



ATMOS[®]

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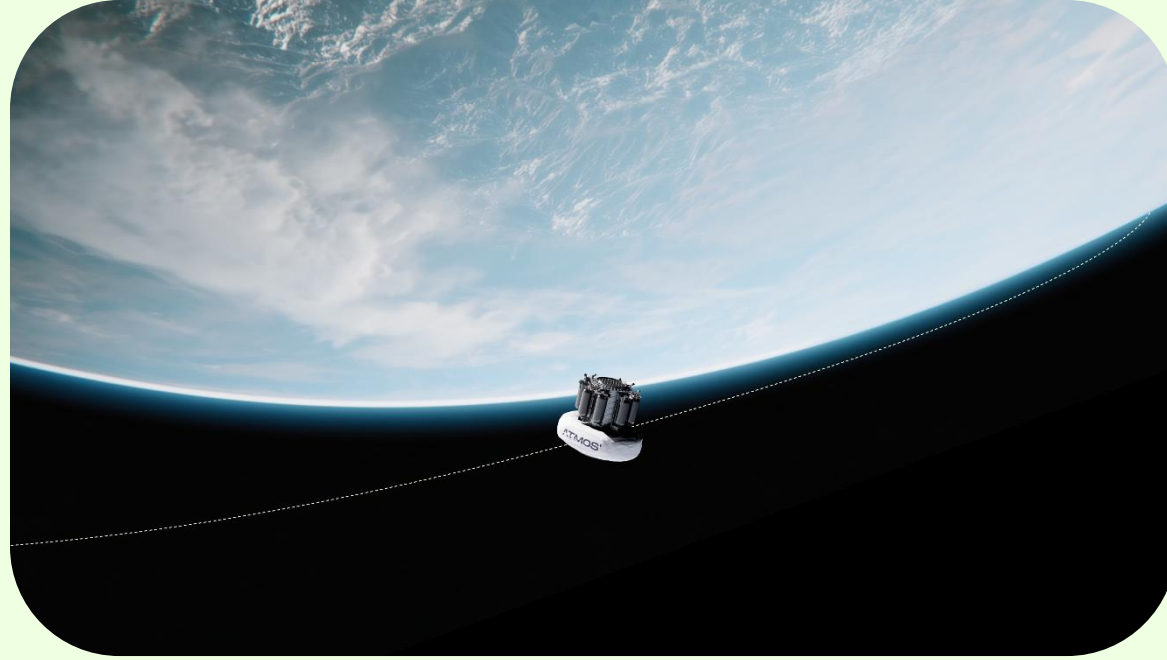
Integrated Thermal Analysis and Battery Energy Management of the Spacecraft Orbital Transfer and Return Vehicle Using TAITherm



THERMO
ANALYTICS 

Agenda

- Introduction
- Thermal simulation of Battery pack
- Boundary conditions for orbital phase
- Thermal simulation result for orbital phase
- Conclusions



OUR CORE TECHNOLOGY: PHOENIX RETURN CAPSULE

The PHOENIX transport capsule features a highly innovative Inflatable Heat Shield to transport and return cargo from Low Earth Orbit (LEO) to Earth.

- Access to and from LEO
- Flexible Mission Duration starting at 3h
- Payload recovery after return from space



LIFE SCIENCES & BIOTECH

IN-SPACE MANUFACTURING

DUAL-USE CARGO



MASS
EFFICIENCY

Up to 10x more
payload for the
same cost



DATA DOWN-
& UPSTREAM

Remote payload
control and
operations



TEMPERATURE
& PRESSURE

Sensor controlled
environment



PRECISION
LANDING

10x better landing
accuracy than round cap
parachute capsules

INDUSTRIES



THERMO[®]
ANALYTICS

Introduction ThermoAnalytics



1996

ThermoAnalytics, Inc.
(TAI) founded



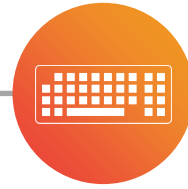
2002

TAI becomes an
employee-owned
company



2004

Novi, MI office
opens



2007

Commercial
Applications
take off



2014

European
office opens



2023

Asian
office opens

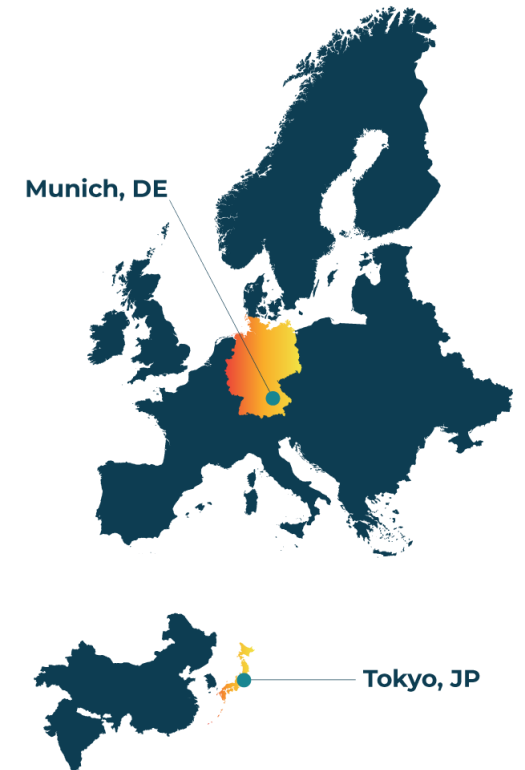
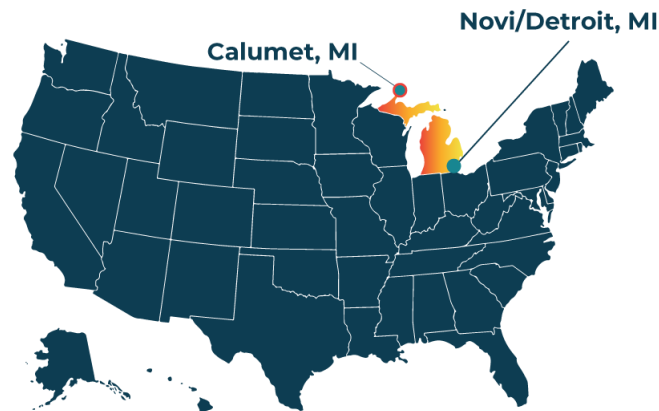
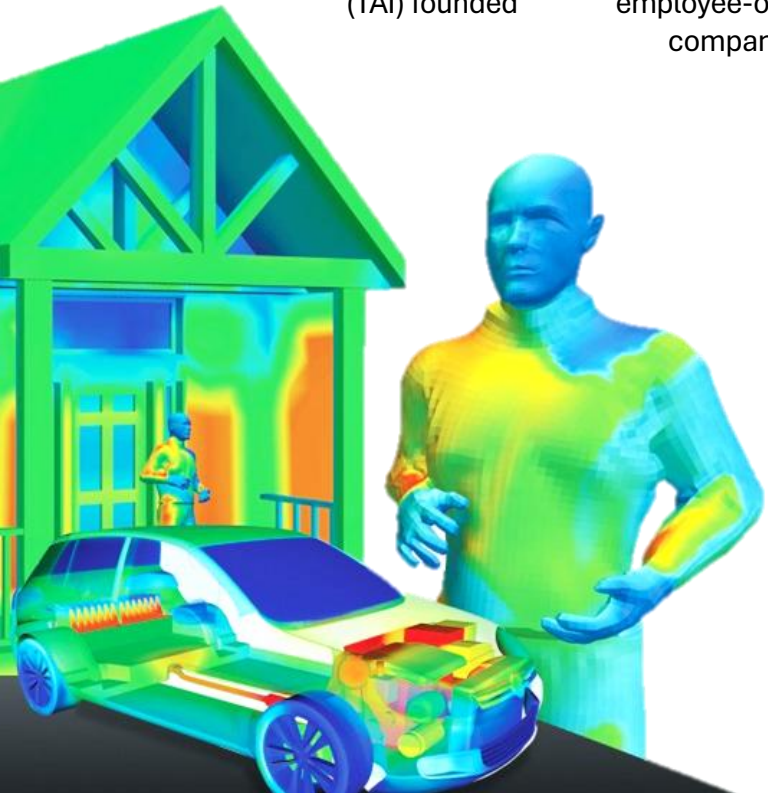


