IMPACT OF CHARGING RATE AND STATE OF CHARGE ON ELECTRIC AIRCRAFT BATTERY DEGRADATION

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OUTLINE

- Background
- Research Problem/Statement
- Multi-domain model
- Flights
- Results
- Conclusion

Aircraft battery LI-POL MGM COMPRO

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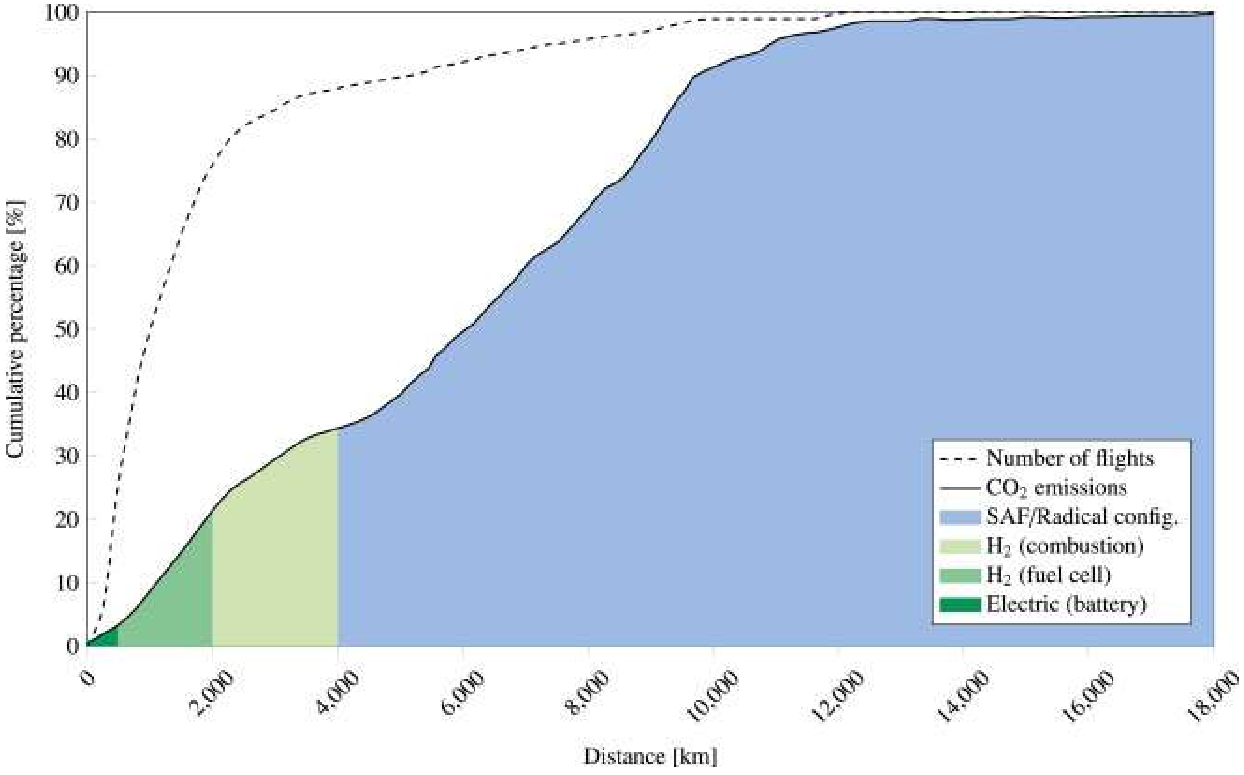
ELECTRIC AIRCRAFT PROGRESS

- Electrification has recently taken over many aspects of the transportation industry as a means to reduce our carbon footprint.
- However, electric aircraft have been in the works since the 20th century with many challenges relating to the battery. Such as the weight, limited range, power density, and much more.



