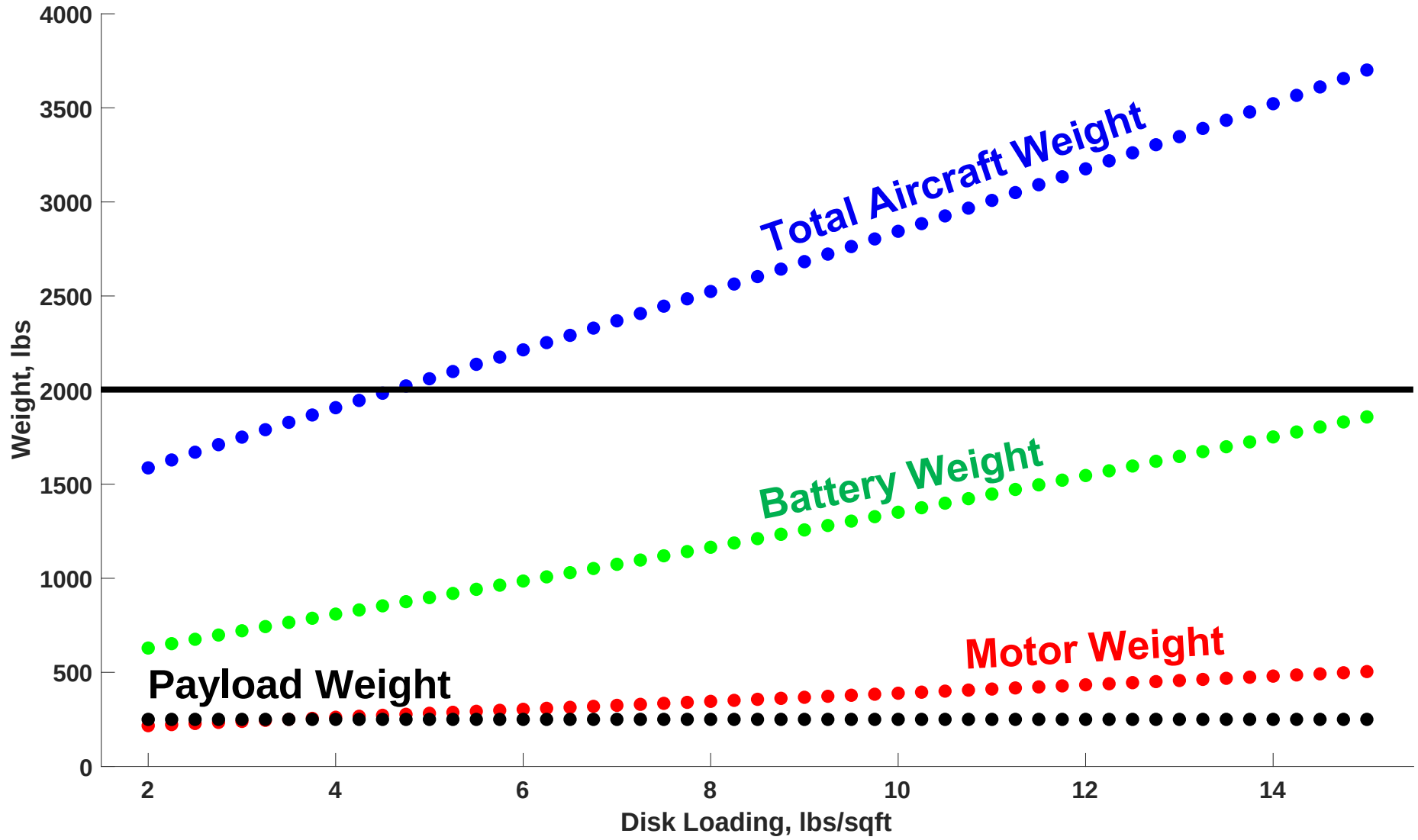
Design Method

1. Objective and criteria
2. Conventional (turboshaft) design
3. Battery testing
4. **Redesign for electric power**

