Ira A. Fulton Schools of Engineering
Arizona State University

Electrical Engineering Capstone Design Project
Future Power Solutions For Exploring Hypothesized Surfaces

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EEE489: Senior Design Lab II (Spring 2025)

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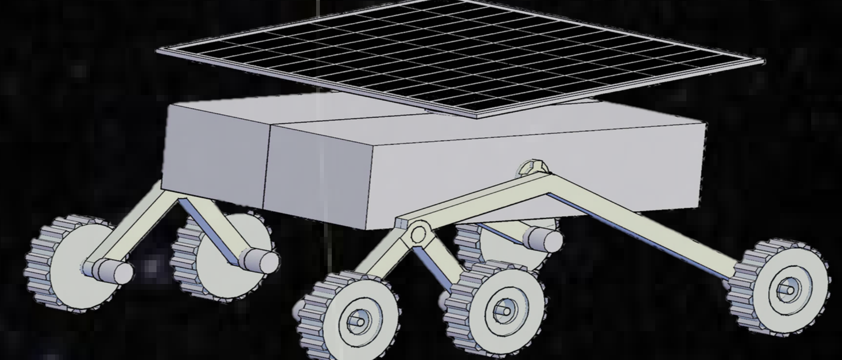
Problem Statement

The extreme and variable environment of asteroid (16) Psyche presents significant challenges for designing a reliable power system to support rover mobility and operations. Psyche's high orbital eccentricity causes substantial fluctuations in solar irradiance, while its rapid 4.2-hour rotational period leads to frequent and brief day-night cycles. These conditions severely constrain solar charging windows and increase dependency on energy storage systems. To ensure continuous and autonomous operation, it is critical to develop and optimize a power system that can effectively balance solar array sizing, battery capacity, and energy budgeting under dynamic environmental conditions.

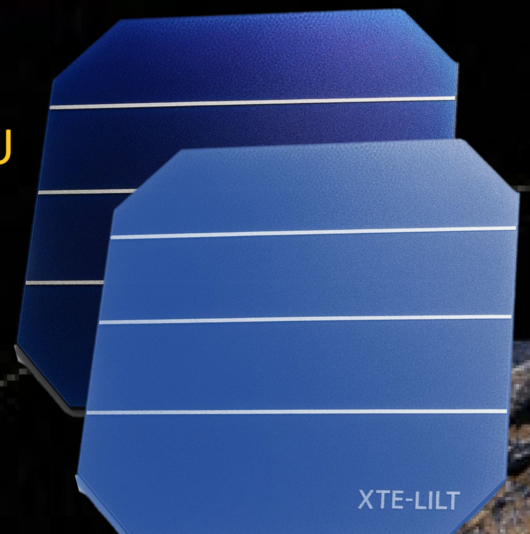
Proposed System

With the mission objectives defined, we shifted our focus to designing a system that could operate reliably on Psyche. This began with modeling the environment and available solar energy, estimating the rover's power demand, and selecting components that could meet those needs. Using python, three main components for mobility which are solar PV array, battery storage and motor load were simulated for each day for a whole Psyche orbit. While taking into account the distance of the asteroid where it is closest or furthest to the sun. Load at different speeds were analyzed which is one of the huge factors in determining the number of solar cells, and battery needed to meet the energy demand. Battery SoC were also analyzed which is a key to determining the degradation of the system.



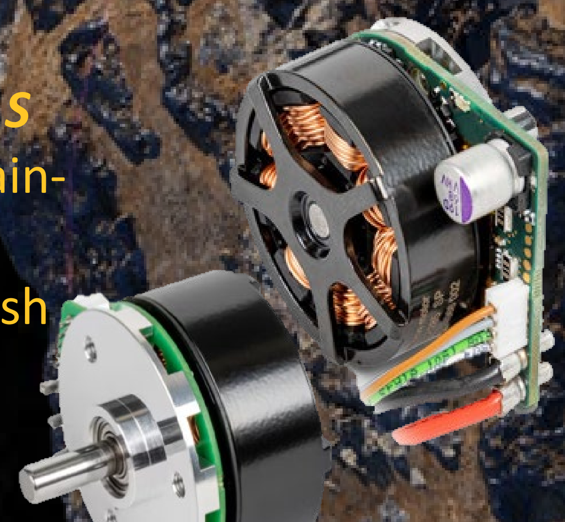
Sub-system Components

SPECTROLAB XTE-LILT
– 37% efficiency at 5.5 AU
– Triple-junction, space-qualified
– Handles cold, low-light conditions