Christian Svensson, Amir A.M. Oliveira, Tomas Grönstedt, Hydrogen fuel cell aircraft for the Nordic market, International Journal of Hydrogen Energy, Volume 61, 2024,

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COMMERCIAL ELECTRIC AIRCRAFT

- Companies like Pipistrel, and RGAC are making or have made a few electric aircraft for use in short-distance flights, and pilot training
  - Pipistrel, a Slovenian aircraft manufacturer, developed a 2-seater aircraft. It carries 172kg worth of load. It has a 57.6kW electric engine, a 20kWhr battery, and a range of 50 minutes
  - Rhyxeon General Aircraft Co., developed China’s first two-seater aircraft utilizing new energy technology. It operates on pure lithium batteries. It carries a 150 kg payload. It has an 80kW electric engine, a 50kWhr battery, and a range of 1.5hours

Pipistrel Velis Electro

RGAC Rhyxeon RX1E aircraft

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CHALLENGES OF ELECTRIC AIRCRAFT IN COMMERCIAL OPERATIONS

Challenges of Electric Aircraft for Commercial Flights:

- Extended charging times increase turnaround, causing delays and higher costs.
- Hot-swapping batteries poses safety risks, including overheating and faults.
- Lack of charging infrastructure limits airport readiness for high-capacity power needs.
- Disrupted flight schedules reduce operational efficiency and profitability.

HOT SWAPPING BATTERY PACKS

- Considering that batteries should be charged at lower rates and ready for swapping between flights to reduce waiting times during layover. The layovers are costly when extended.
- A company that implements a similar method is Gogoro, a Japanese company.
- They developed a battery swapping platform for electric bikes currently being used in 50 cities

Gogoro battery swapping platform

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FAST CHARGING

Fast-Charging Solutions for Electric Aircraft

- Fast-charging systems enable battery recharging while passengers board.
- Reduces ground time and improves flight schedule efficiency.
- Supports high-power demands of electric aircraft safely.
- Enhances passenger experience with seamless boarding and readiness.

Phihong showcases EV charging options

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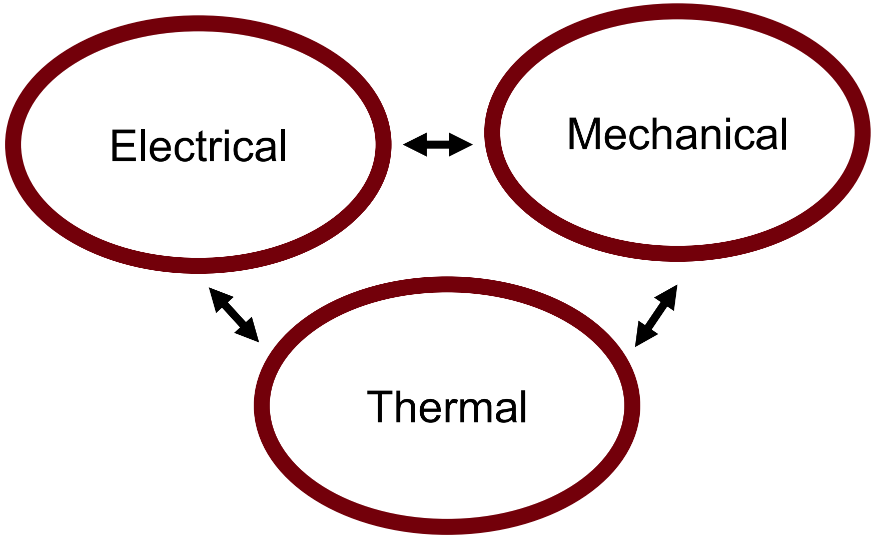
STATEMENT/PROBLEM

- How can we predict battery degradation for specific aircraft and battery specifications across predefined flight patterns?
- How can we use a multi-physics model to predict the combined effect of SOC and charging rate on the battery of predetermined electric aircraft paths?



