Simulation Framework for Design of Long Duration Balloon Power Systems

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Outline

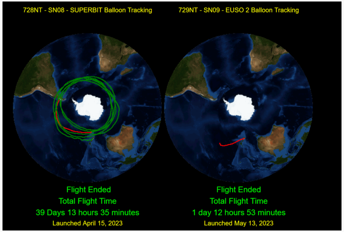
1. Problem space
2. Description of Solar Power Production
3. Battery Bank and Instrument Configuration
4. Simulated Trajectories
5. Single and and Multi-trajectory analysis
6. Future Developments

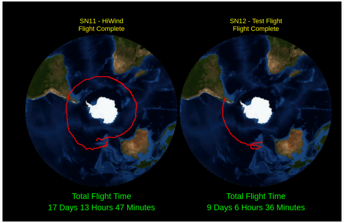
Difficulty in SPB Power System Design

The power system is one of the most critical components of any ULDB payload.

Design constraints include:

- **Power-hungry experiments**
- **Weight Constraints**
- **Size Constraints**
- **Environmental Conditions**
- **Seasonal and location uncertainties**





Ballooning Instrument - Power system Analysis Simulation Software (BI-PASS) collects information about these parameters and uses this information to inform future power system design processes.

BI-PASS is a:

- Easy-to-use Python framework
- Easily modifiable
- Highly configurable
- Tested against conditions seen during EUSO-SPB2 flight (limited data, More power system data would be appreciated!)
- Currently in alpha testing
- Will be publicly available by the end of the summer on gitlab along with a paper.

Solar Power Production Theory

Assuming no atmospheric losses at float altitude

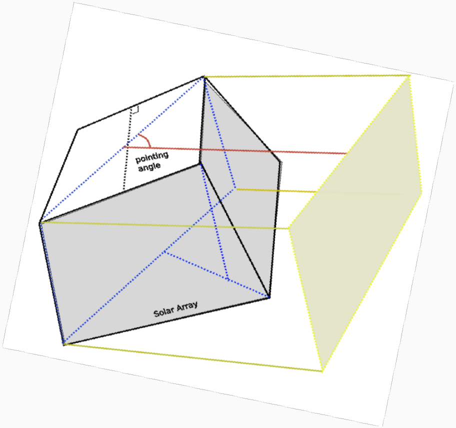
$$\text{Power Production} = \text{Panel}_{\text{eff}} * \text{TSI} * A_{\text{eff}}$$

- $\text{Panel}_{\text{eff}}$ = Solar panel efficiency
- $\text{TSI} \approx 1360\,\text{W/m}^2$ = Total Solar Irradiance at the edge of space

The effective area A_{eff} is calculated based on the angle between the sun and the panels

$$A_{\text{eff}} = A_{\text{panel}} \cdot [\sin(\delta_p) \cdot \sin(\delta_s) + \cos(\delta_p) \cdot \cos(\delta_s) \cdot \cos(\alpha_p)]$$

- A_{panel} = Area of a panel
- δ_s = Solar Elevation Angle
- δ_p = Pointing angle of the given Solar Array
- α_p = Yaw angle of the array relative to zero



Solar Skirt vs Solar Array with Pointing

Solar panel arrangement

- Flexibly configurable through config file
- Defined by pointing direction relative to the sun and tilt angle

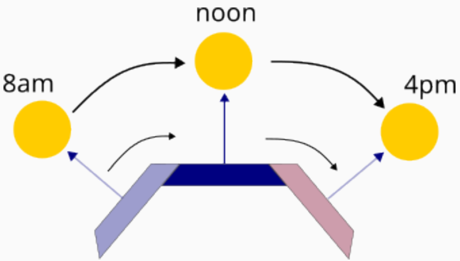
Allow two configurations to be evaluated:

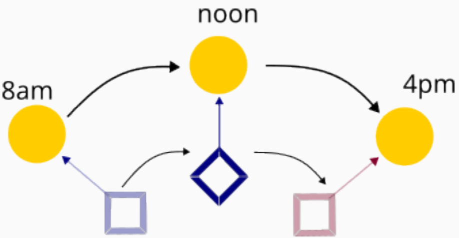
- Sun tracking single solar panel
- Solar skirt (assuming no pointing)

For Solar skirt evaluate two scenarios:

