National Aeronautics and Space Administration

A Parametric Battery Model for the Conceptual Design of Electric Aircraft

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SACD
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Why a Parametric Battery Model (PBM)?

- Electric aviation industry is gaining momentum
- Batteries are rapidly improving
- Electric aircraft conceptual designs usually have an assumed specific energy (SE) and specific power (SP)
  - Battery treated as a black box
  - SE is tied to a discharge rate
  - SP corresponds to a state-of-charge (SOC)
  - Both of which will vary during a mission
- Why is this tool necessary?
  - Battery SE is much lower than jet fuel – we must maximize usable capacity
  - Determining how much of the lower SOC is usable requires power modeling

X-57 Maxwell - NASA

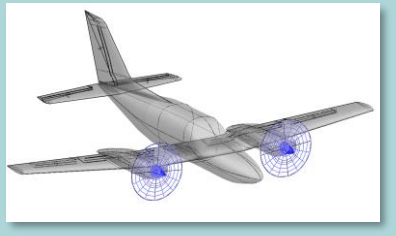
This tool is a fast, cheap method of discovering battery constraints early on at the conceptual level

Application

sUAS

- Small Unmanned Aircraft Systems
- No requirements comparable to reserve of RAM and UAM

Rotary Wing/Multirotor sUAS



RAM

- Regional Air Mobility
- Fixed-wing
- 9 to 19 passenger
- Distances up to 400 nmi
- Under 19,000 lb, 10,000 ft
- Reserve requirement
  - Minimum 30 minute cruise
  - Balked landing climb gradient
  - **Not necessarily max power**

Regional Air Mobility – SACD (nasa.gov)

UAM

- Urban Air Mobility
- eVTOL
- Reserve requirement
  - 20-30 minute Cruise requirement
  - Hover in vertical mode
  - **Close to max power**

NASA VTOL UAM Ref. Vehicles

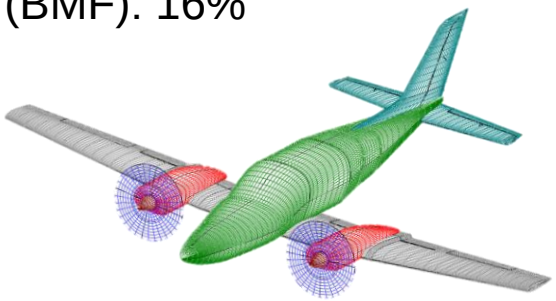
Electrified Aircraft


Cessna 402


Beechcraft King Air

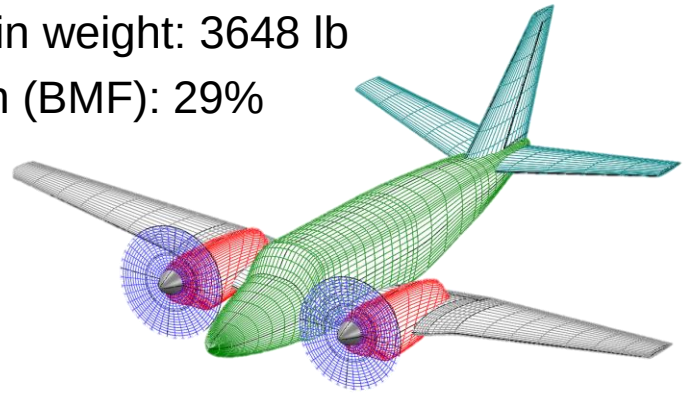
Twin Engine Regional Aircraft (TERA)

- Based on a Cessna 402C
- 8 passenger
- Max takeoff weight: 6850 lb
- Wing area 225.8 ft^2
- Motor power: 242 kW
- Battery and Powertrain weight: 1216 lb
- Battery Mass Fraction (BMF): 16%

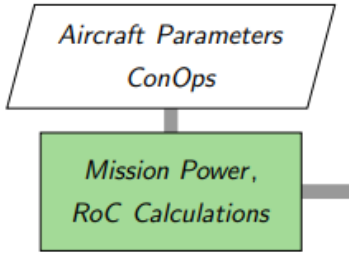


Extended-Range TERA (EXTERA)

- Based on a Beechcraft King Air
- 9 passenger (originally 13)
- Max takeoff weight: 11800 lb
- Wing area 279.7 ft^2
- Motor power: 533 kW
- Battery and Powertrain weight: 3648 lb
- Battery Mass Fraction (BMF): 29%