Multi-physics model

AIRCRAFT SPECIFICATIONS

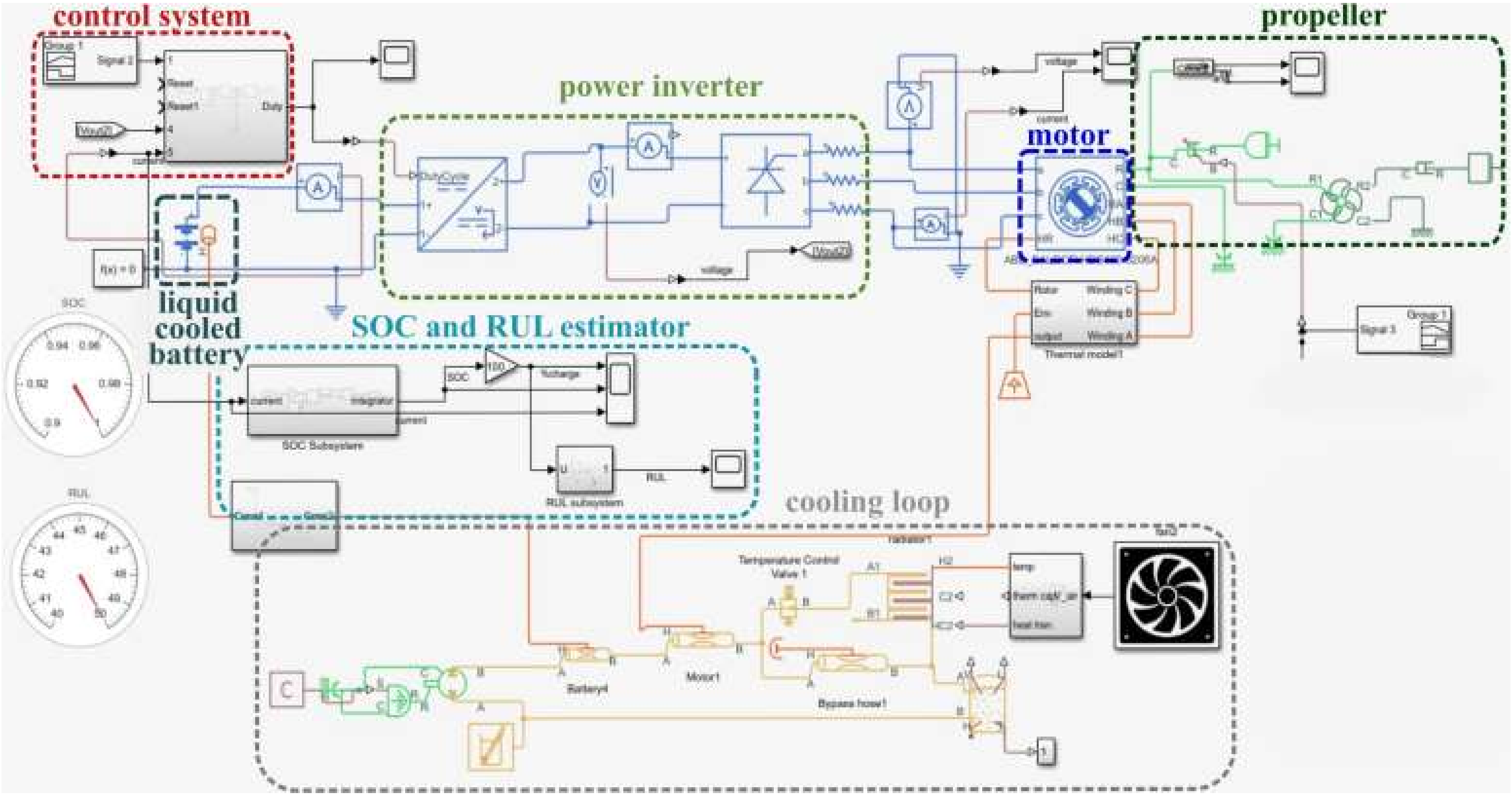
- The Cessna 206 is a six-seater plane commonly used for short-distance flights with a maximum range of 1300km
- It is a fuel-based aircraft
- In this model, it is adapted to serve as a fully electric aircraft with the same specifications

Battery Specifications	**Aircraft specifications**
Capacity – 260 Ahr	Passenger number - 6
Energy Capacity 109 kWhr	Max. Speed- 280 km/hr
Lithium-Ion- NMC cells	Cruise speed- 262 km/hr
	Horsepower- 300hp

Cessna 206 Stationair

MULTI-DOMAIN MODEL

- Here, the electrical, mechanical, and thermal aspects of the aircraft are combined.
- They are shown sectioned into their main components with the SOC and RUL subsystems attached