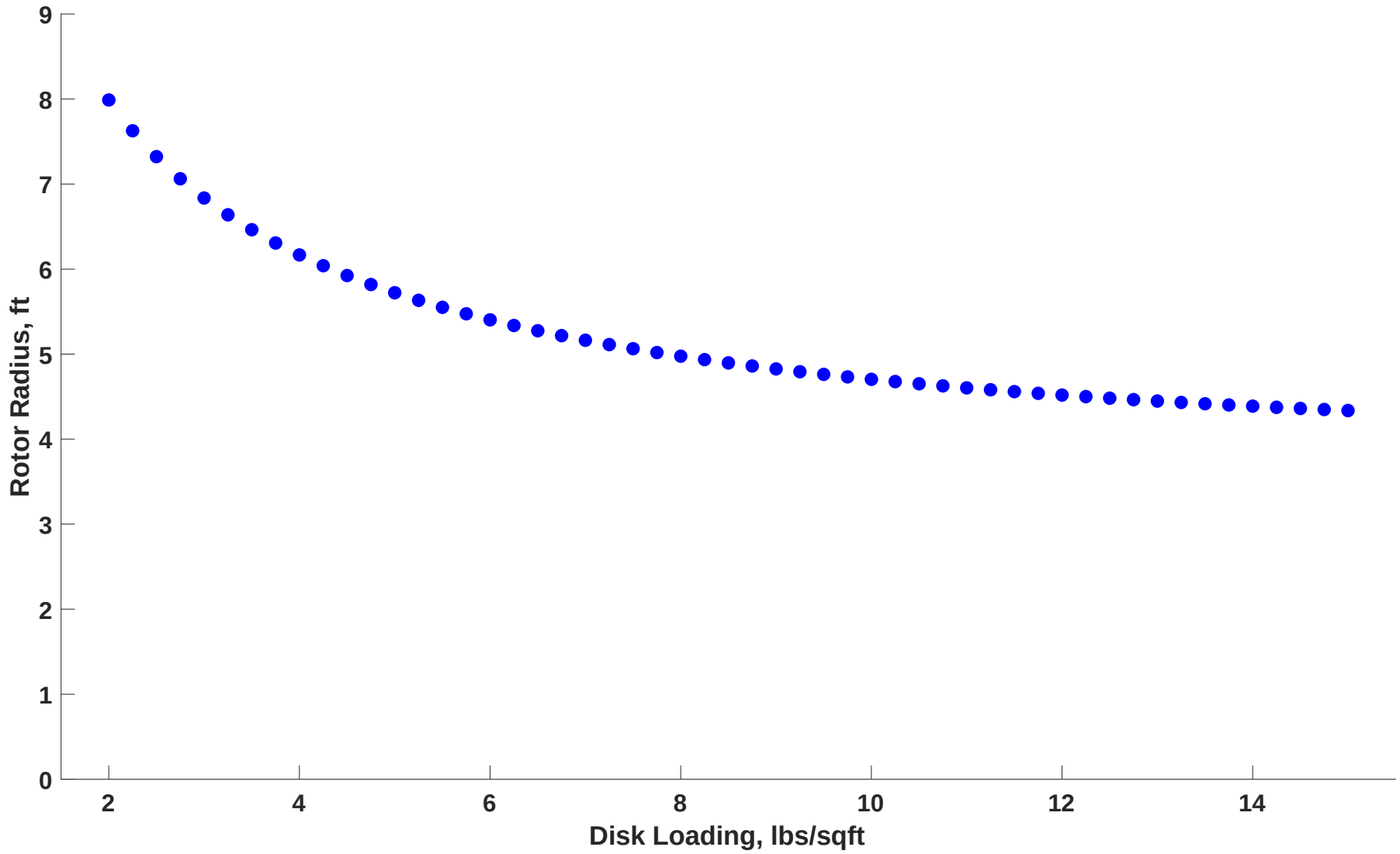
Redesign for Electric Power

- **Engine → Motor**
- **Fuel → Battery**
- **Data collected from batteries used to estimate gross takeoff weight, power, and energy**