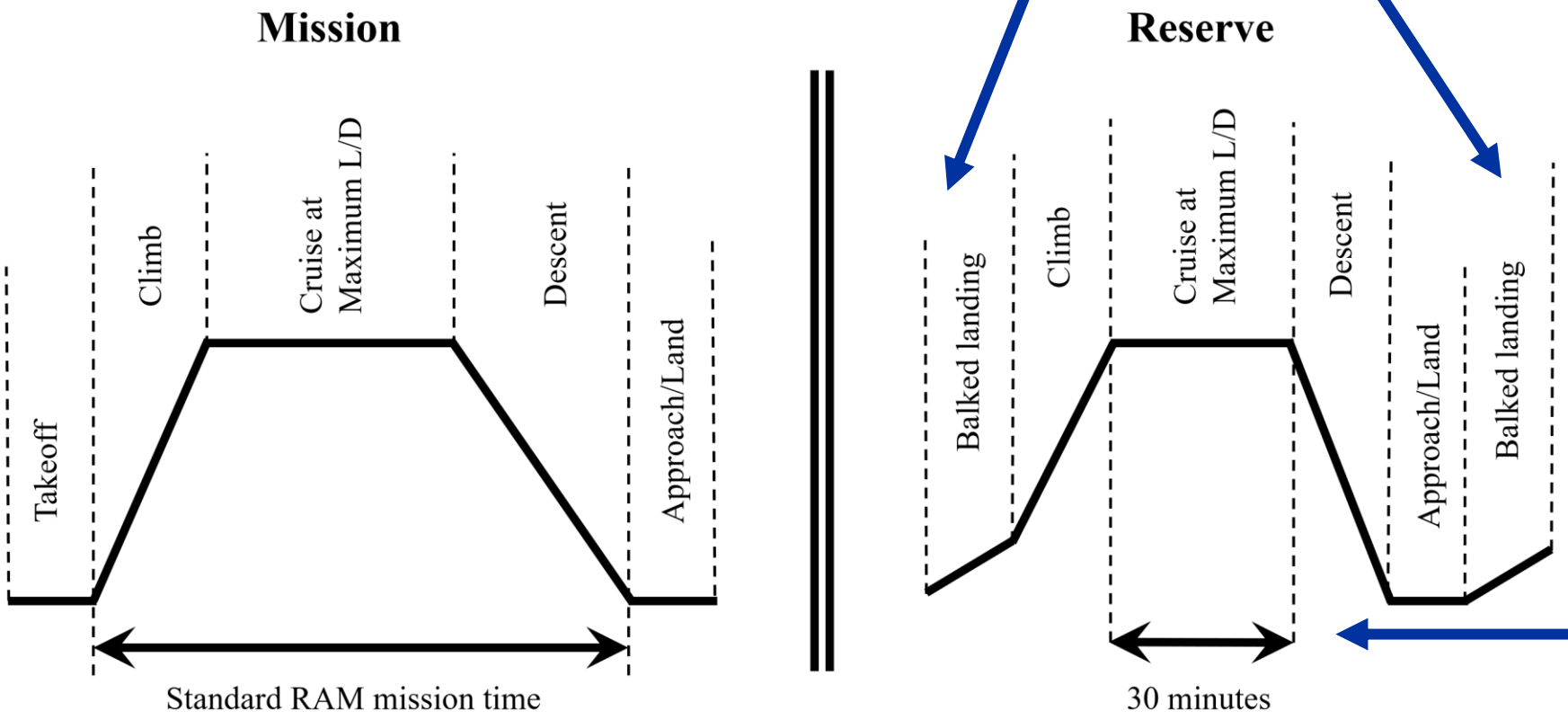


Modeling Approach



Mission

Power requirement: balked landing climb gradient of 3%



Energy requirement: 30 minutes at normal cruise speed

Iteration direction

Simple Battery Model

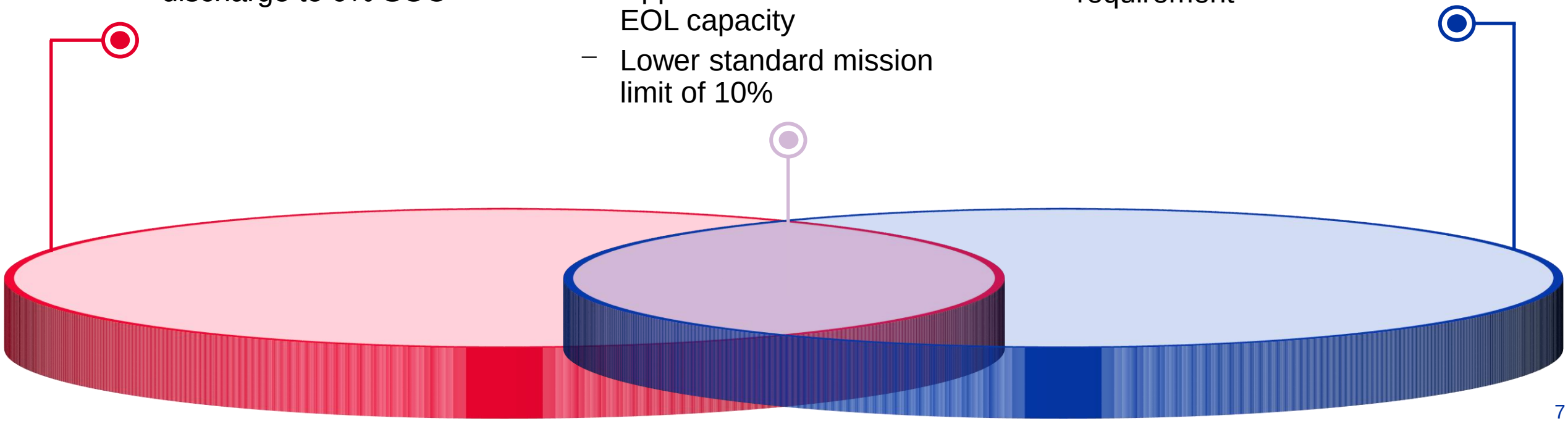
- Sized using SE and weight
- Mission flown with energy required per mission segment
- Constant power availability
- Battery allowed to discharge to 0% SOC

Both

- Fixed battery weight, powertrain
- Variable cruise length
- 90% of total capacity end-of-life (EOL) capacity
- Upper SOC limit of 95% of EOL capacity
- Lower standard mission limit of 10%