NOW

Worldwide
presence

Locations

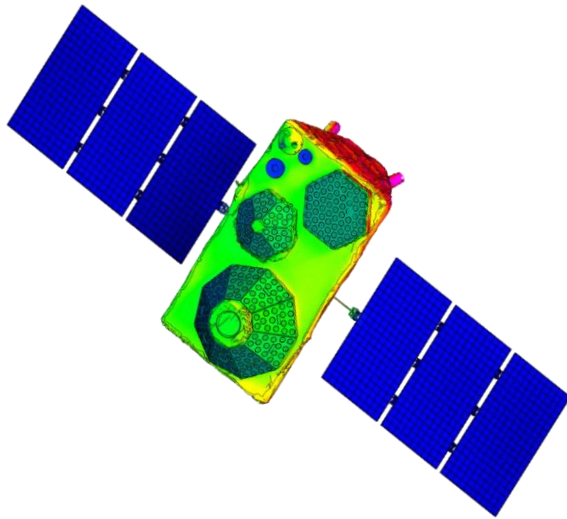
Our offices are located in the United States, Germany, and Japan.



Engineering Solutions for Automotive, Architecture, Aerospace & Electronics

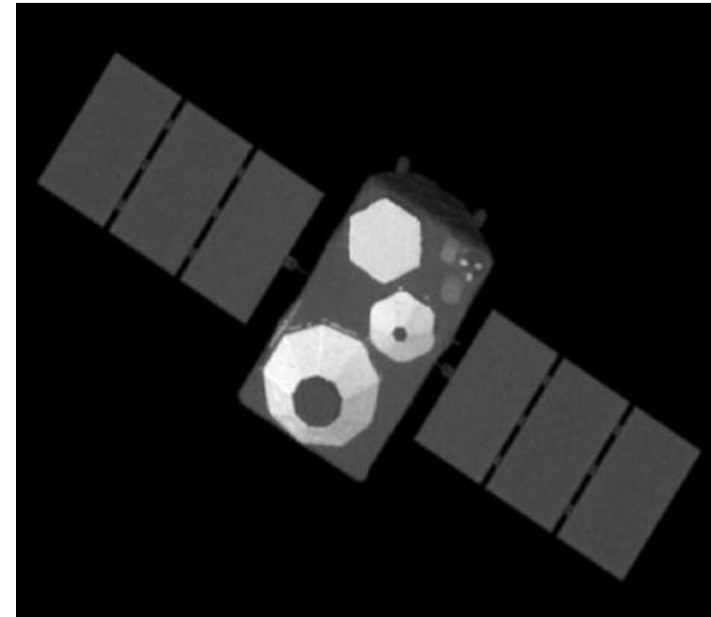
TAITherm

- 3D Transient Thermal Simulation Software
- Highly accurate multi-bounce viewfactor calculations
- Supports large models with detailed geometry
- Very fast runtimes even on local laptop!

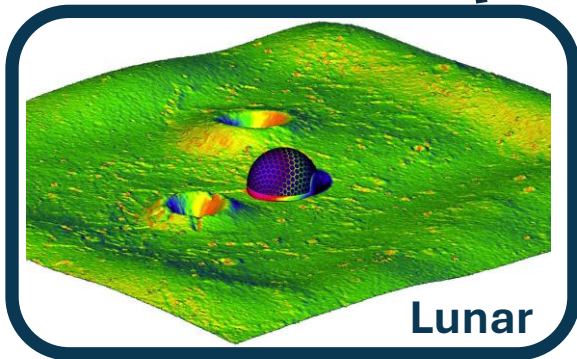
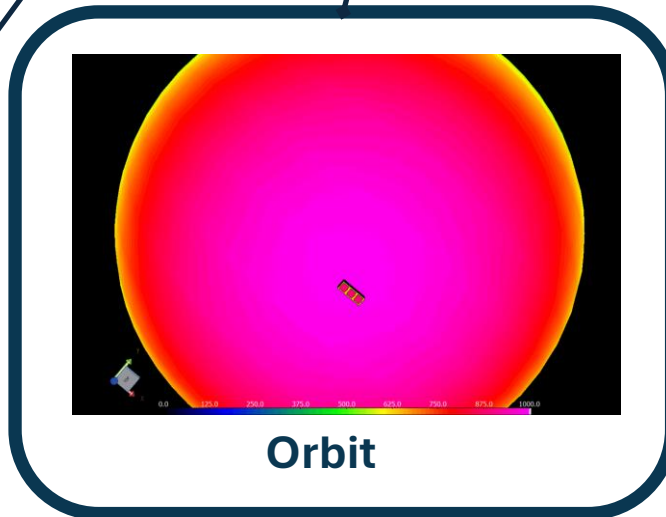
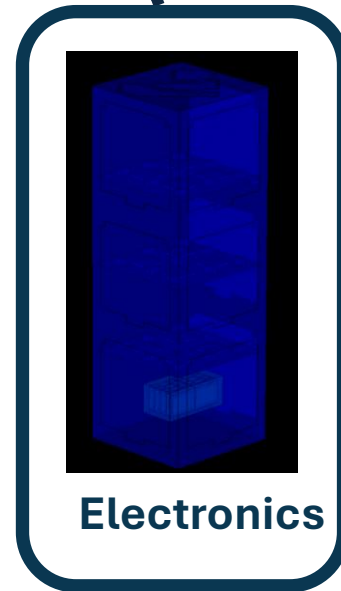
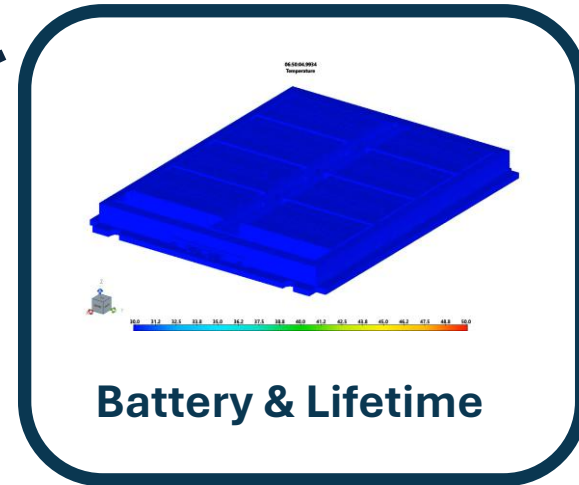
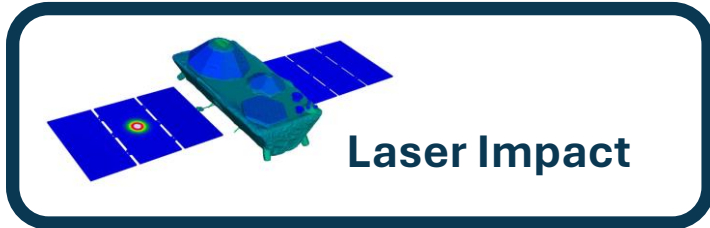
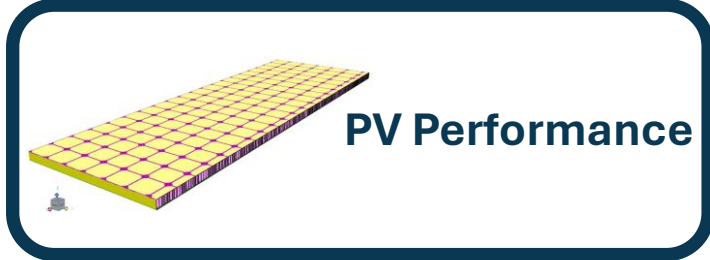
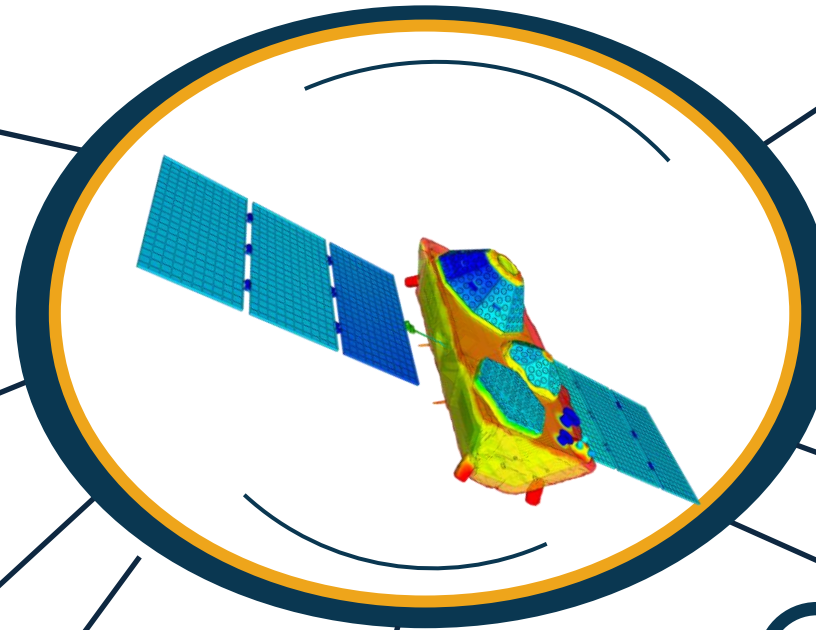