Full Simscape model

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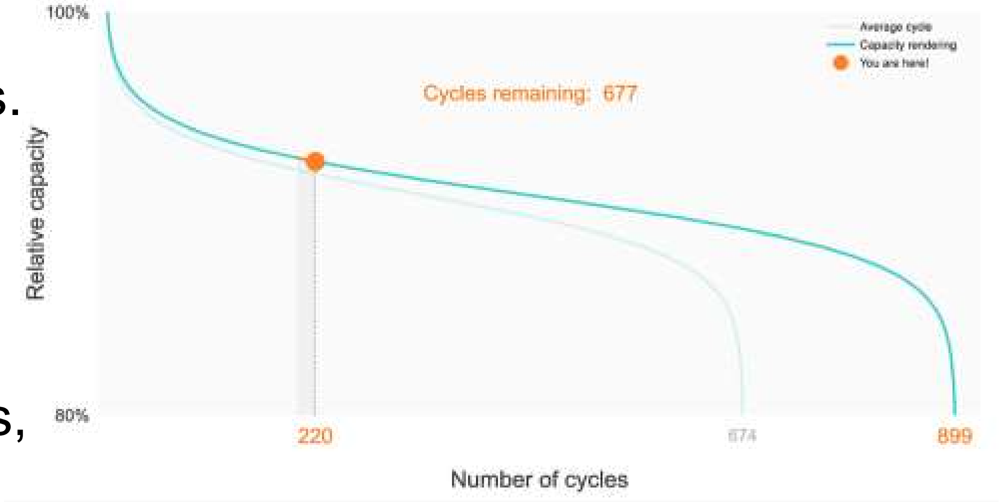
BATTERY CAPACITY TRENDS

- Focused on enhancing the viability of electric aircraft by optimizing battery performance for specific ranges.
- Targeted battery degradation influenced by charge rates and starting state of charge.
- The NMC degradation model predicts battery state-of-health (SOH) by analyzing stress factors such as temperature, depth-of-discharge (DOD), charge rates, and middle state of charge (mSOC).
- Empirical approach calibrated with 232 degradation tests provides accurate SOH estimation over full equivalent cycles (FECs).
- Insights from the model are adapted to suit our aircraft model and produce results shown later



Average battery lifetime

$$SOH = 100 - \beta \cdot exp\left(k_T \cdot \frac{T - T_{ref}}{T} + k_{DOD} \cdot DOD + k_{Cch} \cdot C_{ch} + k_{Cdch} \cdot C_{dch}\right) \cdot \left[1 + b_{mSOC} \cdot mSOC \cdot \left(1 - \frac{mSOC}{2 \cdot mSOC_{ref}}\right)\right] \cdot FEC^{\alpha_{opt}}$$

Josu, O., Iñigo, G., Andoni, S.-d.-I., Xabier, L., Txomin, N., and Iosu, A., “Modelling the cycling degradation of Li-ion batteries: Chemistry influenced stress factors,” Journal of Energy Storage, Vol. 40, 2021. https://doi.org/10.1016/j.est.2021.102765.

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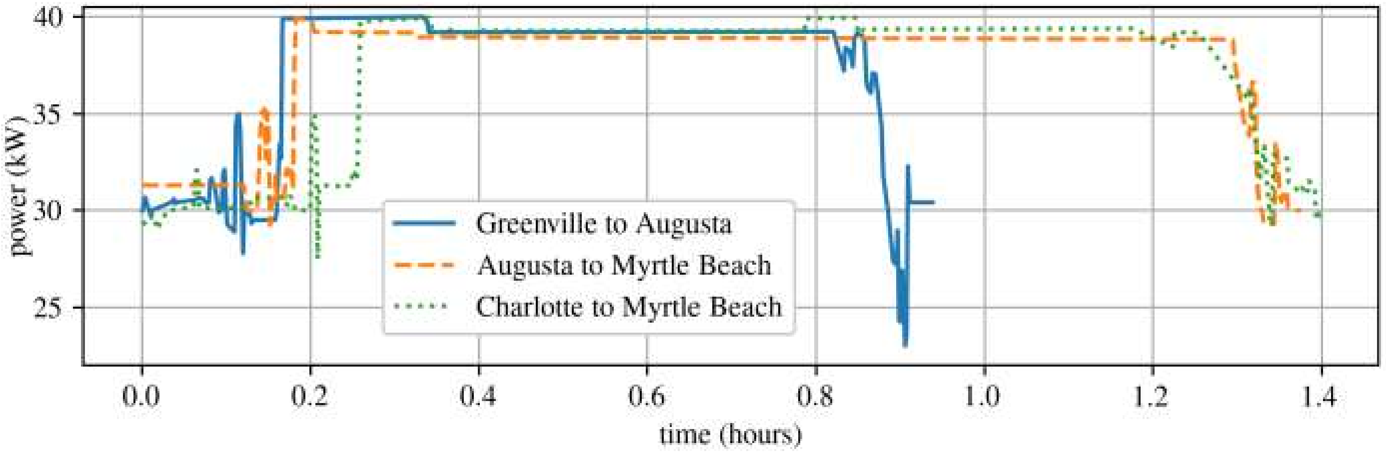
FLIGHT PATHS