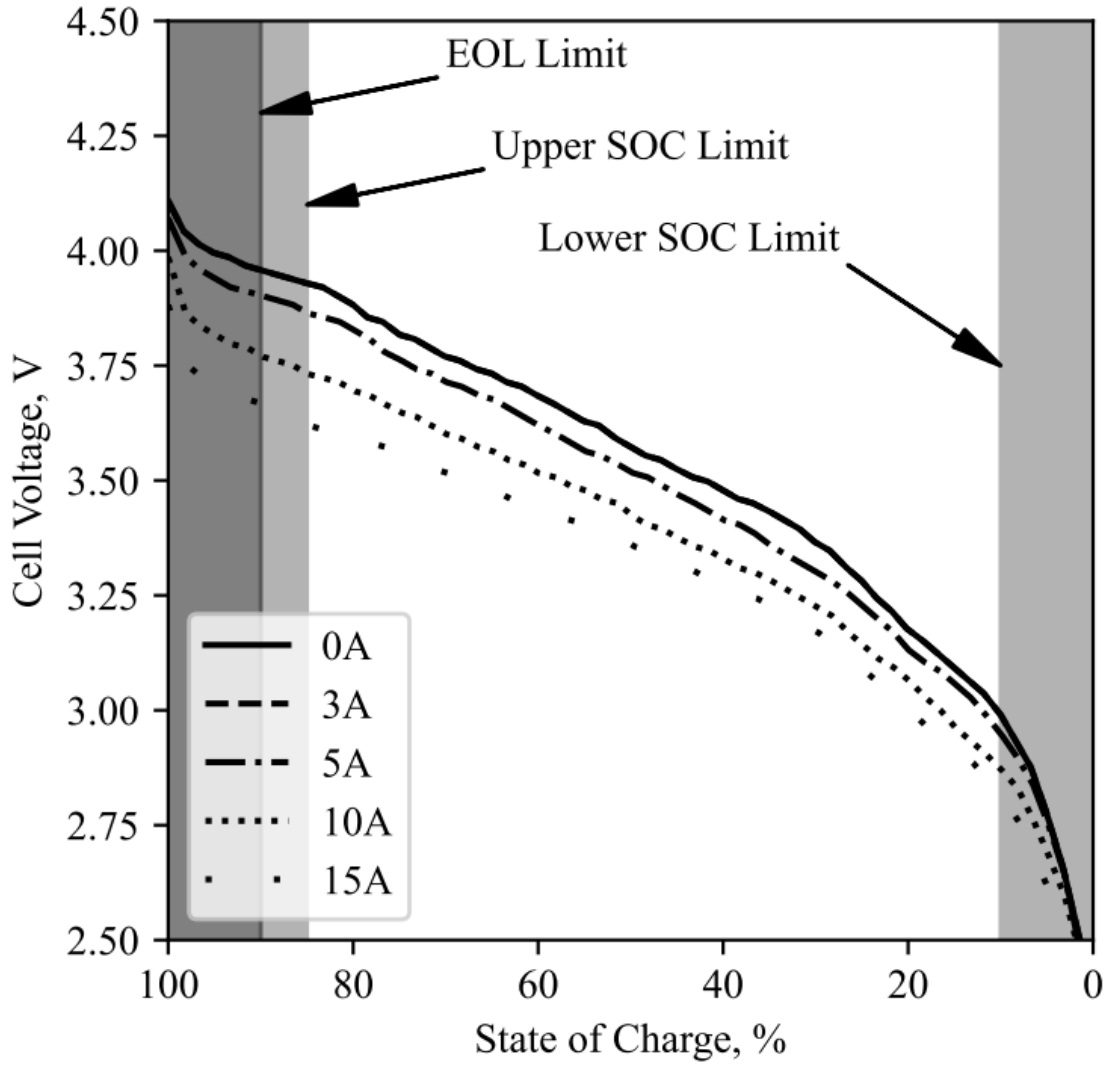
Parametric Battery Model

- Configured using cell weight, knockdown factor (25%)
- Modeled with cell discharge data
- Lower, unusable SOC limit set by balked landing power requirement



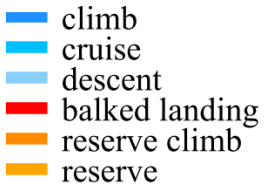
Parametric Battery Model

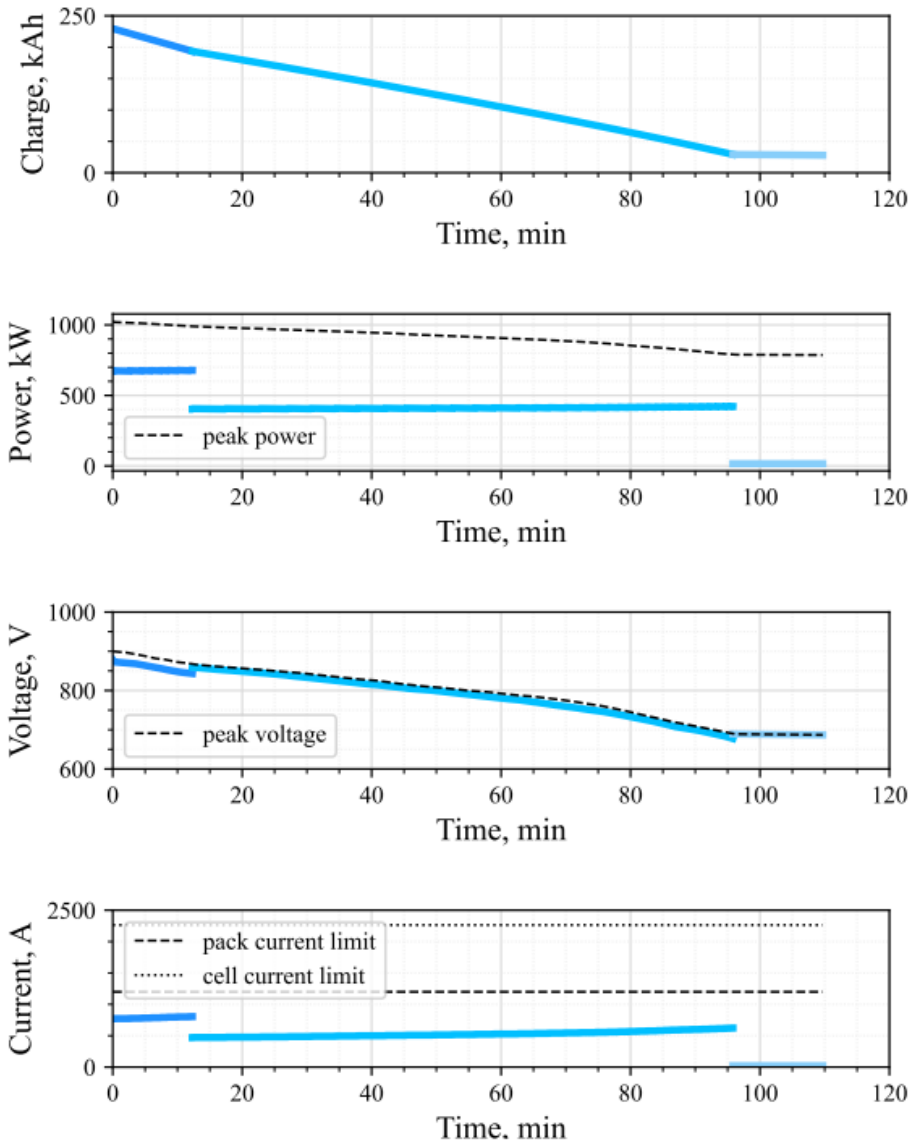
- Voltage drop
  - ~25% with SOC
  - 10% at higher power levels
  - A high power load will lower the voltage to meet a current demand
  - At low SOC, this issue is exacerbated as it already is at a lower voltage
- Cell characteristics from NASA's X-57
  - 3.00 Ah (varied)
  - 4.2 V, 20 A
- Pack
  - 900 V (Paschen curve)
  - Pack current varied
  - Cells set in series, then parallel
  - Overall representation of battery pack, but in reality will have submodules