- **Ideal** corner tracking the sun
- **Worst** single panel tracking the sun

All other configurations are between these two scenarios

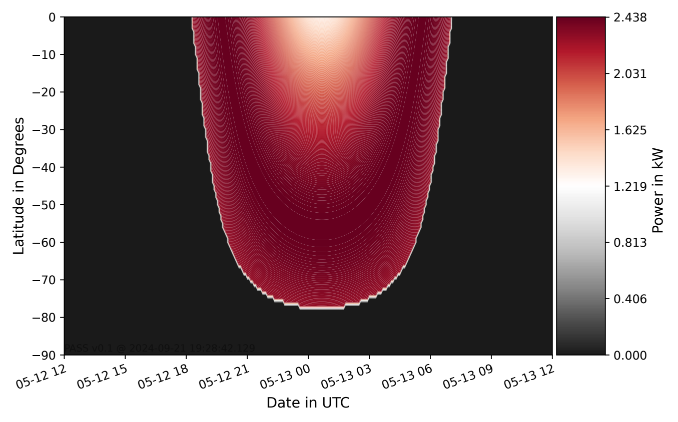




Solar Power Production Implementation

Example implementation of single panel design

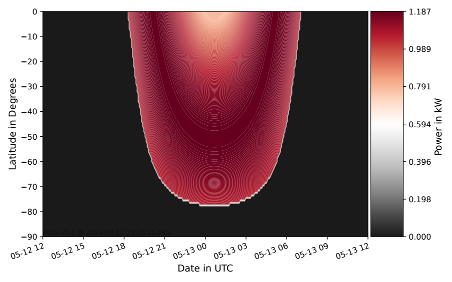
Number of Panels	15
Tilt Angle	15°
Solar Panel Efficiency	22%
Solar Panel Area	0.54 meters

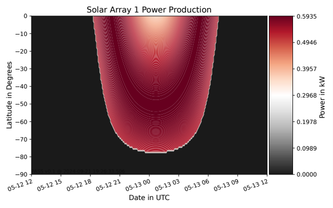


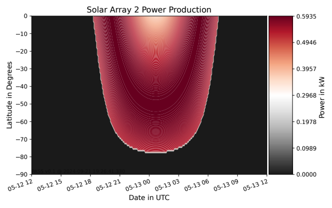
Solar Power Production Implementation

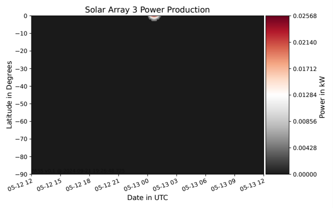
Example implementation of solar skirt design

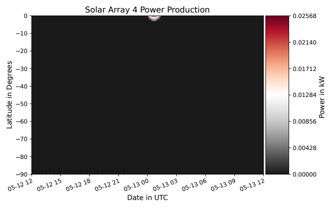
Number of Panels per Array	5
Number of Arrays in Skirt	4
Tilt Angle	15°
Solar Panel Efficiency	22%
Solar Panel Area	0.54 meters











Battery Bank and Power Consumption

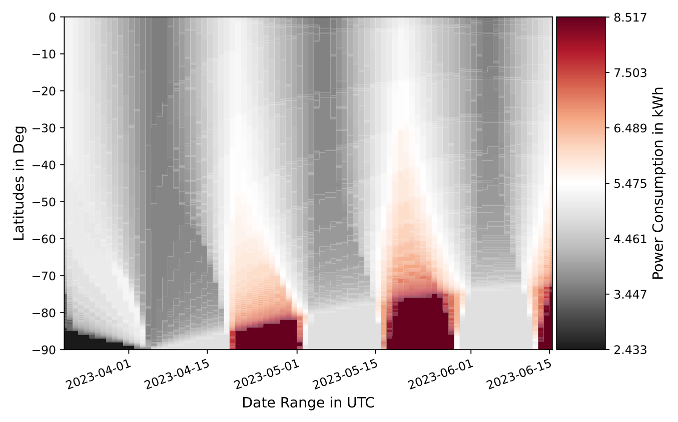
Battery bank fully defined through config file

Battery Type	Lithium ion
Number of Batteries	6
Single Battery Capacitance	1800 Wh

Example power consumption

Daytime Power Consumption	100 W
Nighttime Power Consumption	200 W
Operational Power Consumption	350 W
Loadshedding Power Consumption	80 W