Weight Predictions

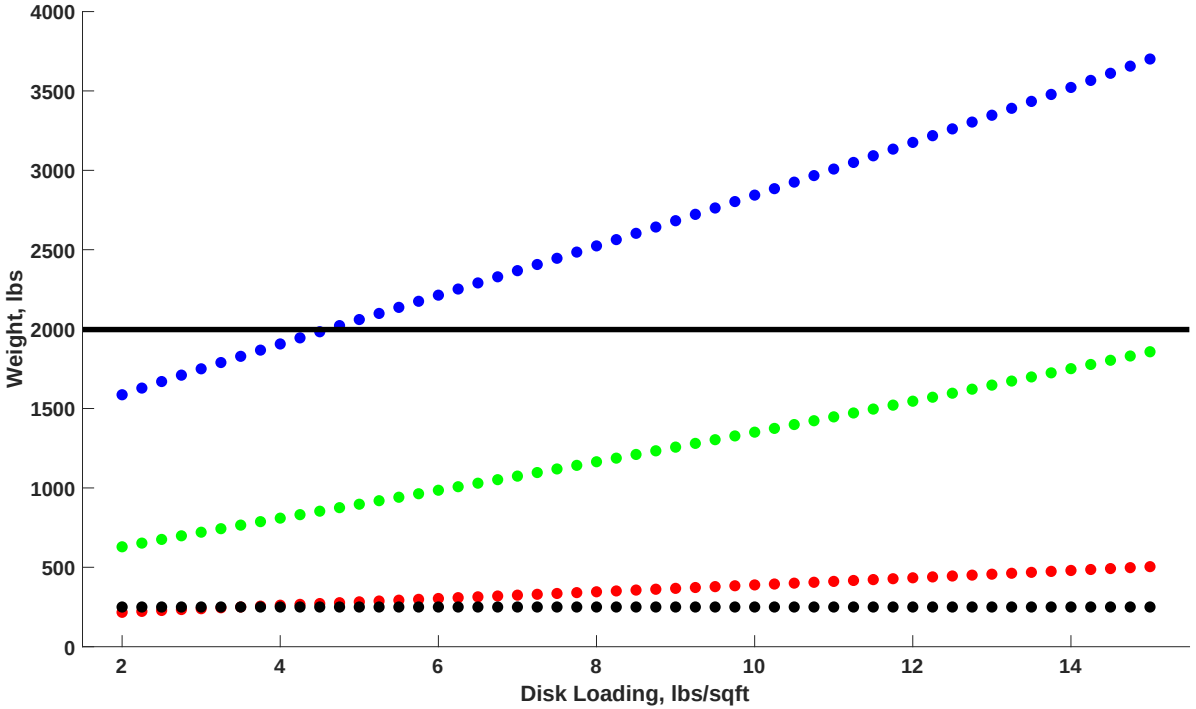


Rotor Radius

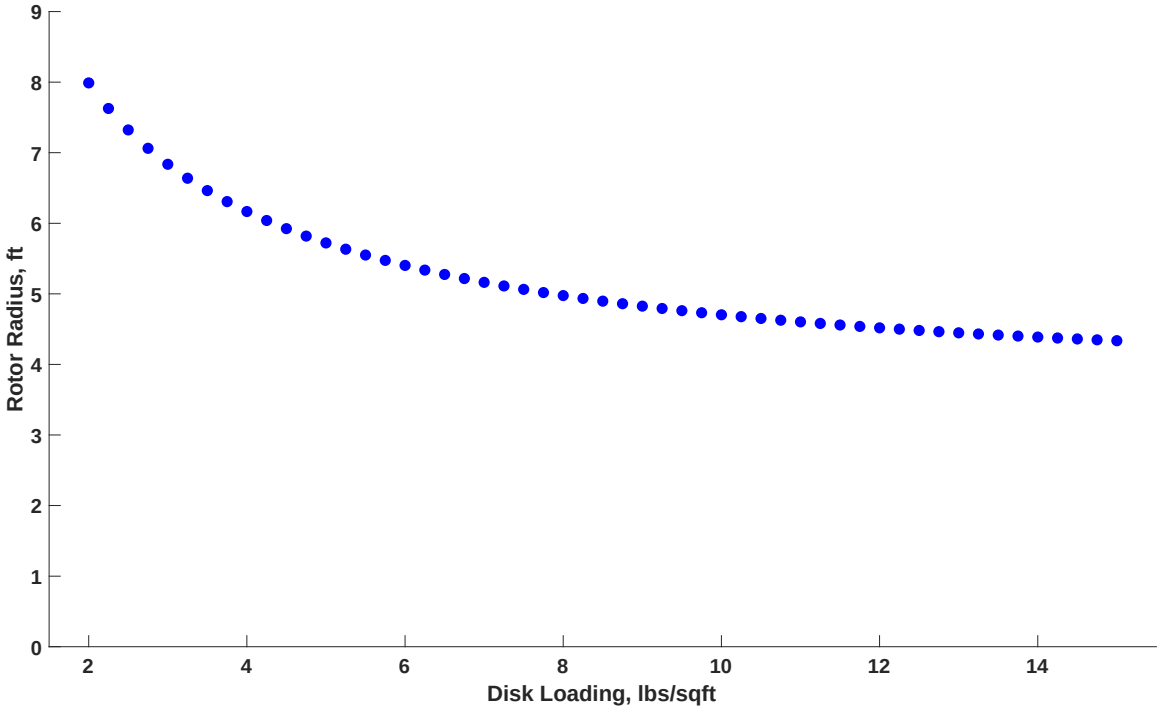


Weight vs Rotor Size

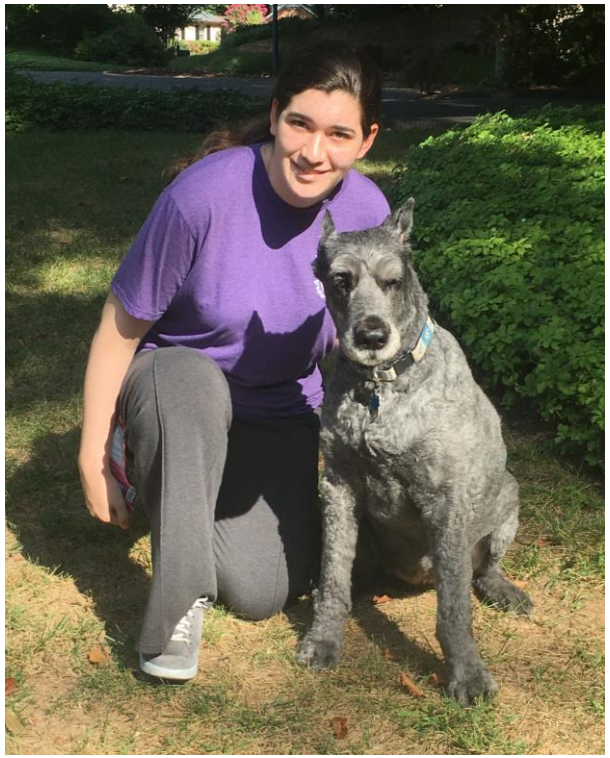
Weight increases with disk loading…



But rotor size decreases with disk loading!



Final eVTOL Specifications



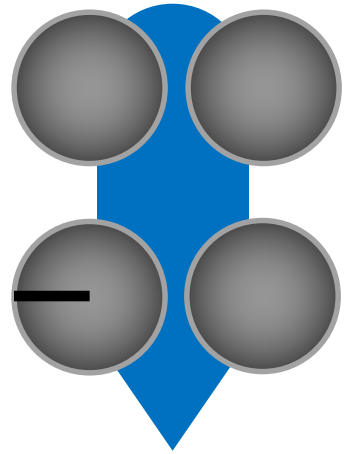
Disk Loading = 4 $\frac{lbs}{ft^2}$

Gross takeoff weight = 1907 lbs

Payload = 400 lbs

Battery weight = 810 lbs

Rotor radius = 6.2 feet



Total Mission Time = 27 minutes

Mission Range = 25.6 nautical miles (29.5 miles)

Thank You!