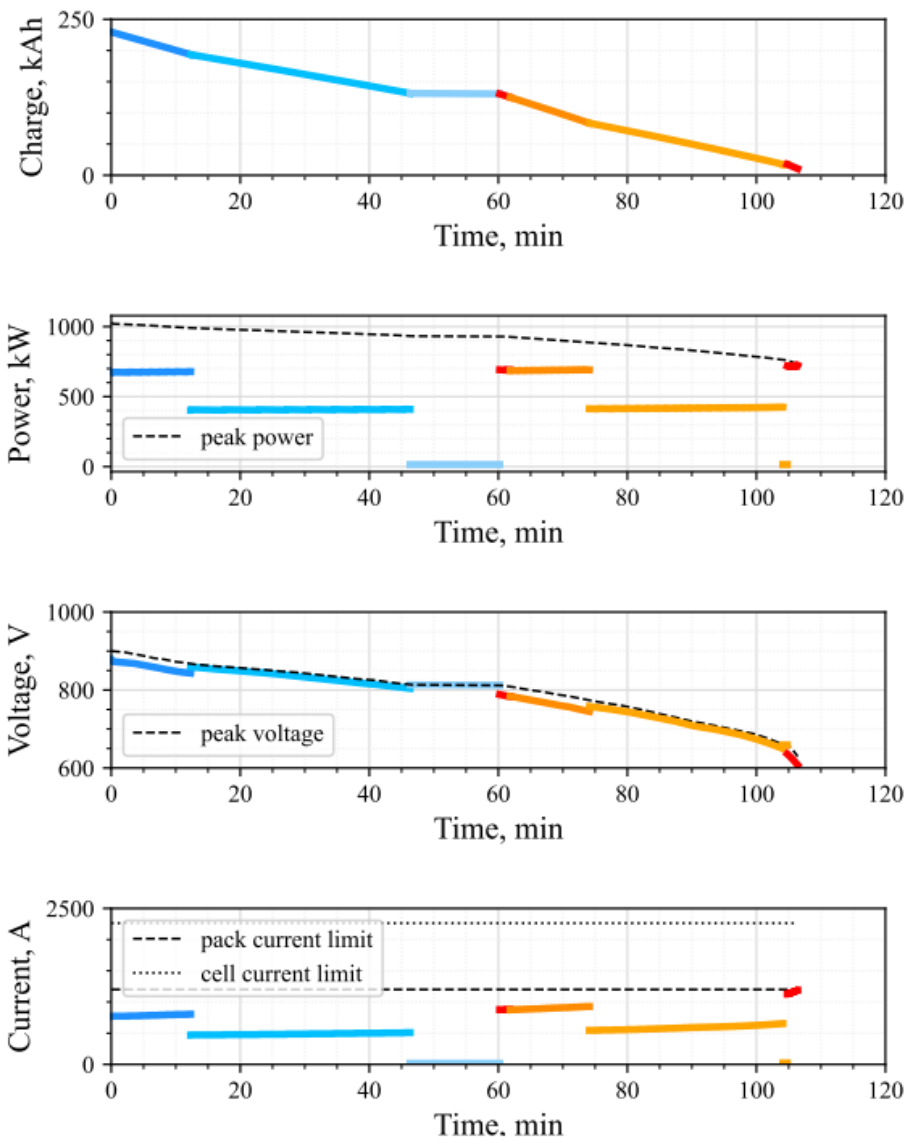
Balked Landing

- EXTERA aircraft
- 600 Wh/kg
- 1200A current limit
- 190 nmi range without reserve
- 77 nmi range with reserve





