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Space Dynamics Laboratory
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Power-Optimal Slew Maneuvers in Support of Small Satellite Earth Imaging Missions

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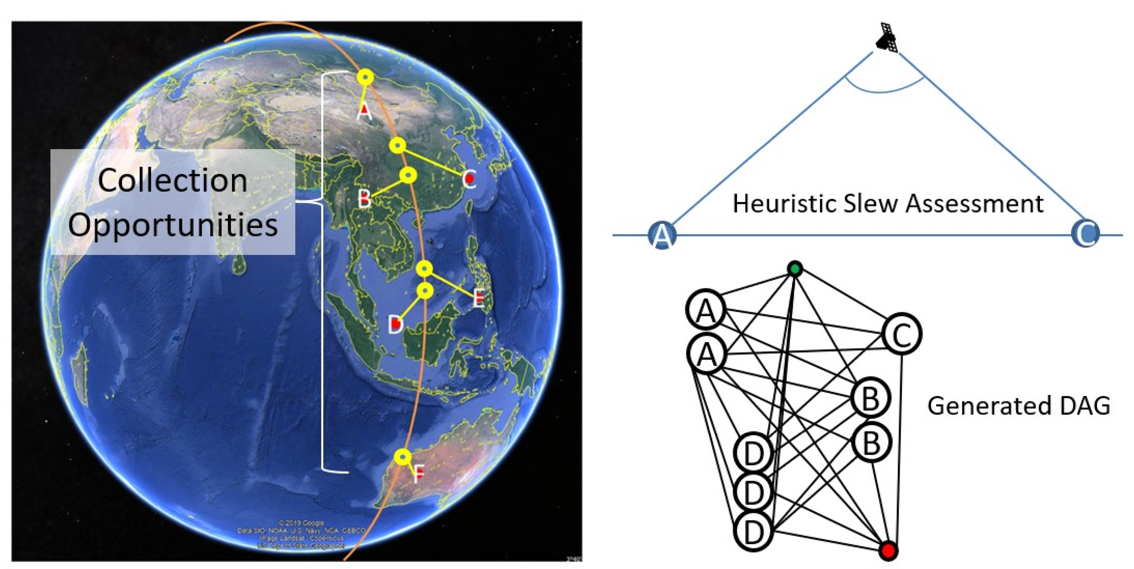
Background

Small satellite image collection missions typically rely on controllers that simply move the spacecraft between commanded orientations without considering solar exposure. Slewing may keep solar arrays in shadow, draining the satellite's power. To compensate, satellite operation teams command the vehicle to enter a "sunbathe" state between collections. This additional level of complexity requires manual or rigidly prescribed specification of the the "sunbathe" operation. There is opportunity for power collection during movement if satellite slews are controlled to optimize solar exposure in combination with control input.

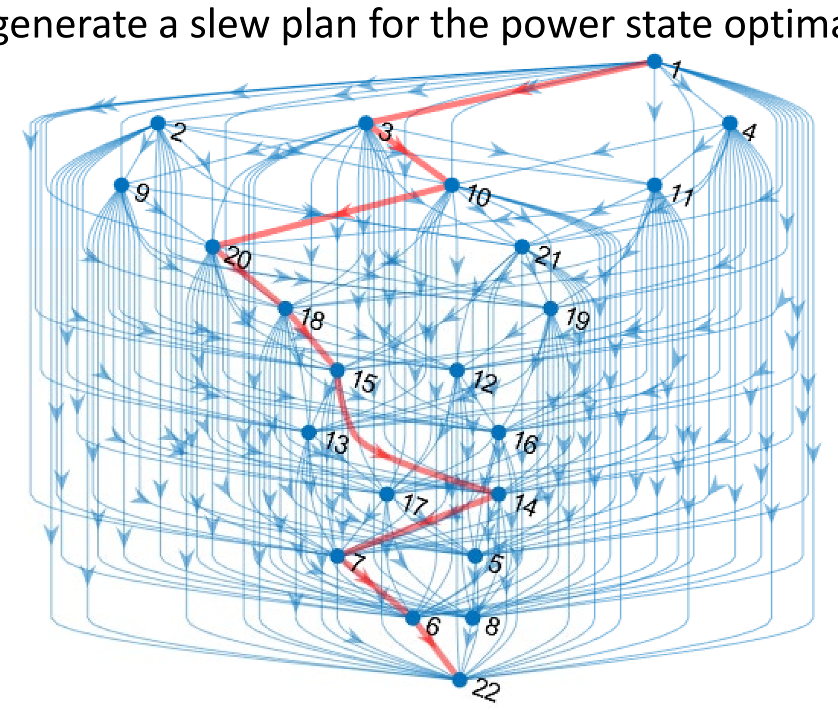
Approach

We developed a satellite slew maneuvering controller that optimizes power state. By controlling reaction wheel accelerations and orienting solar arrays during slew maneuvers, opportunities for both image collection and power collection and consumption are considered.