MuSES

- Predicts Infra-Red Signature based on calculated temperatures
 - How visible is satellite for other IR camera?
 - Train algorithm to detect other satellites
 - Train algorithm for ground detection



Space Applications



MODEL GEOMETRY FOR ATMOSPHERIC RE-ENTRY SIMULATION

- The ATMOS IAD is a 6 m single volume toroidal inflatable structure
- It features a 770 mm radiatively cooled rigid heatshield directly below the payload bay



Note: This is an image of PHOENIX-1.

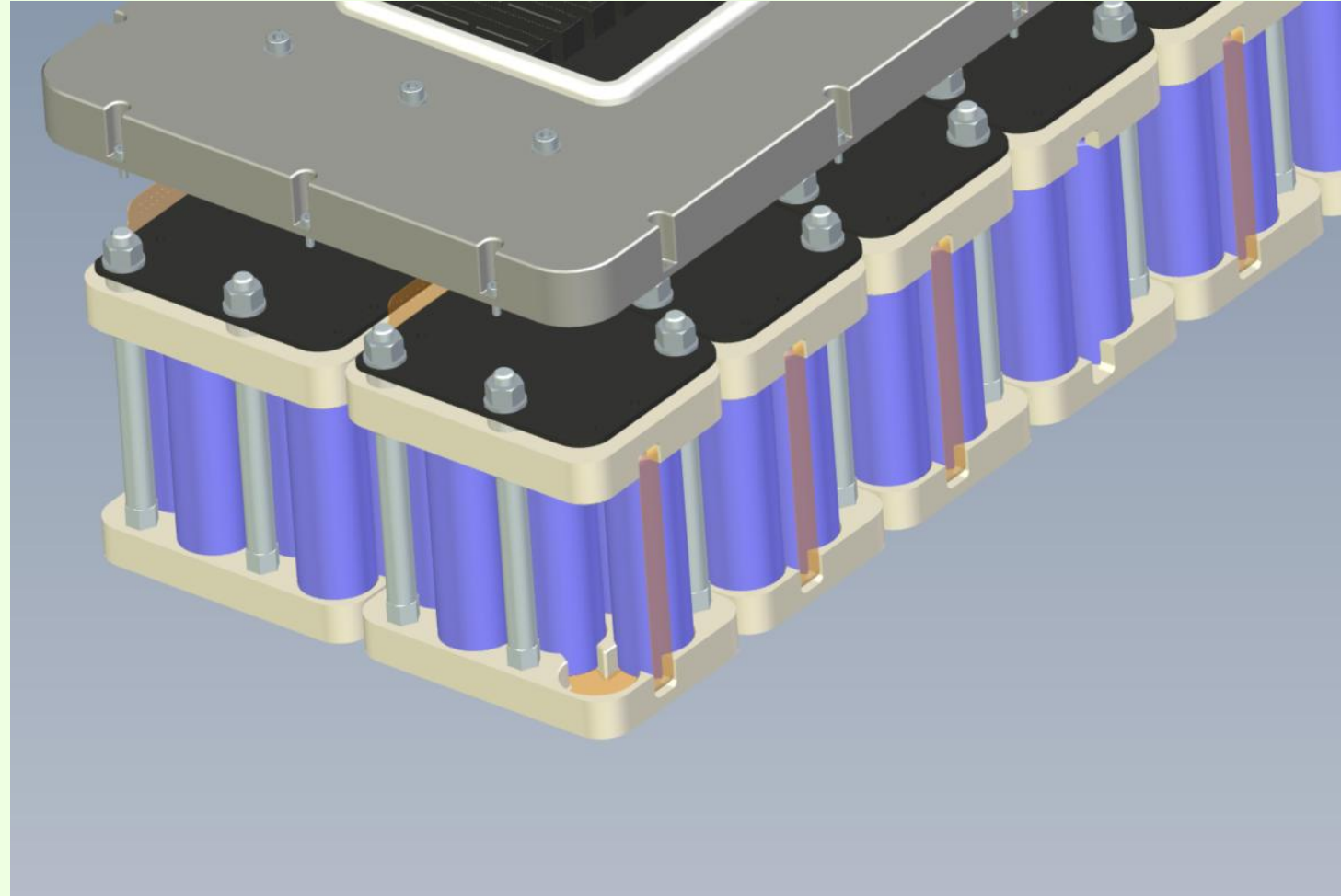
PHOENIX-2(Right side) is the next version, which is currently developing.

Local model - Battery pack Simulation, Introduction

- Predict battery pack temperatures using TAlTherm 3D Software
- Compare with Experiment for:
 - 50 Cycle Charge/Discharge phase
 - Full Discharge Phase

Local model - Battery pack Experiment, Set-up

- Vacuum chamber
- Ambient 25°C



Local model - Battery pack Experiment, Set-up

- Battery Pack
 - 14P8S
 - Samsung 25R 18650 lithium-ion cells
 - 35Ah, 1.036kWh, 28V
- Phase 1: 50 Cycles
 - Duration 6 hours
 - Discharge 120A during 20 seconds
 - Charge 16A during 400 seconds
- Phase 2: Constant Discharge
 - Duration: 1.5 hours
 - Discharge 17.5A

Local model - Battery pack Simulation, Set-up Thermal Model

- 52,000 elements
- Shell Based (Finite Difference)
- Duration: 7.5h
- Runtime on 16 procs: 20min

Model Size (mm):

X = 171.712

Y = 390.735

Z = 123.5

Visible Size (mm):