- There are three flight paths across the Southeast of the United States simulated through the model
  - Greenville, South Carolina to Augusta, Georgia; Total energy- 35kW
  - Augusta, Georgia to Myrtle Beach, South Carolina; Total energy- 52kW
  - Charlotte, North Carolina to Myrtle Beach, South Carolina; Total energy- 52kW



Flight routes and load profiles

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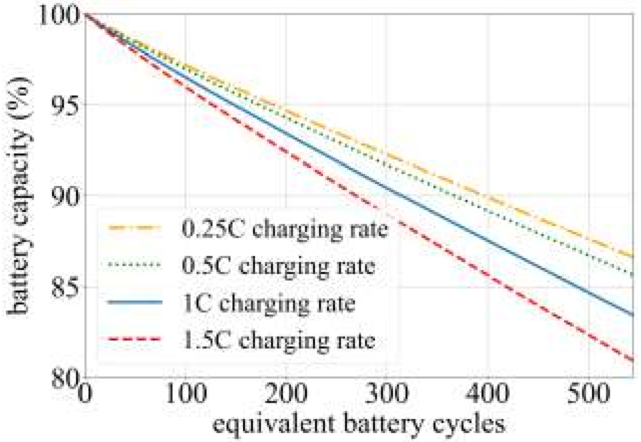
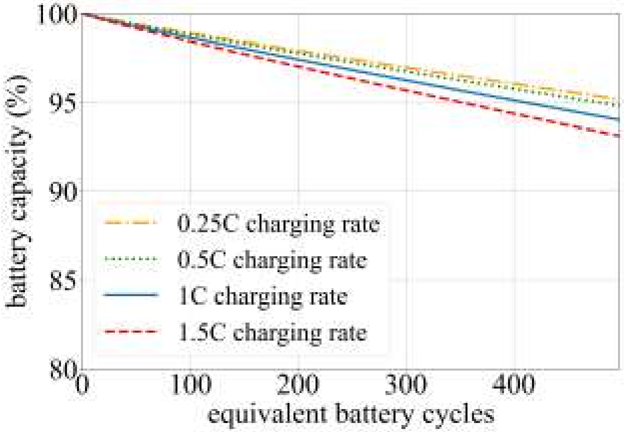
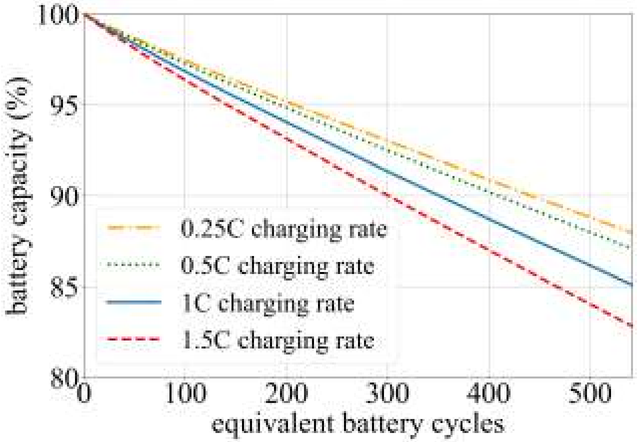
RESULTS (100% SOC EACH FLIGHT)



Augusta GA to Myrtle Beach SC



Greenville SC to Augusta GA



Charlotte NC to Myrtle Beach SC

- Shown are the results for the 4 different charging rates, 0.25C, 0.5C, 1C and 1.5C
- The lower rates show a decreased degradation in the battery