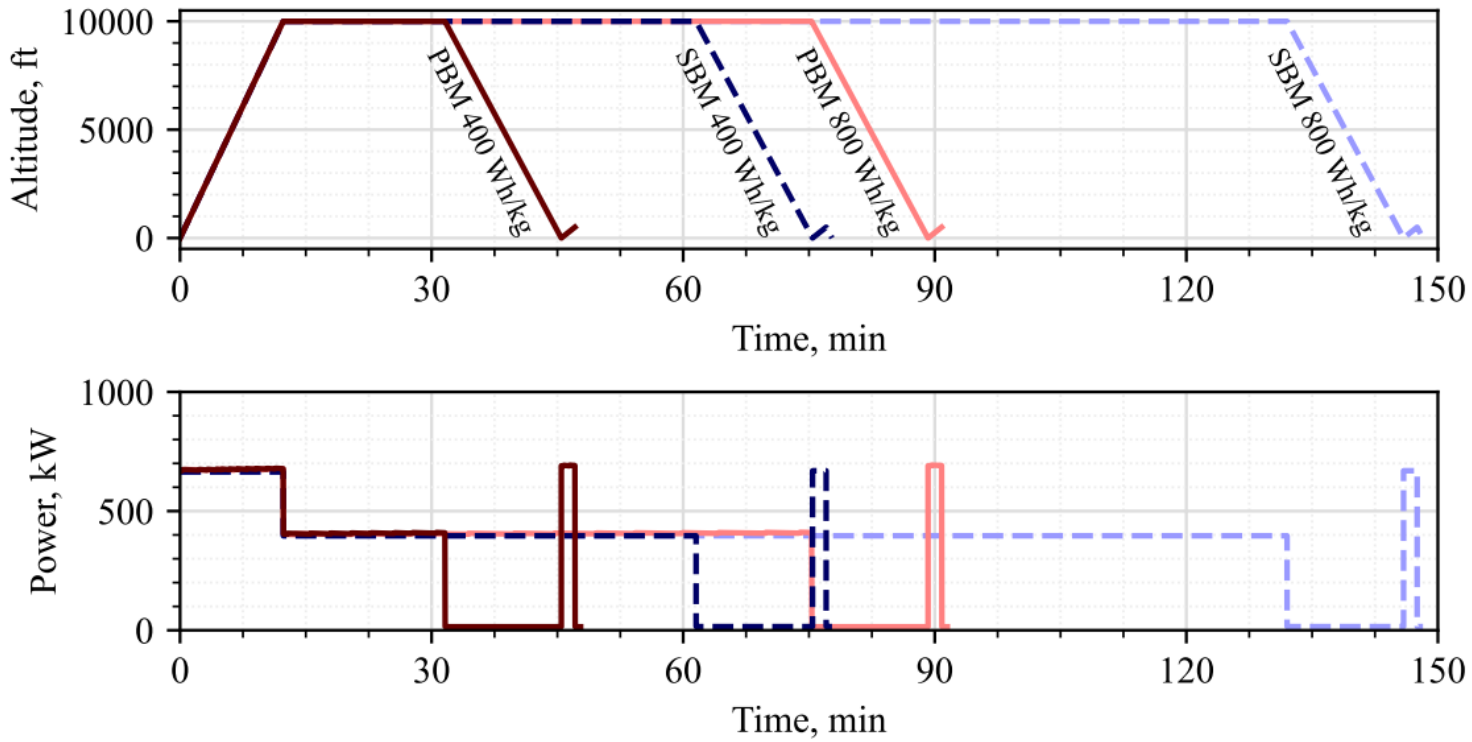
(a) Without balked landing or reserve cruise