X = 151.8

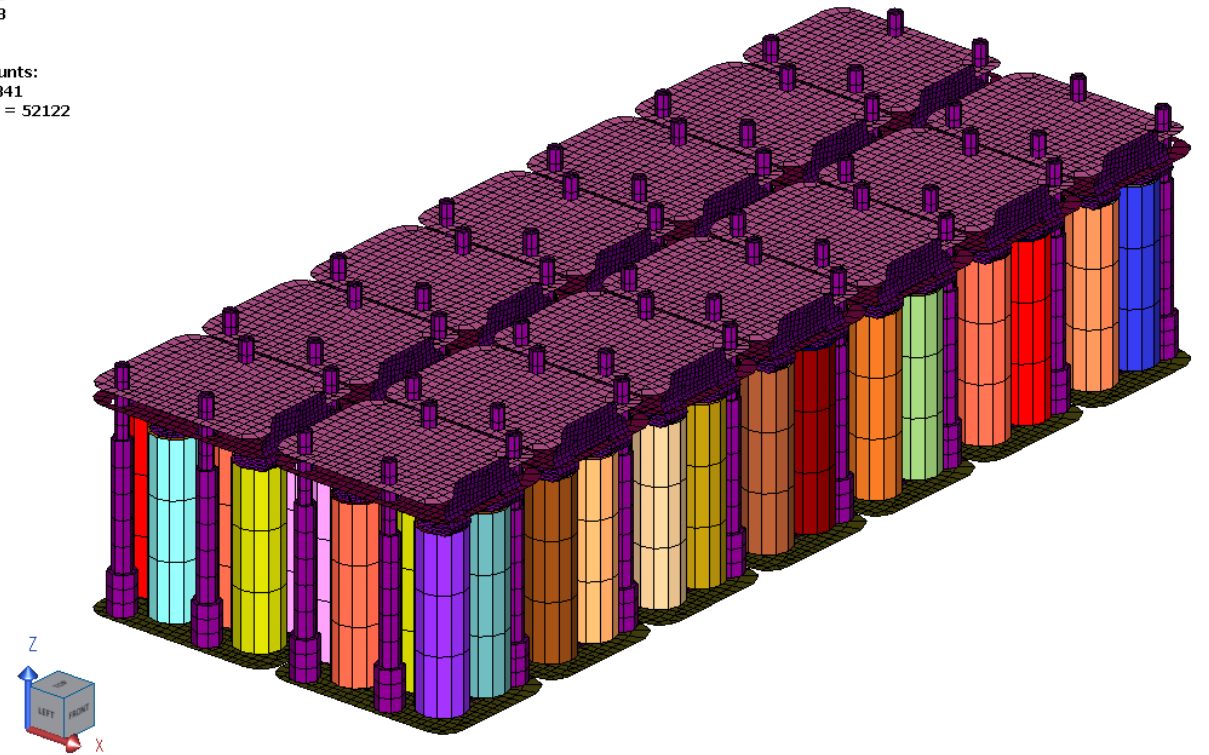
Y = 375.8

Z = 87.5

Visible Counts:

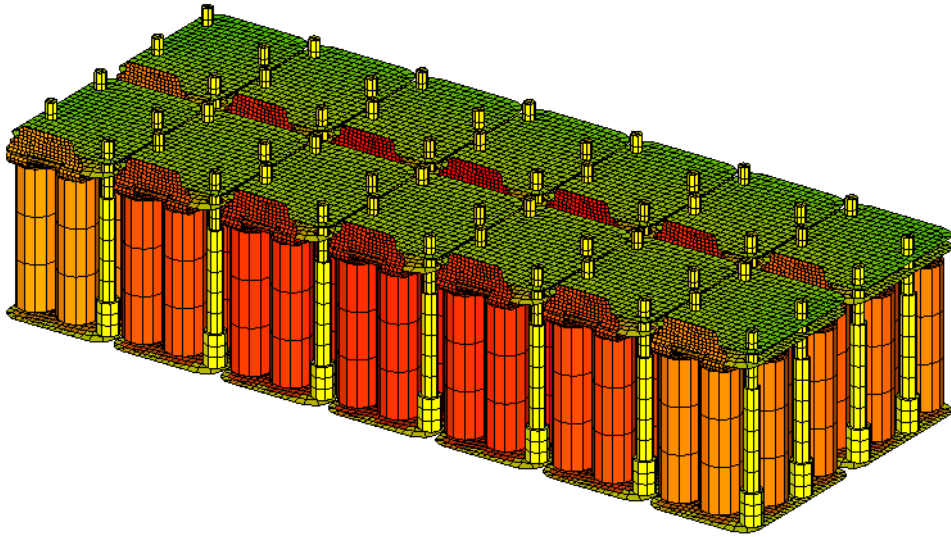
Parts = 341

Elements = 52122

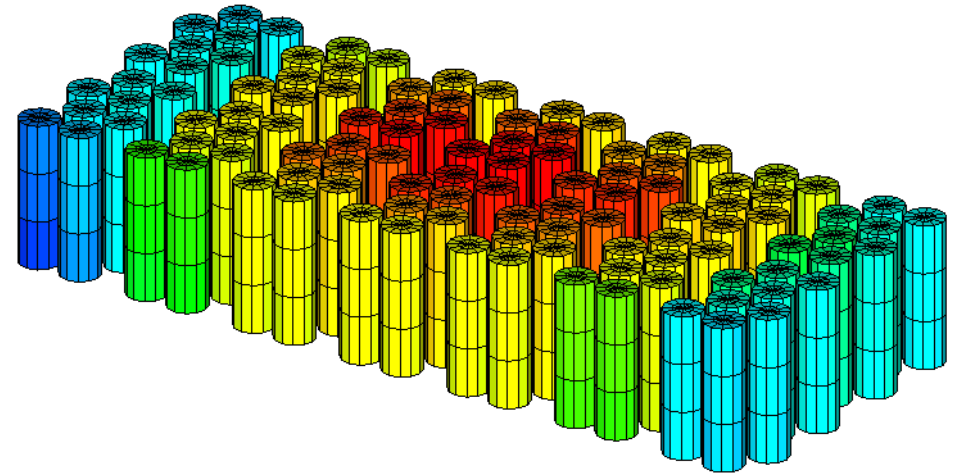


Local model - Battery pack Simulation, Results

06:00:00.0011
Temperature



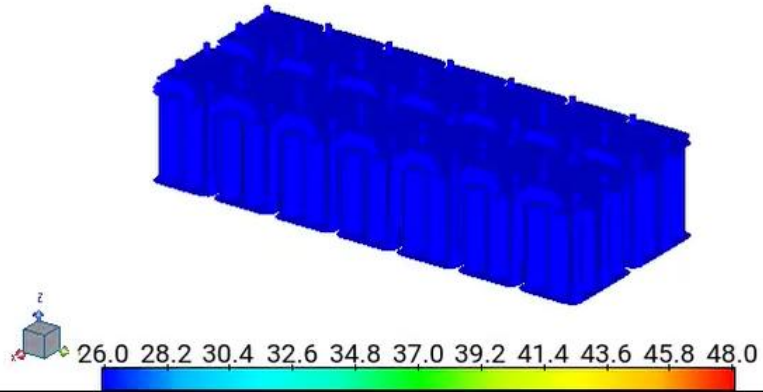
06:00:00.0011
Temperature



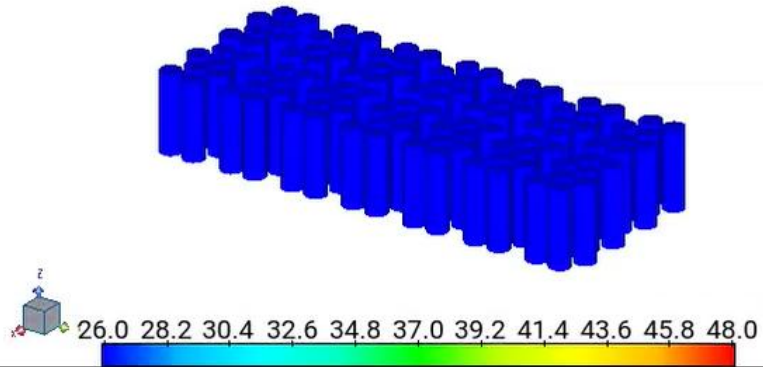
Note: Strong temperature gradients, due to radiation and conduction effects