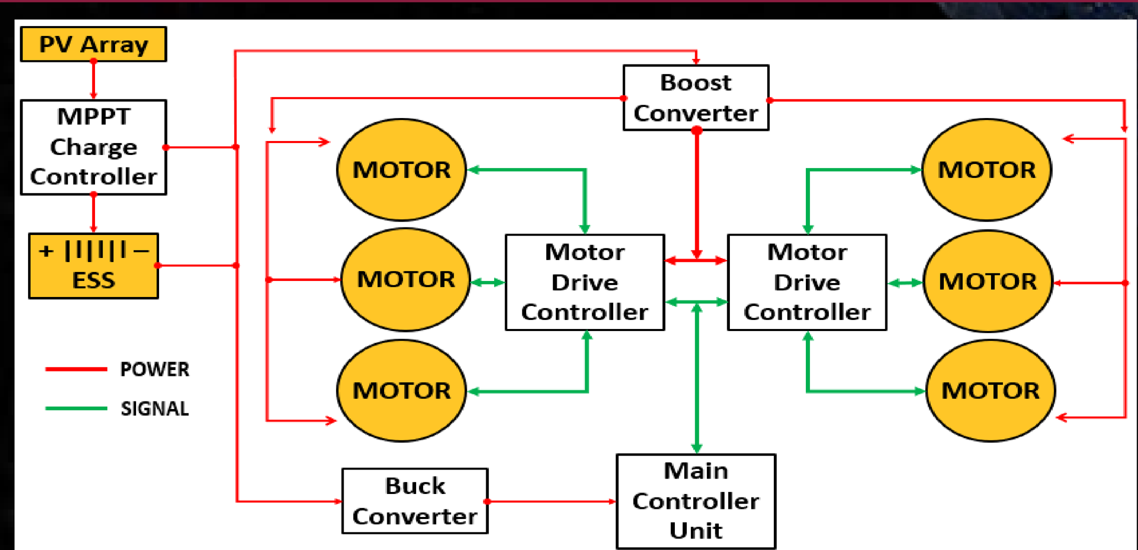


EAGLEPICHER LP32975 (12Ah)
– Lithium-ion, flight-proven
– Operates in vacuum/extremes
– High energy storage

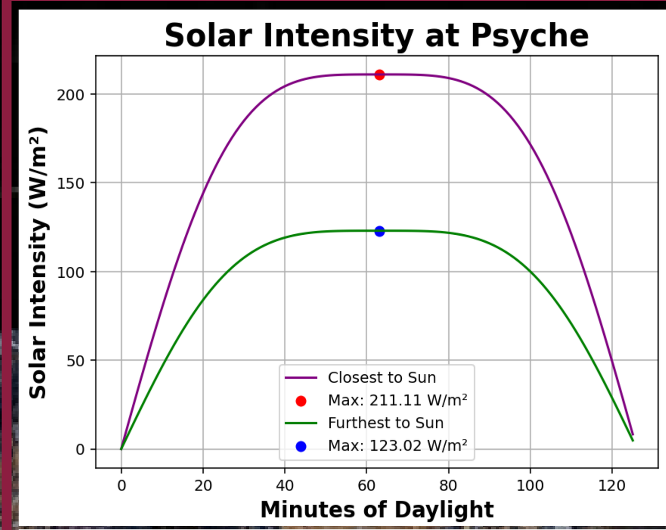
Maxon ECX FLAT 32 S
– Compact and terrain-ready
– Reliable under harsh conditions
– Ideal for rover mobility