- Nighttime: No sun
- Operational: No sun, no moon



Power Production comparison with EUSO-SPB2

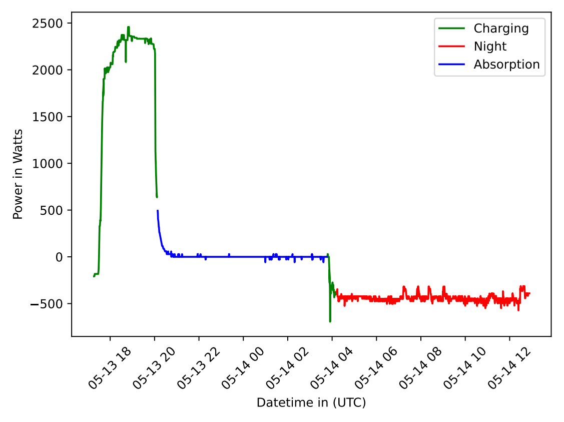


Figure 1: Flight Data

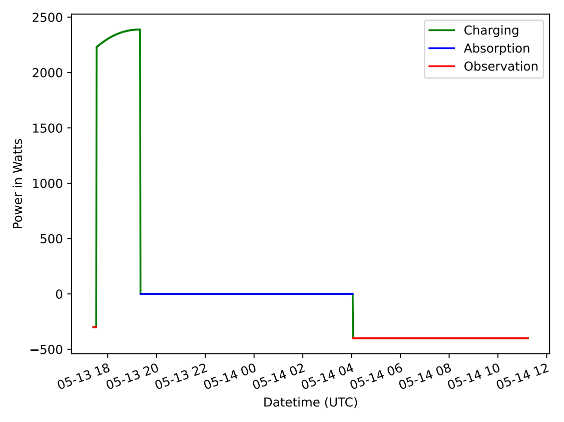


Figure 2: Simulations from BI-PASS

Simulated Trajectories

To project power-system performance, test on many simulated flight trajectories

1. Set starting location to (-44.648, 169.606) Wanaka, NZ
2. Pick the next closest time stamp and altitude to the NASA MERRA2 data [slide 19]
3. For a given coordinate, calculate weighted mean Northward and Eastward wind speeds from four surrounding grid points
4. Convert the velocity to deg moved in lat(red) and long(green).
5. *Add a random component (purple)
6. Repeat from 2

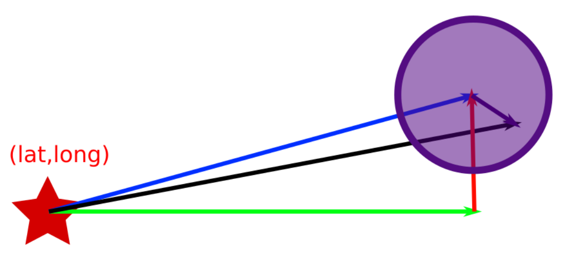


Figure 3: **Note that without a random component, this method will simulate the 'Wind Patterns' while the random component accounts for sporadic wind gusts which can shift the balloon into a different wind zone*

For updates to the simulated trajectory analysis software see "Trajectory Simulation and Wind Gust Analysis for the NASA Super Pressure Balloon" Poster by Xavier Adams

Simulated Trajectory for SuperBIT

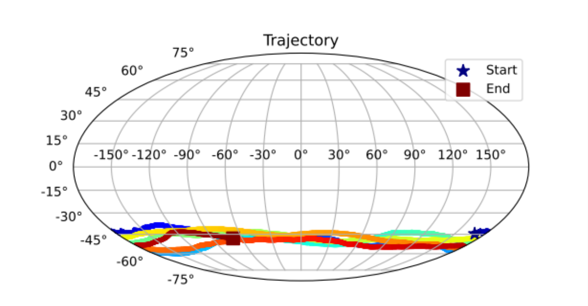


Figure 4: Flight Data

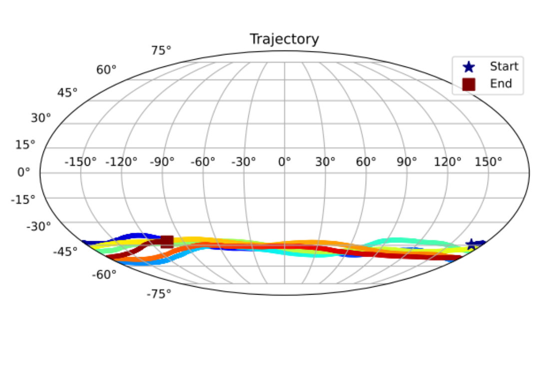


Figure 5: Simulated flight

Single Trajectory Analysis: Minimum and Maximum Case for a Solar Skirt Configuration