Local model - Battery pack Simulation, Results

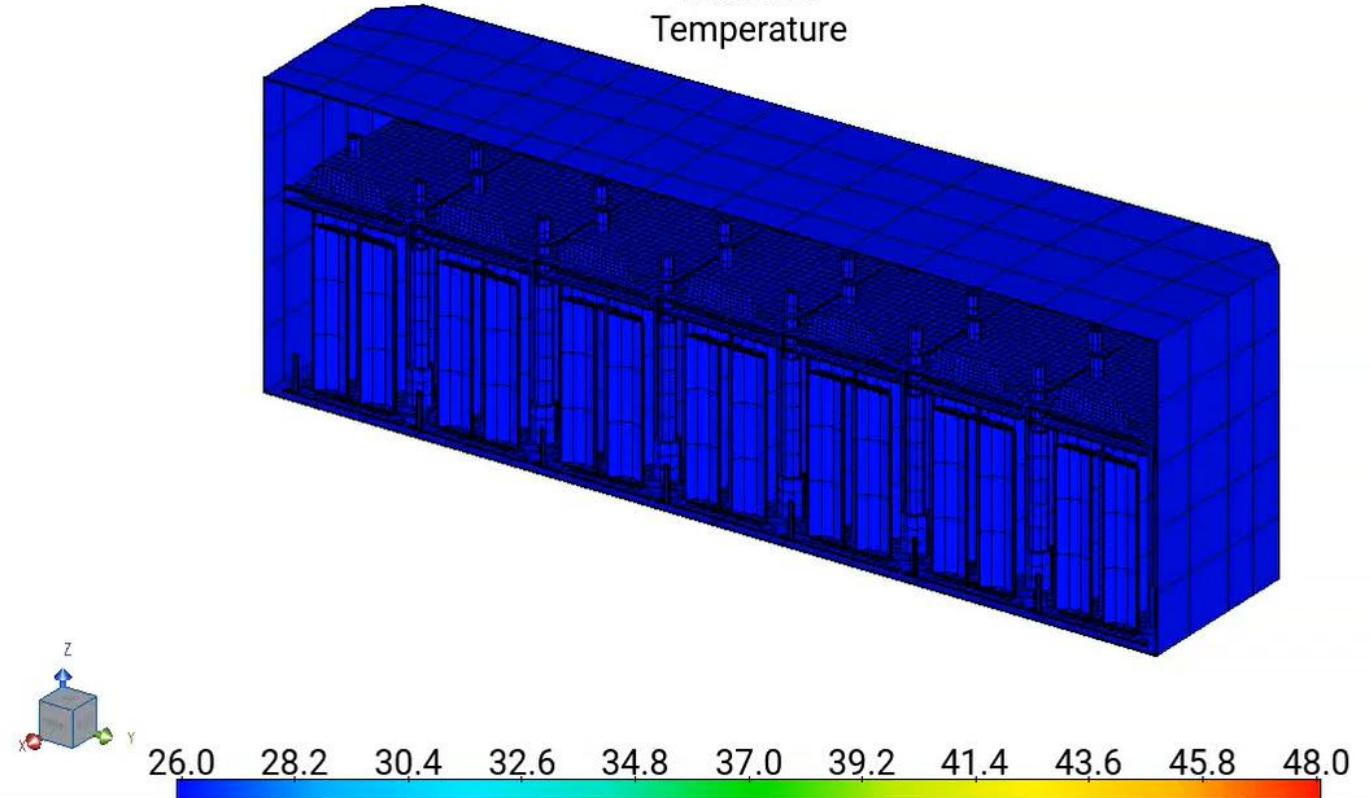
00:00:00
Temperature



00:00:00
Temperature

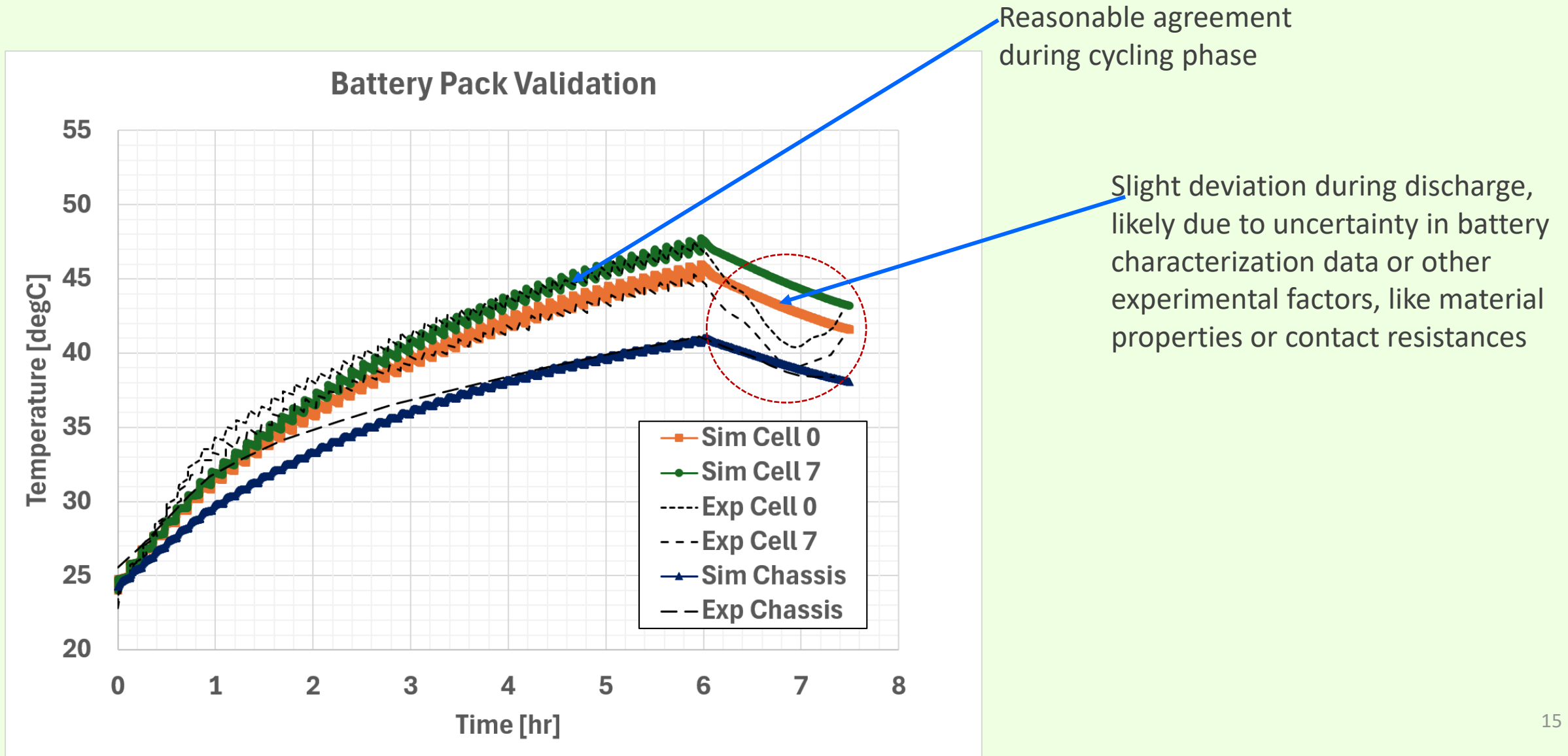


00:00:00
Temperature



Note: Strong temperature gradients, due to radiation and conduction effects

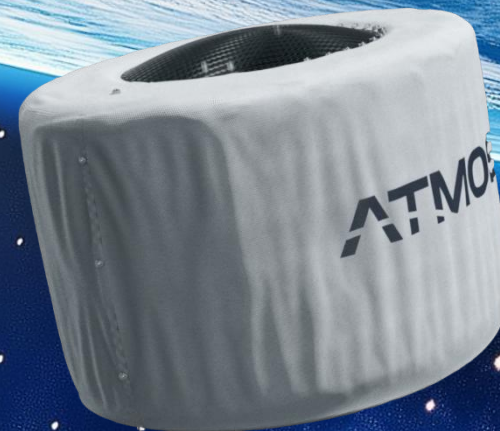
Local model - Battery pack Simulation, Results



