Battery Performance Degradation over Life Cycle

Achintya Pinninti, pinnintiachintya@gmail.com
Aerodynamic Research and Design Lab
Irvington High School, Class of 2020
USC Viterbi Department of Aerospace and Mechanical Engineering, SHINE 2019

USC Viterbi School of Engineering
Department of Aerospace and Mechanical Engineering

SHINE
Summer High School Intensive in Next-Generation Engineering

Introduction

Electric propulsion using batteries is a potential alternative to conventional propulsion using hydrocarbons. Battery-powered aircraft produce less emissions and may be quieter. However, there are unanswered questions about the efficiency and reliability of using batteries to power aircraft. My project aims to answer some of these questions.

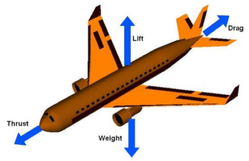
Objective & Impact

My Ph.D. mentor's research primarily focuses on modeling components (batteries, motors, and converters) for electrified aircraft. His research will prove whether battery-powered aircraft are viable with current and potential future technology. For my project, I was primarily involved with testing the batteries. Just like our phones, these batteries also lose capacity throughout their life cycle. My task was to analyze how batteries performed throughout their life cycle by repeatedly charging and discharging the batteries at different currents. This simulates how batteries would perform if they were to be used on a real flight. After every 5 cycles, the data collected was graphed to see whether there is a noticeable drop in capacity or time taken to discharge. If there is a noticeable drop in the capacity after a small number of cycles, then battery power may not be reliable for aircraft propulsion.

The NASA X-57 Maxwell, an all-electric plane which started development in 2015. Picture credit: NASA.

Skills Learned

Basic aerodynamic design
- Control Surfaces
- Reynolds Number
- Types of Jet Engines
- Breguet Range Equation
- Thrust, Weight, Lift, and Drag
- Fuel Efficiency and Lift-to-Drag Ratio



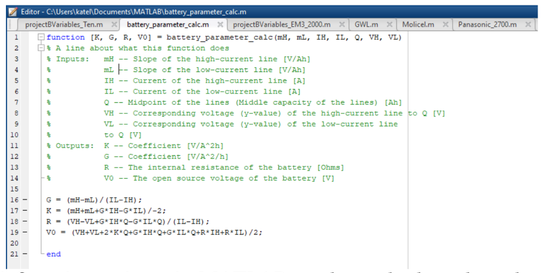
Picture credit: NASA

Analog Electronics
- Kirchhoff's Circuit Laws
- Current, Voltage, Power, Resistance
- Parallel and Series Connections
- Breadboarding
  - Operational Amplifiers and Circuits
  - Negative Feedback

Linearity

Battery Characteristics
- Battery Discharge Curve
- Nearly Linear Battery Discharge Model
- Capacity and Voltage

MATLAB



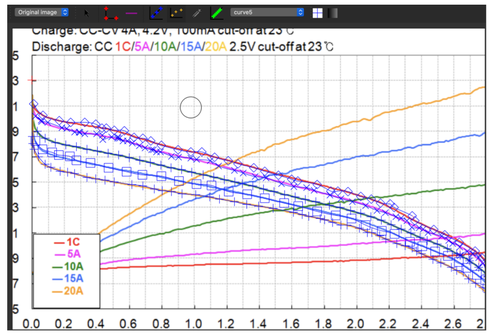
```
function [K, G, R, V0] = battery_parameter_calc(mH, mL, IH, IL, Q, VH, VL)
% A line about what this function does
% Inputs:   mH -- Slope of the high-current line [V/Ah]
%           mL -- Slope of the low-current line [V/Ah]
%           IH -- Current of the high-current line [A]
%           IL -- Current of the low-current line [A]
%           Q -- Midpoint of the lines (Middle capacity of the lines) [Ah]
%           VH -- Corresponding voltage (y-value) of the high-current line to Q [V]
%           VL -- Corresponding voltage (y-value) of the low-current line
%           to Q [V]
% Outputs:  K -- Coefficient [V/A^2h]
%           G -- Coefficient [V/A^2/h]
%           R -- The internal resistance of the battery [Ohms]
%           V0 -- The open source voltage of the battery [V]

G = (mH-mL)/(IL-IH);
K = (mH+mL+G*IH-G*IL)/-2;
R = (VH-VL+G*IH*Q-G*IL*Q)/(IL-IH);
V0 = (VH+VL+2*K*Q+G*IH*Q+G*IL*Q+R*IH+R*IL)/2;

end
```

A function written in MATLAB used to calculate the values of four crucial variables with seven given inputs. Picture credit: Katelyn Sulett.