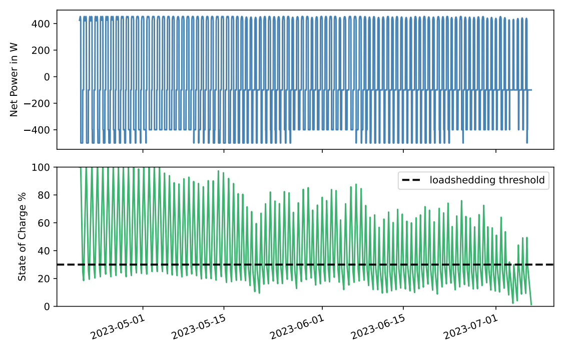


Figure 6: Minimum Case for a Solar Skirt → **Only one side of the Solar Skirt** pointed toward the Sun.

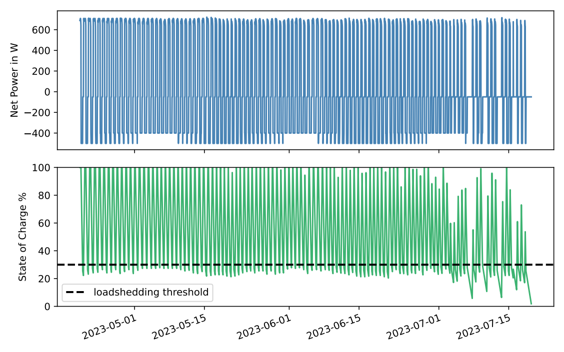


Figure 7: Maximum Case for a Solar Skirt → **Corner of the Solar Skirt** pointed toward the Sun.

Multiple Trajectory Analysis

- Solar Skirt with 3 batteries and 5 panels per side.
- 800 total trajectories each 50 days in length
- Trajectory start days beginning in April - May 2023.
- Average flight length before L2 failure: **47.02 (min) and 47.04 (max)**

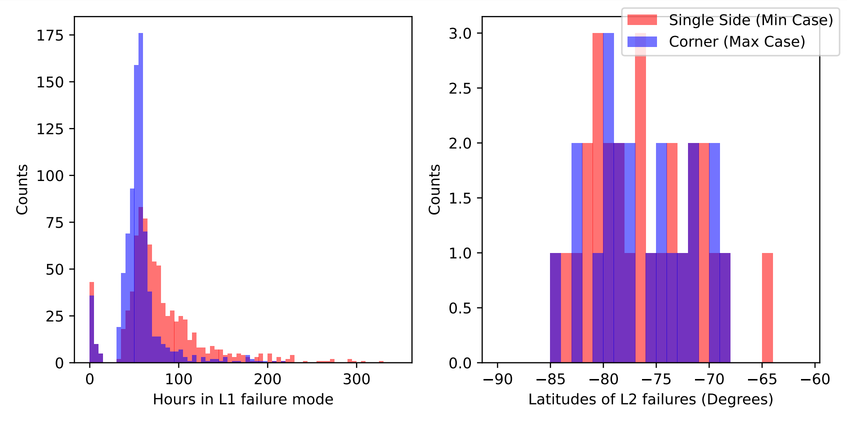


Figure 8: Comparision of the minimum case (single side to the sun) and maximum case (corner to the sun) for a solar skirt configuration.