(b) With balked landing and reserve cruise

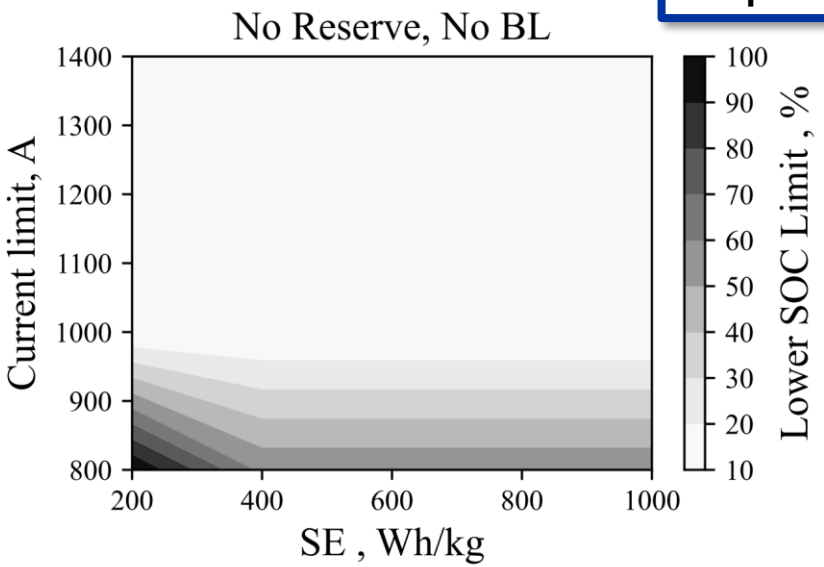
Parametric vs. Simple Battery Model

- Balked landing only
- 900 A pack current limit
- Limited pack current results in larger disparity between models
- At the same SE there can be a sizeable difference between models
- SBM does not account for power limitations



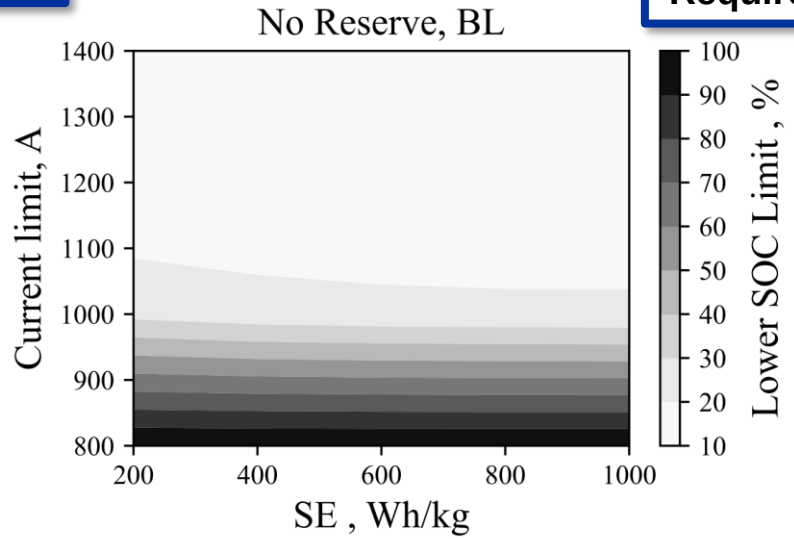
Standard Mission Lower State-of-Charge

EOM Power Requirement

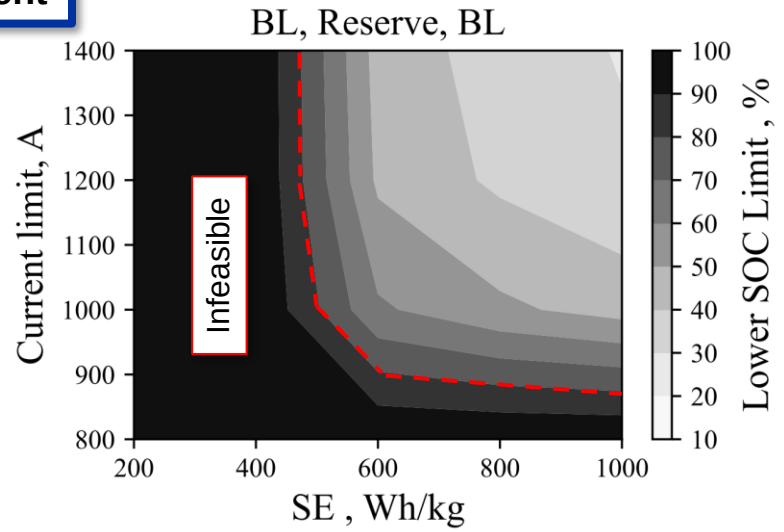


- Low SE (200 Wh/kg) and low pack current (800 A) is most limiting

EOM Energy & Power Requirement



- Introduction of power requirement highlights current limit



- Low SE are infeasible
- Current limit trend still relevant due to BL
- Lower SE more sensitive to current limits

Concluding Remarks

- The lower SOC limit for the standard mission is determined by the reserve mission segments
- The absolute, unusable SOC limit is set by the balked landing power requirement
- The capacity below the lower limit for battery health can be used for a portion of the reserve mission energy requirements, even with an EOM high power requirement
- Underlying parameters such as cell voltage drop and pack level current play strong roles in the feasibility of a battery powered mission

This study is our team's first application of parametric battery modeling to electric aircraft design!