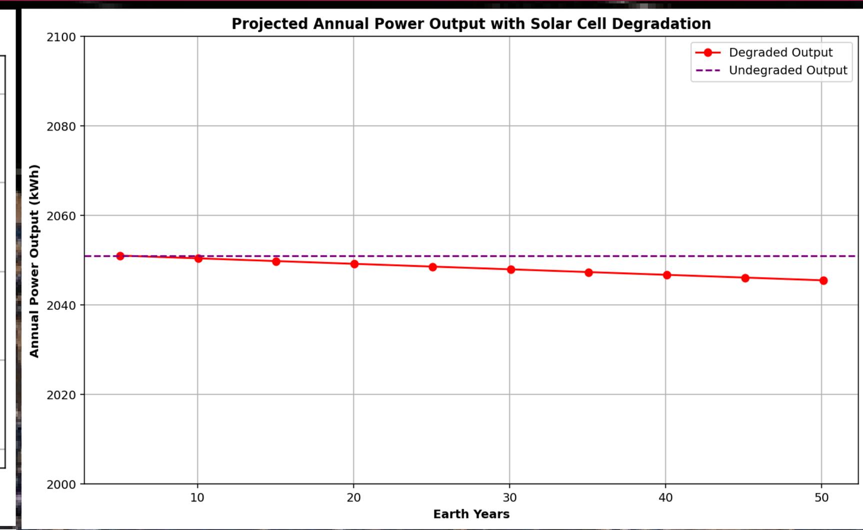


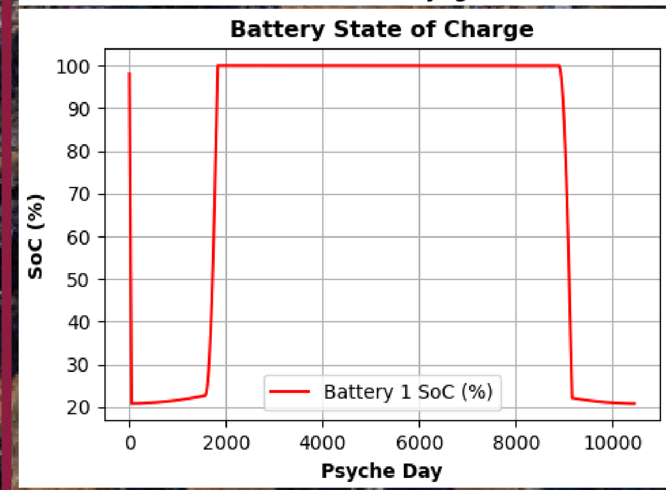
To ensure compatibility with the harsh conditions of asteroid (16) Psyche, components were chosen based on their flight heritage in NASA missions, and evaluated for resilience to thermal extremes, vacuum conditions, and operational longevity.