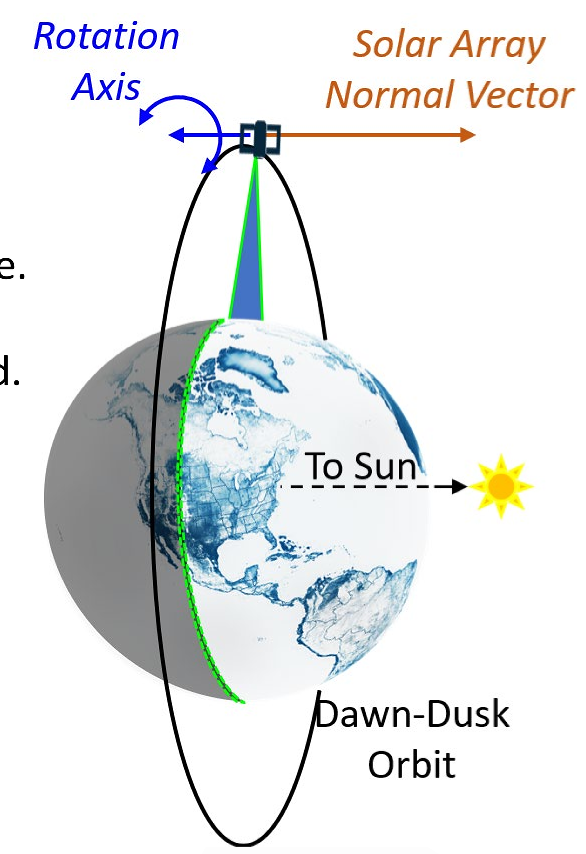
Planning

1. Image collection targets are scored by priority and adjusted for cloud cover, perspective angle, etc.
2. Objective function considers target value and slew cost (function of slew angle and time expense).
3. Targets discretized into time windows of collection opportunities as nodes in a directed acyclic graph (DAG).
4. The optimal collection path through the DAG is computed to generate a slew plan for the power state optimal controller.†



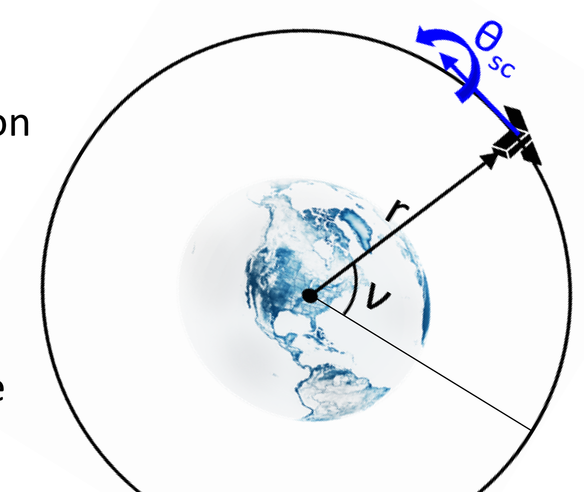
†Reference: S. Augenstein, A. Estanislao, E. Guere, S. Blaes, "Optimal scheduling of a constellation of earth-imaging satellites, for maximal data throughput and efficient human management," in Twenty-Sixth International Conference on Automated Planning and Scheduling, 2016.