Local model - Battery pack Simulation, Conclusions

- Simulated battery pack for 50 cycles followed by full discharge
- Results in reasonable agreement with experiment
- Slight deviation, due to unknown experimental parameters
 - This requires further investigation

TAITherm-Predicted Results Orbital Phase (PV, Battery & Electronics Cooling)



Orbital Set-up

- Orbital details and Load condition

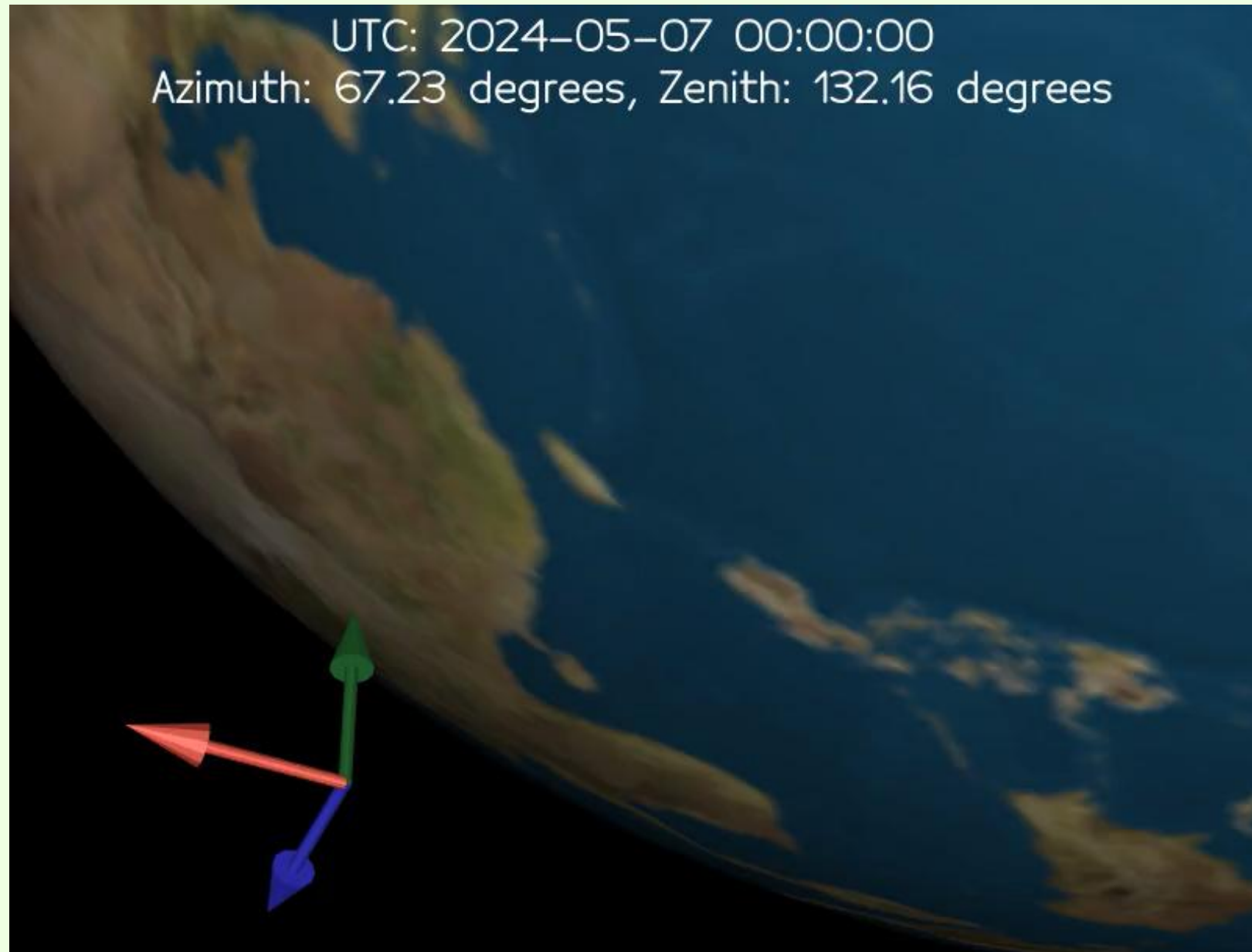
Max Solar Flux s/c [SUN to Face1]

Hot Case1 Boundary Conditions: ON condition

Solar Flux	1412.738 W/m2
Albedo	0.31
Earth IR	265
ALL System ON condition	
Internal Heat Generation	70 W+ 70W payload
Internal Heat Generation	70 W+ 100W payload(peak)
Altitude	520 km
Inclination	90°

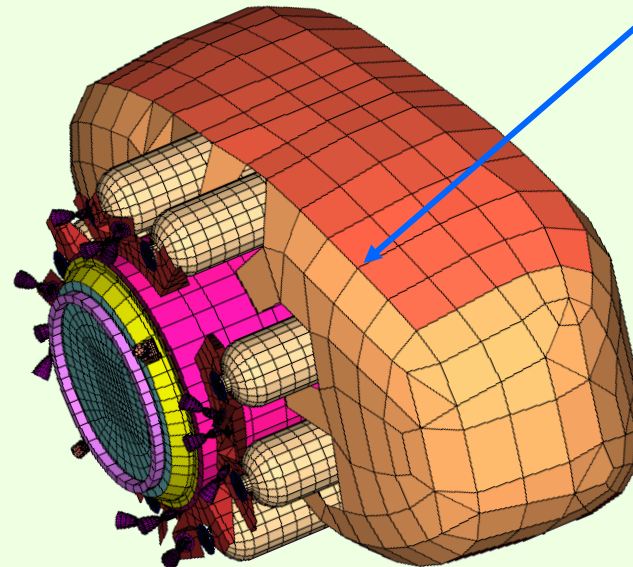
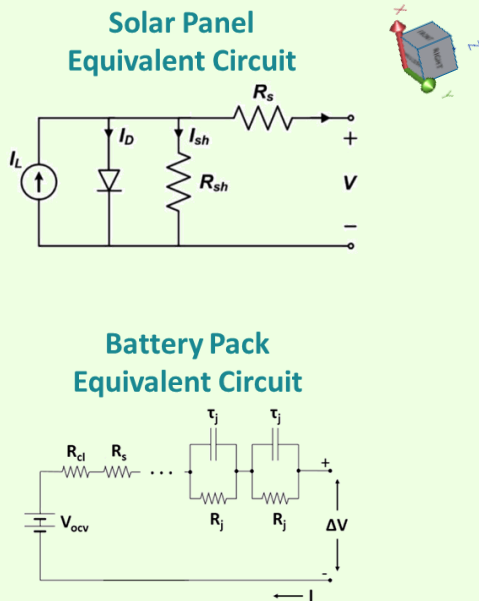
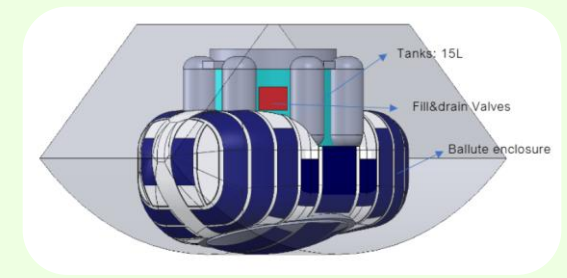
- Internal Heat Generation is dependent on the mission mode (Detumbling, Safe mode, Idle mode, Payload mode, Ground contract) in the orbit and De-orbit Burn