National Aeronautics and Space Administration

Thank you

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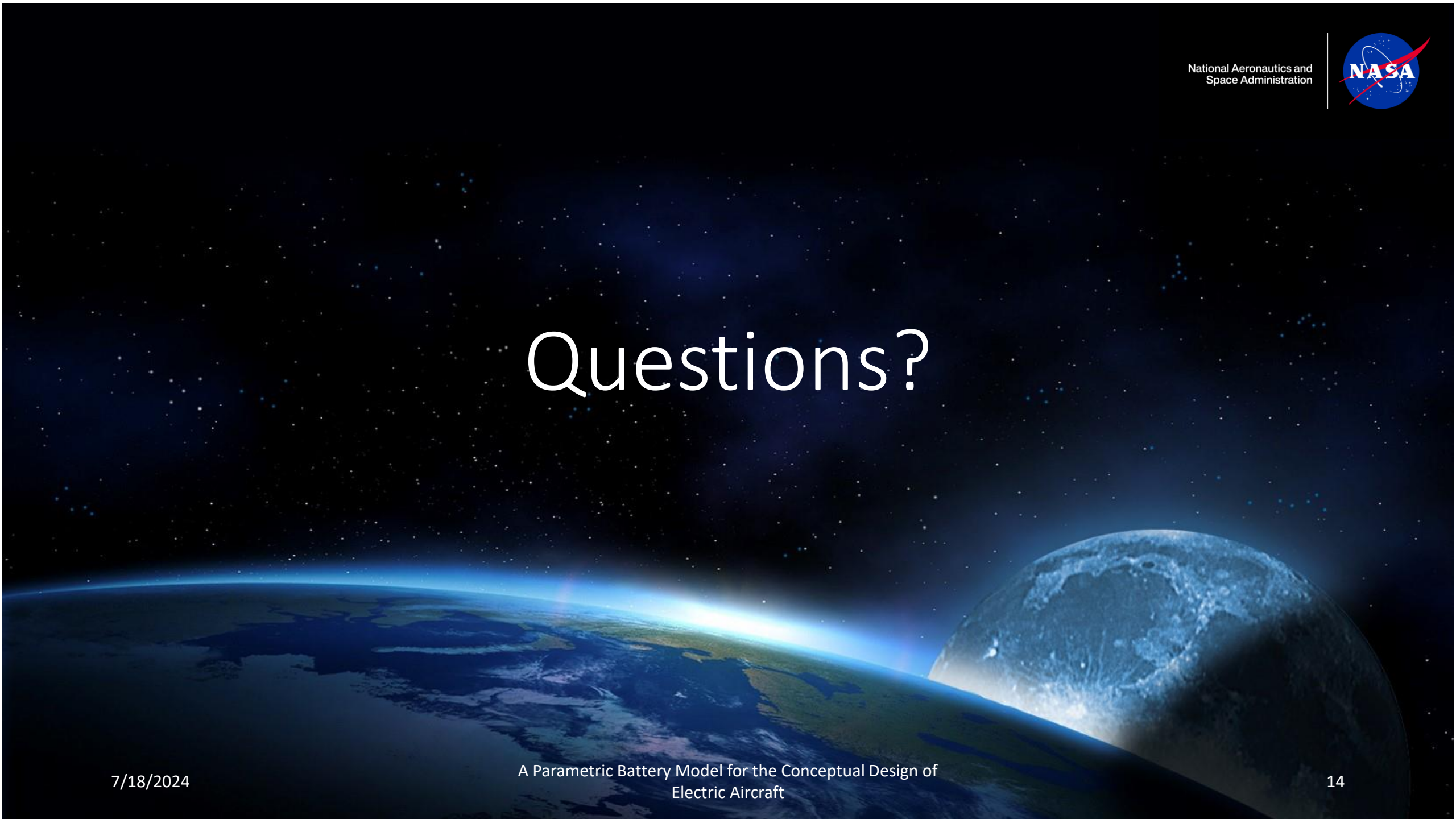
- Transformative Aeronautics Concepts Program (TACP)
- Convergent Aeronautics Solutions (CAS) Project
- Aircraft as Energy Nodes (ÆNodes) Activity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Questions?