Case Study: Dawn-Dusk Sun Synchronous Orbit



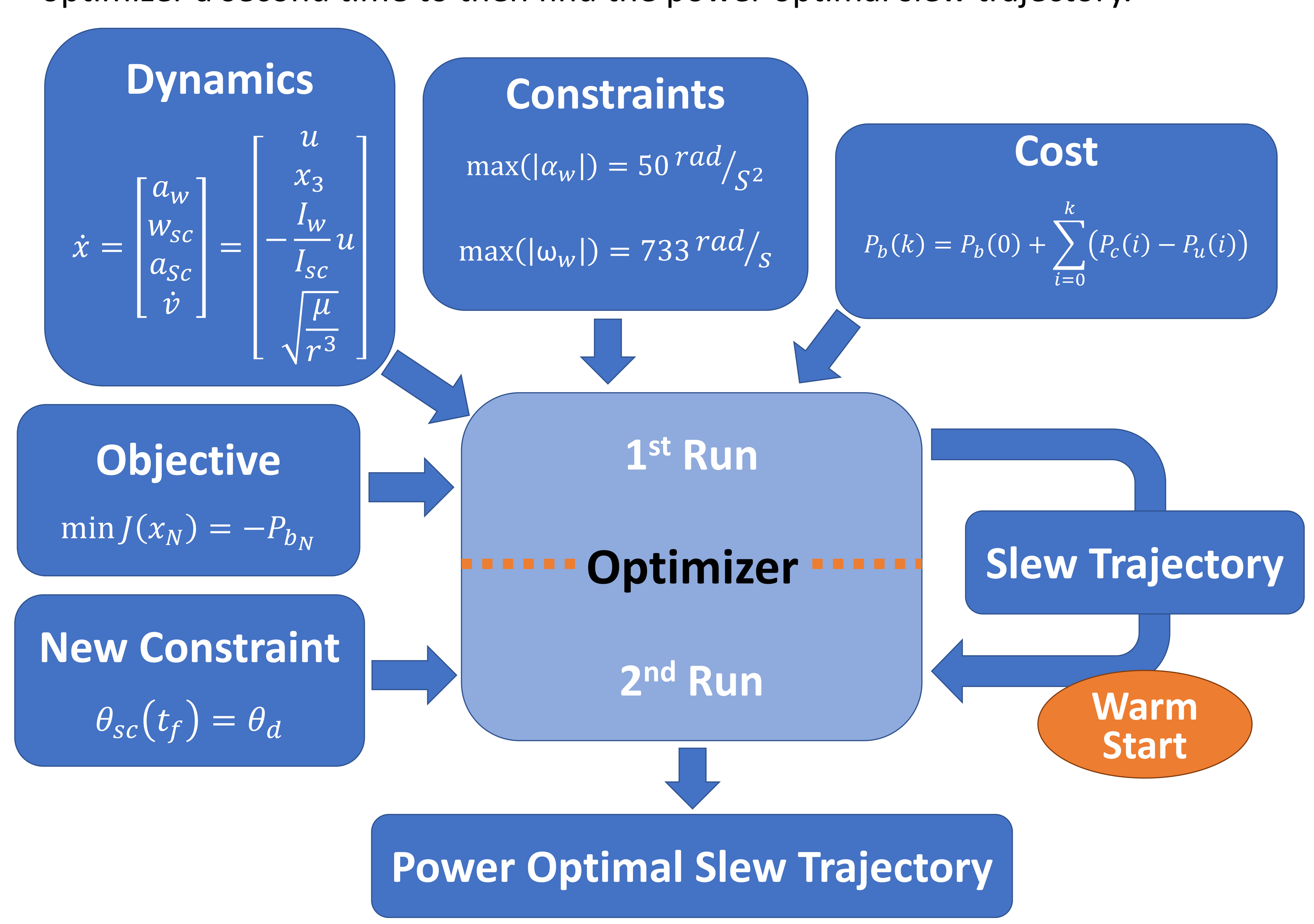
- This orbit always offers full solar charging, eliminating the consideration of satellite states in eclipse.
- Because of the constant angle between sun vector and orbit plane, the system dynamics are simplified.
- Power state optimal control law and traditional approach were simulated.
- Compared 3 slew maneuvers corresponding to boundary conditions for sunbathing and image collection endpoints.
- Compared image collection plan of 14 target-time pairs.
- Simulation parameters based on feasible and conservative values for small satellites.