Multiple Trajectory Analysis: Two Config Analysis

- 1st case: Solar Skirt with 4 batteries and 5 panels per side.
- 2nd case: Solar Skirt with 3 batteries and 10 panels per side.
- 800 total trajectories each 50 days in length
- Trajectory start days beginning in April - May 2023.
- Average flight length before L2 failure: **47.08 (case 1) and 47.04 (case 2)**

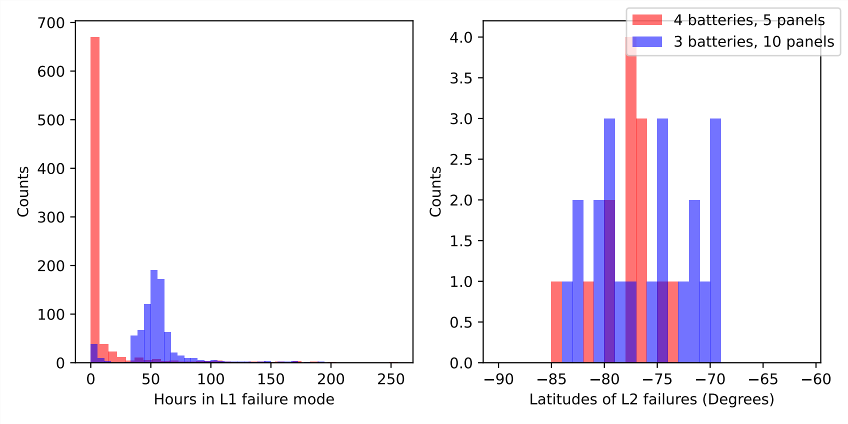


Figure 9: Comparison of two configurations where we increase the number of batteries vs a number of solar panels.

Future Development

Summary:

- BI-PASS stimates power generation and consumption based on given system configuration
- BI-PASS can estimate the performance of a power system on a given flight trajectory
- BI-PASS provides statistical design arguments based on simulated flight trajectories generated from MERRA-2 data

Future developments:

- Finalize and publish the current state of the software
- Design a Graphical User Interface
- Develop in flight software
  - Based on predicted flight trajectory KML
  - Predict power system performance
- Optimize performance
- Automatic inclusion of environmental constraints like temperature effects on battery and solar panel performance

Comments, feedback, and collaboration are more than welcome to julia_burton@mines.edu!!

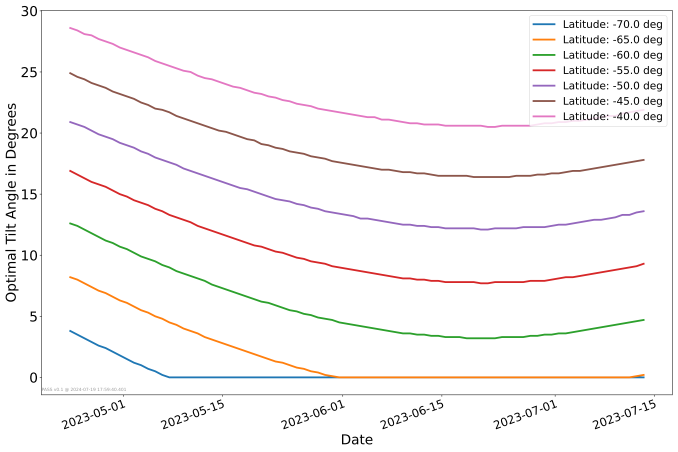
Backup Slides

Solar Power Production Implementation

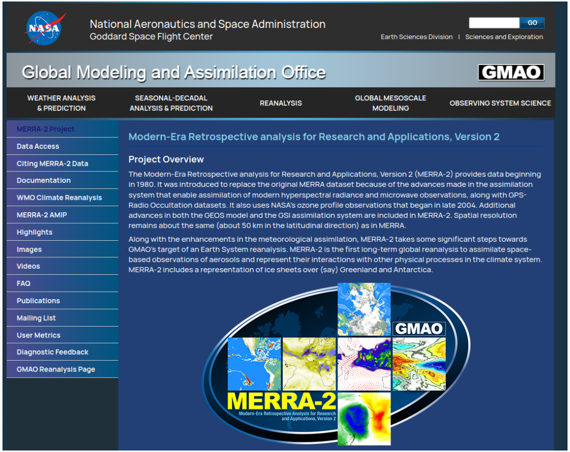
Track the solar elevation angle throughout the day

- If the sun is above the horizon, the charging mode is active
- Relative angle between sun and detector panels define efficiency
- Optimization is possible, but depends on latitude of the balloon

Optimal tilt angle relative to vertical panels in counterclockwise direction



MERRA-2



Global Modeling and Assimilation Office (GMAO): inst3_3d_asm_Cp: MERRA-2 3D IAU State, 443 Meteorology Instantaneous 3-hourly (p-coord, 0.625x0.5L42), version 5.12.4.

Simulated Trajectory Dataset