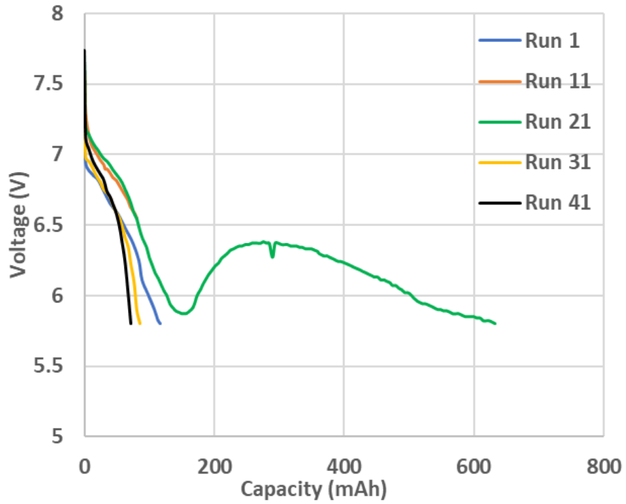
Engauge Digitizer (Data Grabber)



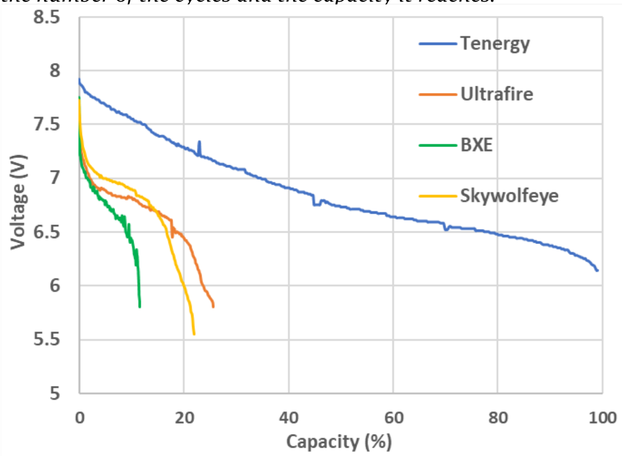
The Engauge Digitizer tool being used to generate data points from a given curve.

Outcomes/ Conclusions from Research

After testing 4 different batteries at 3 different currents, I noticed that:
- Available capacity is substantially less than rated capacity for most batteries.
- At higher currents, the available capacity decreases even further
- The first 40 cycles show little change in the battery capacity.
- At times, the batteries can be unreliable as the voltage can fluctuate as high up as ±0.8V from the previous mark.



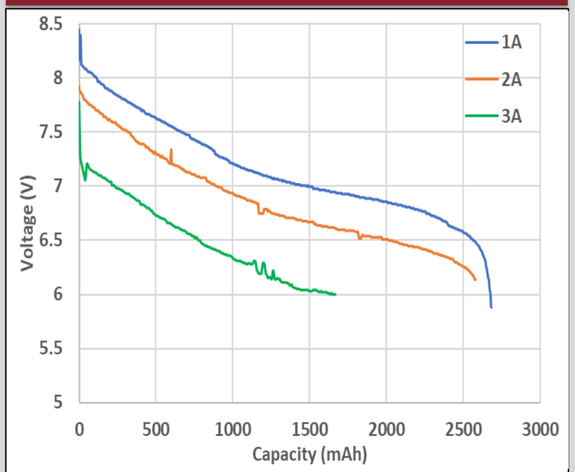
Plot of voltage vs. capacity from various runs of discharging Ultrafire batteries at 3A. This graph shows no clear trend between the number of the cycles and the capacity it reaches.



Plot of voltage vs. capacity as a percentage of the rated capacity. Tenergy was the only battery that came close to its rated capacity, while none of the others even came close.

A picture of our experimental setup used to test battery discharge.

Outcomes/Conclusions (cntd.)



Graph showing how discharging at lower currents yields higher capacities. At 1A, the battery reached the highest capacity of 2650 mAh, slightly above the rated capacity.

Acknowledgements

I would like to thank my Ph.D. mentor Saakar Byahut and Prof. Alejandra Uranga for giving me this amazing opportunity. I would also like to thank my lab partner Katelyn Sulett and my SHINE cohort, Dr. Katie Mills, Dr. Megan Herrold, and the rest of the SHINE team for making this a great experience. I would like to thank all the aerospace Ph.D. and undergraduate students for their guidance. Finally, I would also like to thank my parents for allowing me to pursue this opportunity.