Slew Maneuver Control



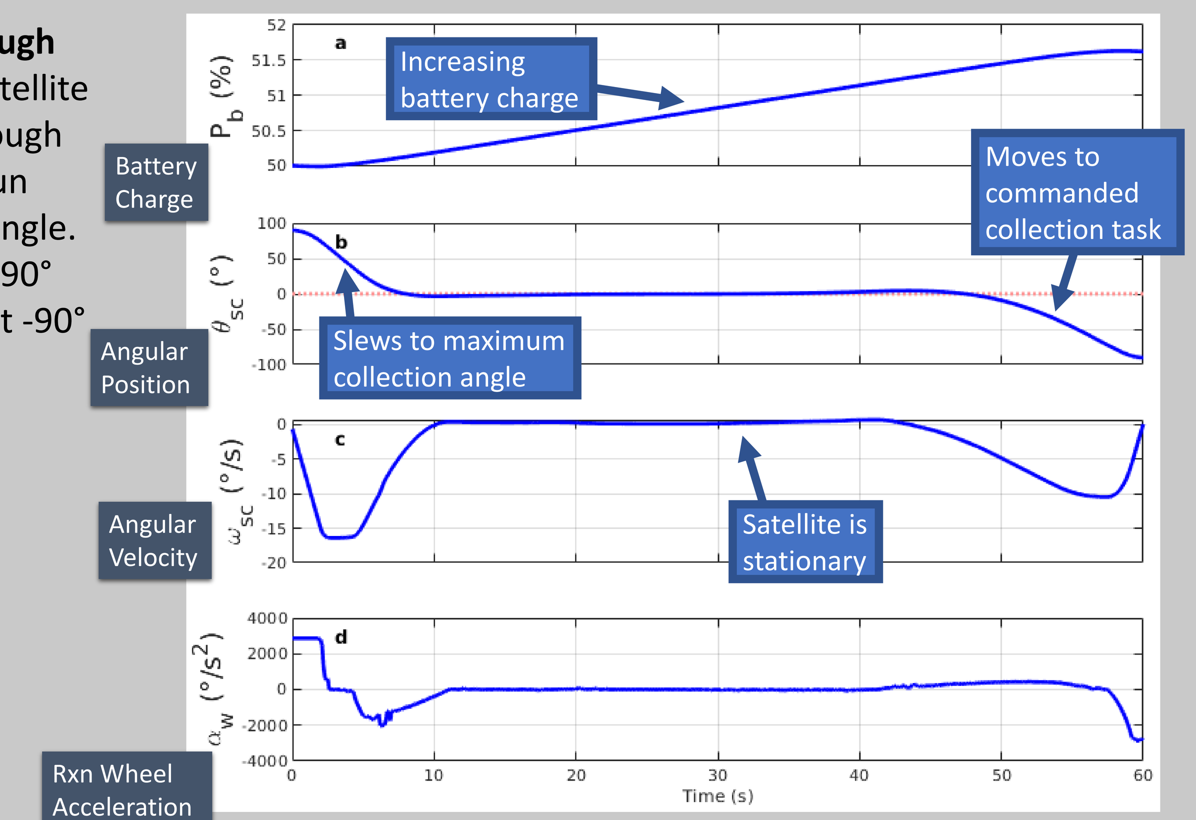
To optimize power state, momentum wheel acceleration is controlled to orient the spacecraft solar arrays for maximum power collection.

- ***Optimizer:*** finds a slew trajectory to maximize charge given inputs and state dynamics.
- ***Constraints:*** the physical limits of the hardware. The satellite is also constrained to move about only one axis of rotation.
- ***Objective*** minimizes the ***Cost*** based on battery charge state.
- ***System Dynamics:*** the physics controlling the angular acceleration and inertial moment of the wheels and spacecraft.
- ***Discrete Simulation Method:*** Multiple Shooting, Direct method using exact discretization.
- To give a "warm start," the optimizer is first run with an unconstrained final state. The resulting slew is a first guess trajectory that is refined by running through the optimizer a second time to then find the power optimal slew trajectory.