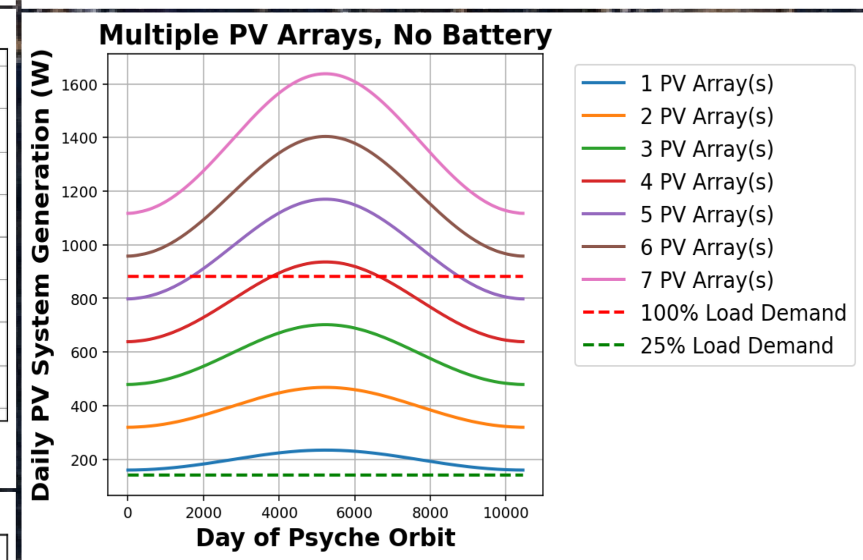


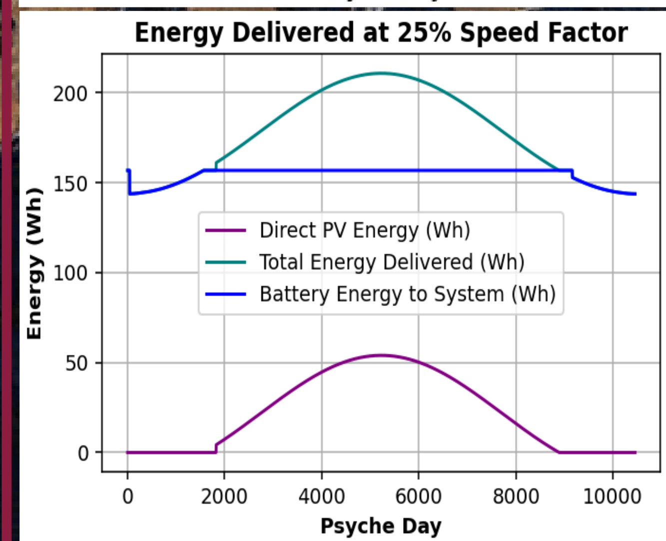
Simulation Results

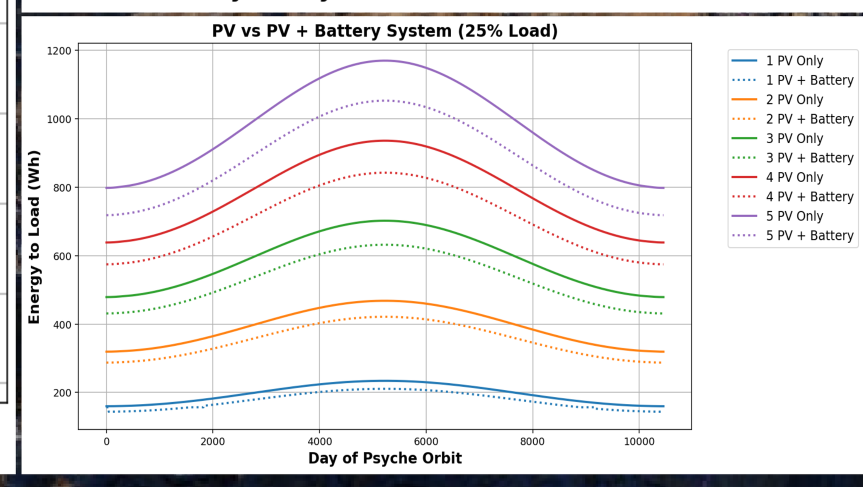


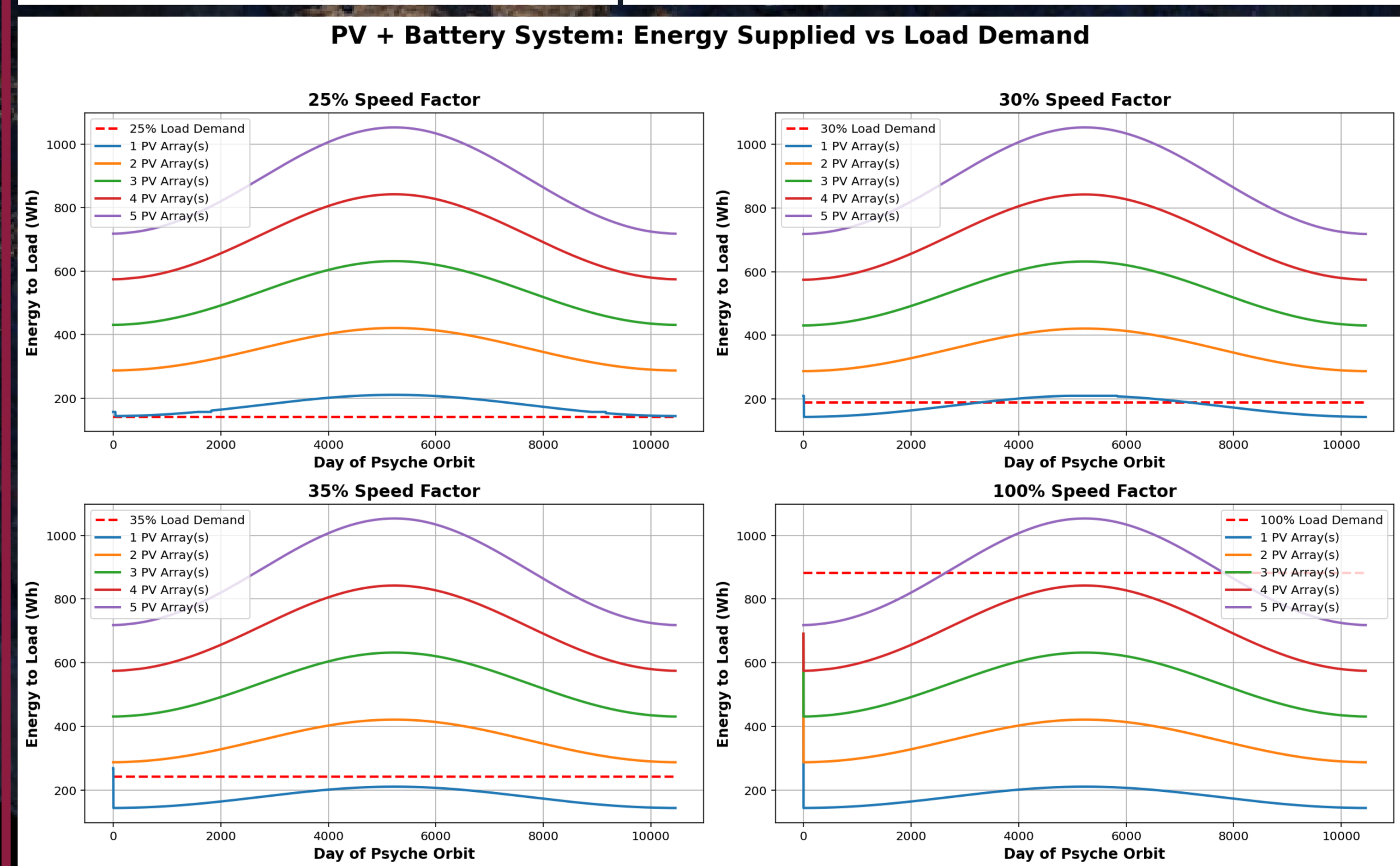












Future Work

To extend this project and refine its applicability for future missions, several hardware and system-level enhancements are proposed:

- Integration of advanced power electronic components such as MPPT (Maximum Power Point Tracking) solar charger and a buck-boost converter would significantly improve energy harvesting and regulation efficiency under varying solar conditions.
- Development of a dedicated power and battery management system is recommended to monitor and control charge and discharge cycles of each battery cell, ensuring battery health and energy optimization.
- Implementing individual microcontrollers for each motor allowing for localized control and fault tolerance.
- A central controller unit that would coordinate logic across subsystems, enabling intelligent energy routing and system diagnostics.
- An analysis of the total system mass is also crucial, as it directly influences power requirements and overall load efficiency. Future iterations should evaluate how mass impacts daily energy consumption.

While our system focuses solely on rover mobility, future missions will require additional power for on board instruments, communication, and data handling. Compact rover designs like Japan's MINERVA demonstrate what's possible with minimal power, but a full-scale mission on Psyche may need more robust solutions. This could include scalable battery platforms, alternative energy sources such as NASA's MMRTG, or hybrid systems. Another possibility is evaluating solid-state batteries as a potential alternative could provide benefits in energy density, safety, and thermal stability—especially important in deep-space environments like Psyche. Our work highlights the power potential of solar-based designs on Psyche and lays the foundation for future energy system development.

Conclusion

This project demonstrates the viability of a solar photovoltaic and battery-powered system to support rover mobility on asteroid (16) Psyche. Through simulation of real environmental constraints—including variable solar irradiance, rapid day-night cycles, and degraded performance over time, we successfully modeled energy generation, load demand, and battery behavior across a full Psyche orbit. Our findings show that a properly sized solar and battery system can sustain mobility at 25% duty cycle using proven, space-qualified components. However, for a complete mission architecture that includes communications, instrumentation, and autonomous operations, additional power system capacity or alternative energy strategies will be necessary. This work lays a critical foundation for future energy system designs tailored to deep-space environments. It highlights key trade-offs in efficiency, storage capacity, and load scheduling. Future work may involve mass optimization, enhanced control via distributed microcontrollers, integration of MPPT and buck-boost converters, and consideration of solid-state battery technologies. Ultimately, the system's modularity and adaptability make it a strong candidate for supporting long-duration surface operations on Psyche and similar small-body targets.