UTC: 2024-05-07 00:00:00
Azimuth: 67.23 degrees, Zenith: 132.16 degrees



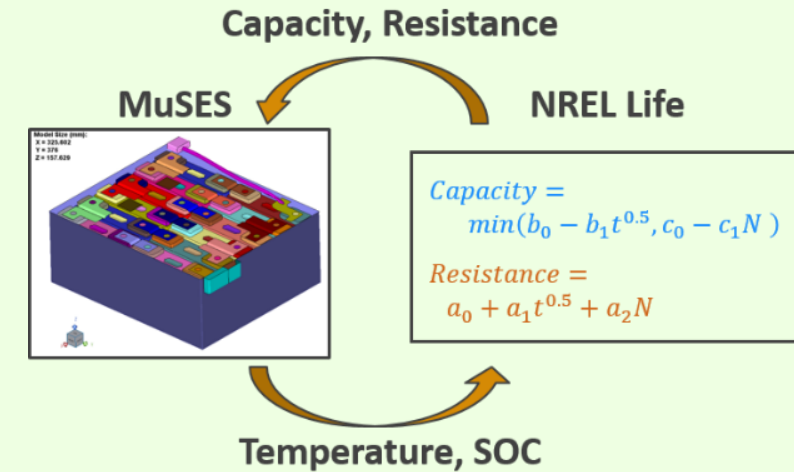
Solar Module, PV Setup & Performance

- Ascent Solar CIGS (Thin-Film) modules.
- Cell Type: CIGS (Copper Indium Gallium Selenide)
- Nominal Efficiency: ~ 21%
- Temp Coefficient: -0.34% / °C (typical for Ascent CIGS)



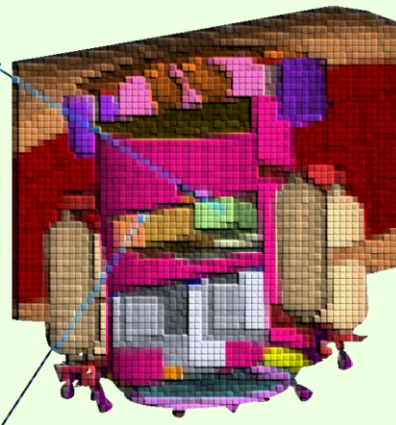
Set-up Power Demand and Cooling system

- 35 Ah battery pack capacity; power demand is driven by on-board electronic components.
- Starting SoC: 50%
- Battery Plate & Payload Plate are cooled with coolant
- Coolant releases heat at the TopLid and Coolant volumetric flow rate: 50 L/hr
- Simulated with fluid nodes



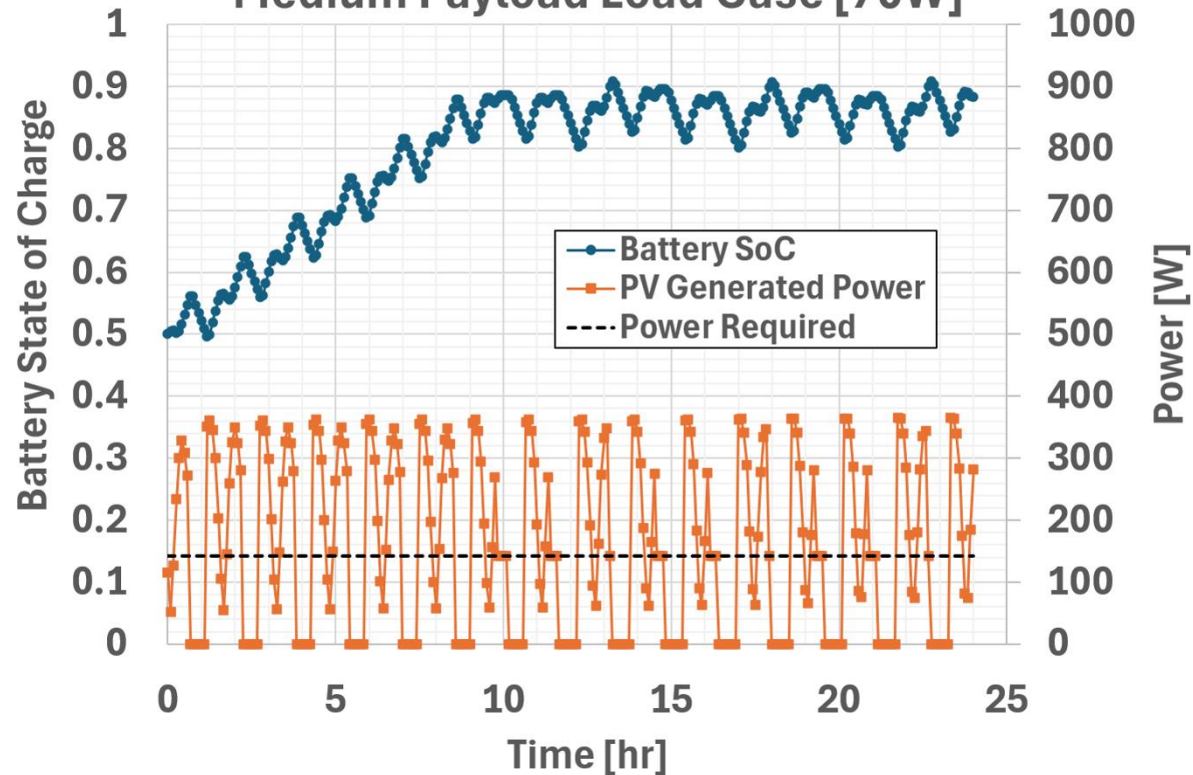
Payload, Compare :
70W (medium) vs 100W (peak)

Component	Power [W]
EPS_PCDU	10
OBDH_OBC	7
GNC_Magnetorquer	3
EQP1B-Magnetorquer	3
EQP1B-IMU-Space-Graded	1
EQP1B-DAU-3	1
EQP1B-IMU-Non-Space-Graded	1
Battery Plate Components	25
Reaction Wheels	21

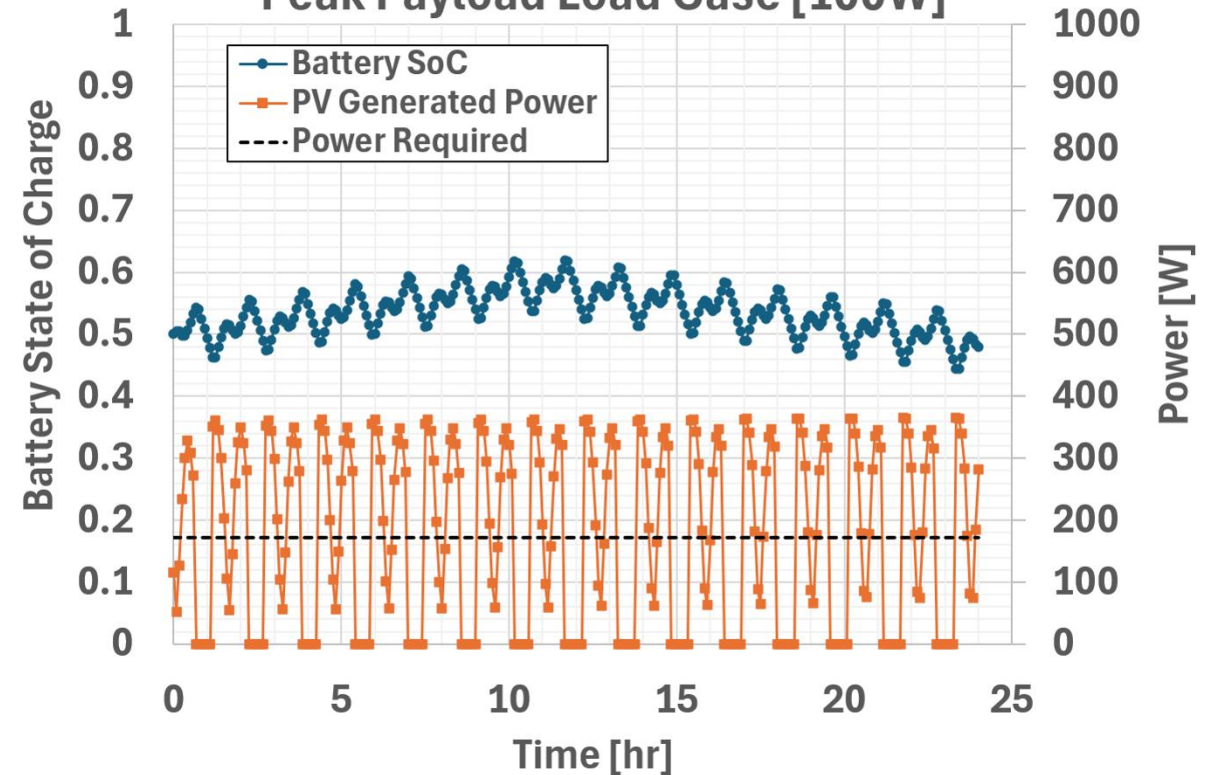


Results System Energy

Battery Performance and Power Demand Medium Payload Load Case [70W]