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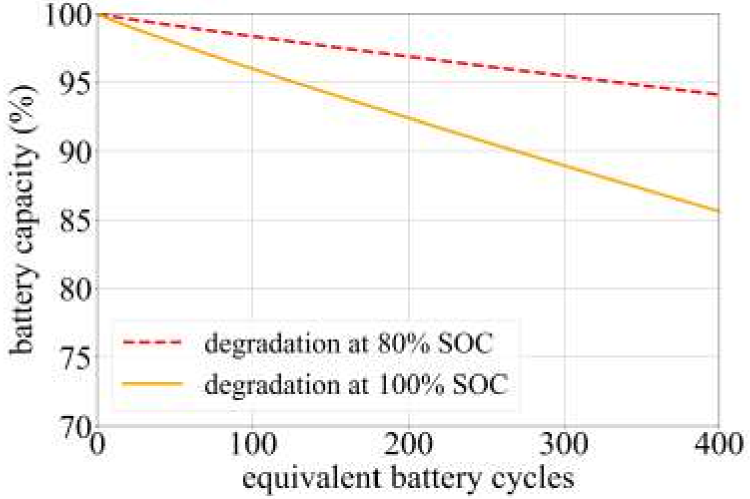
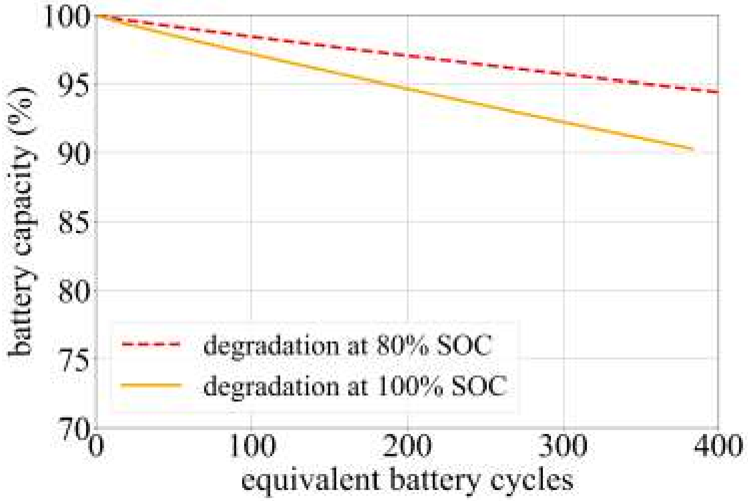
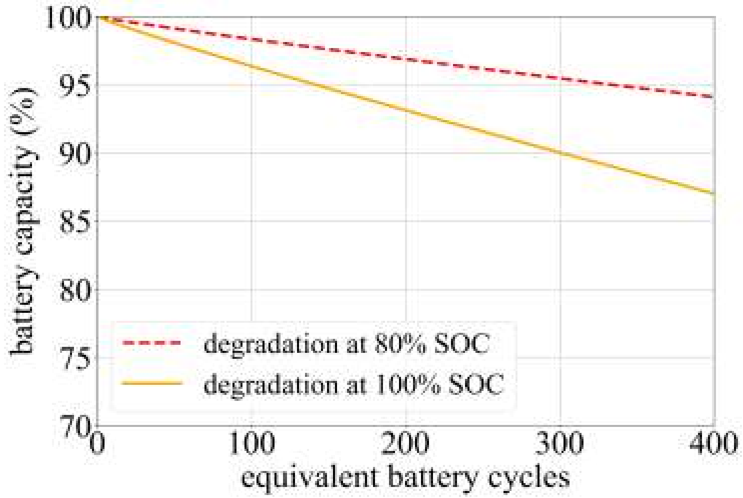
RESULTS



Augusta to Myrtle Beach



Greenville to Augusta



Charlotte to Myrtle Beach

- For the longer flights, the difference in degradation is about 7% while the shorter flight has a difference of 5%
- A change in SOC thus has a stronger effect on degradation than a change in the charging rate

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CONCLUSIONS

- Results show that longer flights increase the degradation rate
- A lower maximum SOC like 80% drastically increases the lifespan of the battery pack
- An increase in the charging rate led to an increased degradation rate also

THANK YOU

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Model repository (GitHub)

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