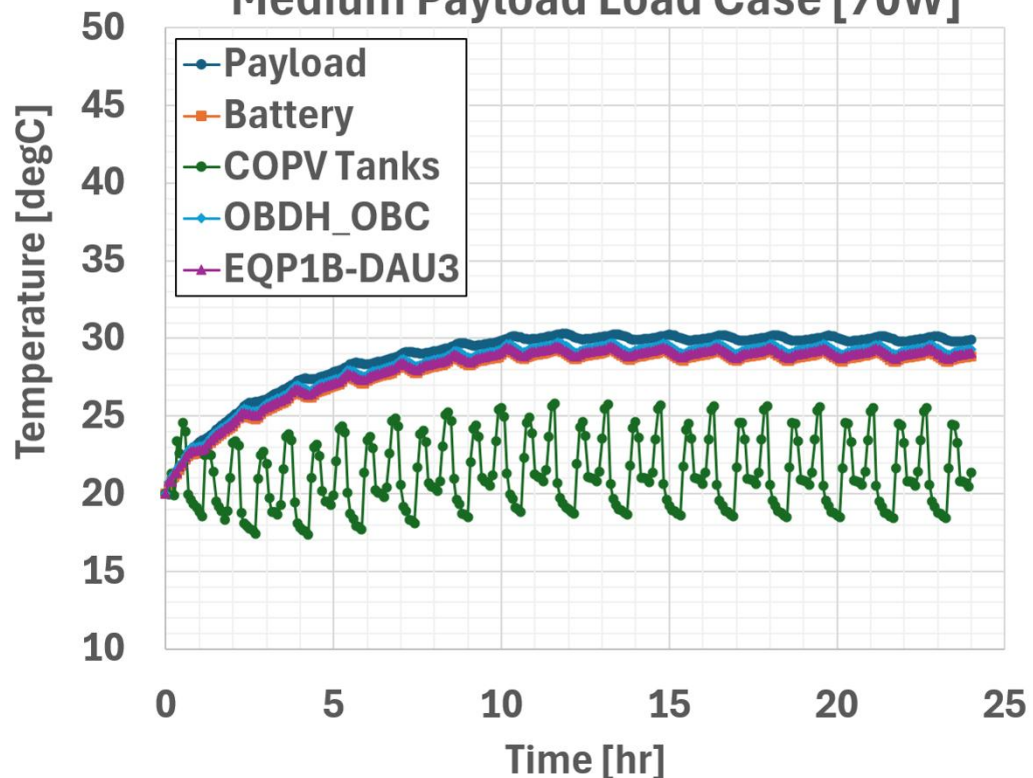


Battery Performance and Power Demand Peak Payload Load Case [100W]

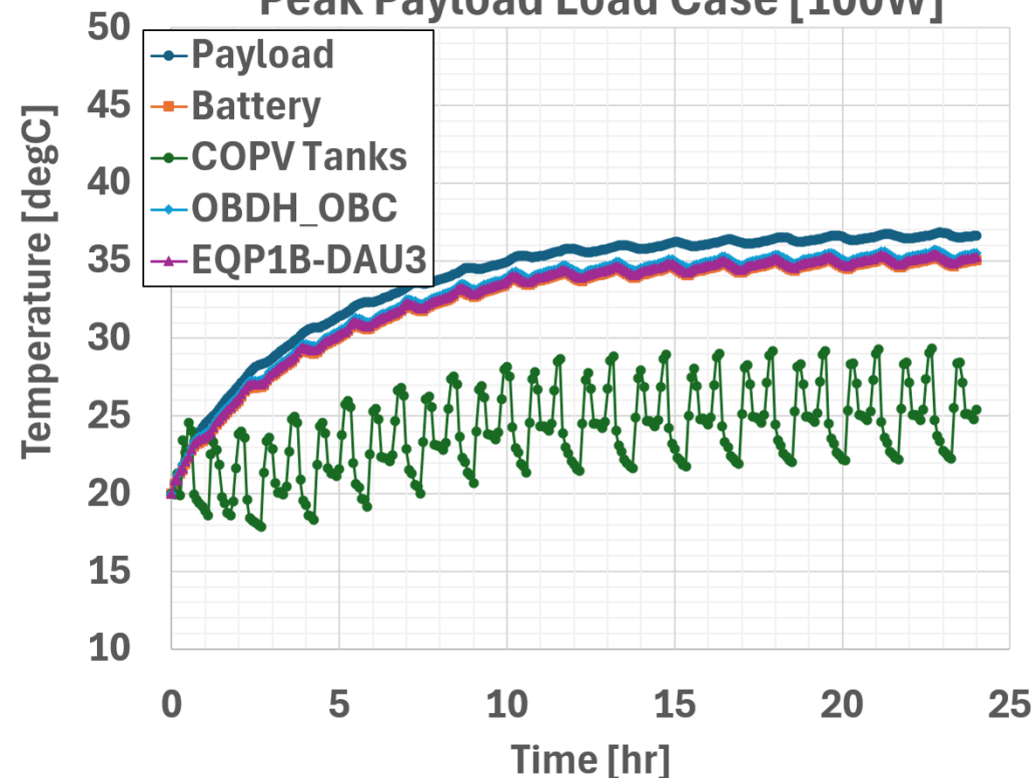


Results Component Temperatures

Component Maximum Temperatures
Medium Payload Load Case [70W]



Component Maximum Temperatures
Peak Payload Load Case [100W]

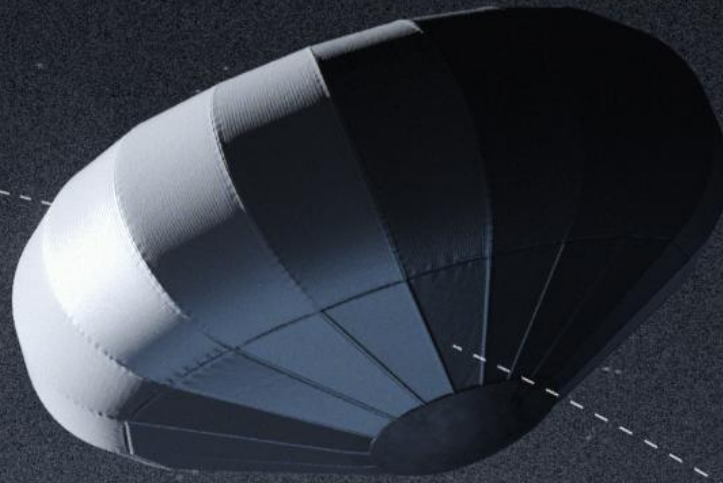


Conclusions

- Battery
 - Simulated battery pack for 50 cycles followed by full discharge
 - Results in reasonable agreement with experiment
 - Slight deviation, due to unknown experimental parameters
 - This requires further investigation
- Orbit
 - Simulated Satellite in orbit with PV panels, battery and electronics active

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