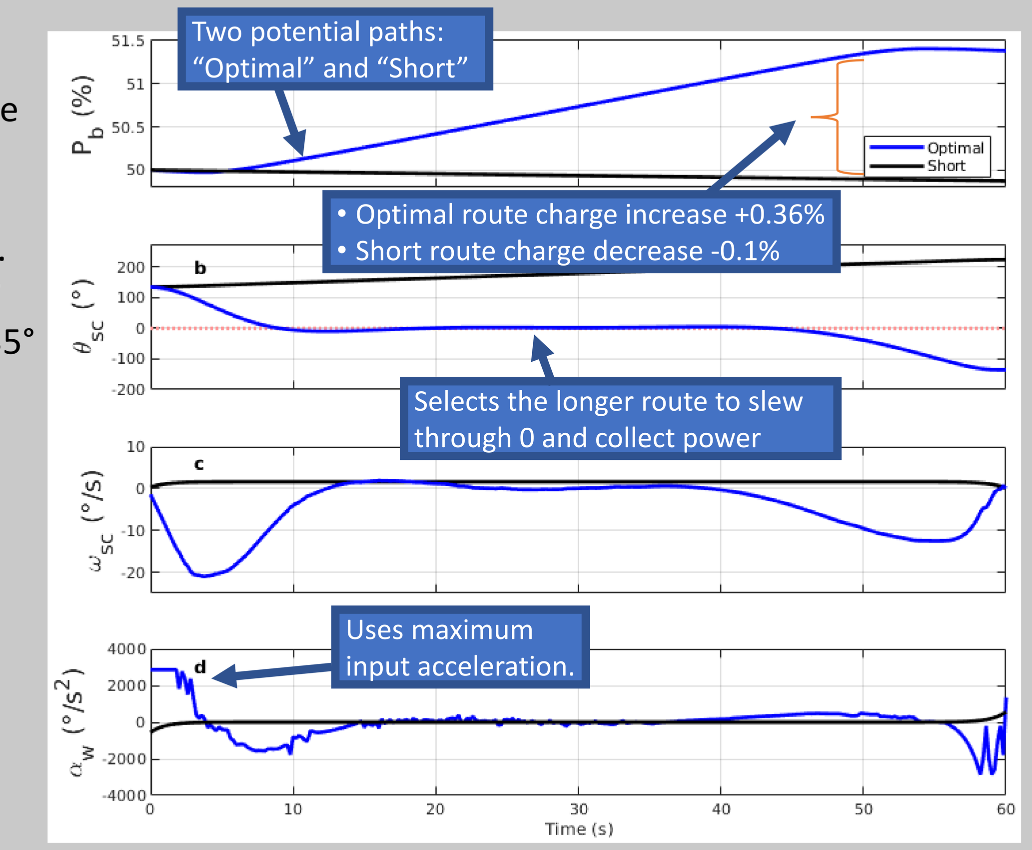


Results: Slew Maneuver Simulations

Pass Through Zero 1: Satellite slews through optimal sun pointing angle.
➢Start at 90°
➢Target at -90°

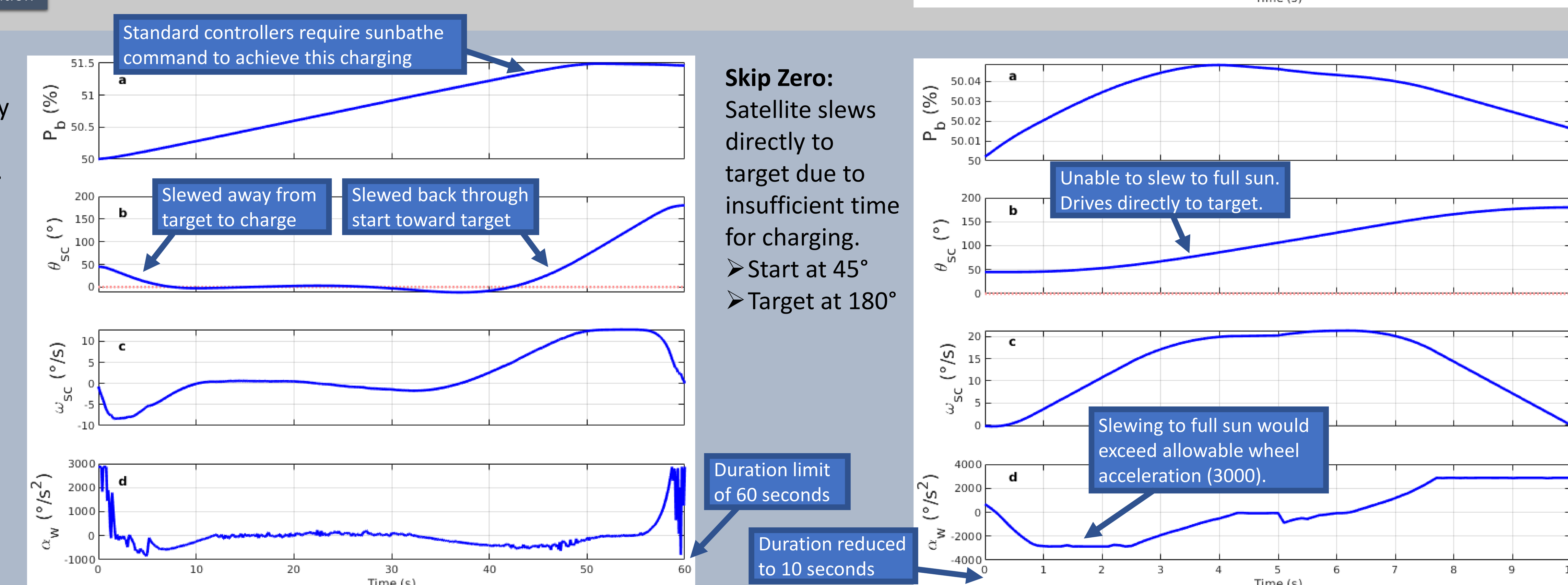


Pass Through Zero 2: Satellite slews through optimal sun pointing angle.
➢Start at 135°
➢Target at -135°

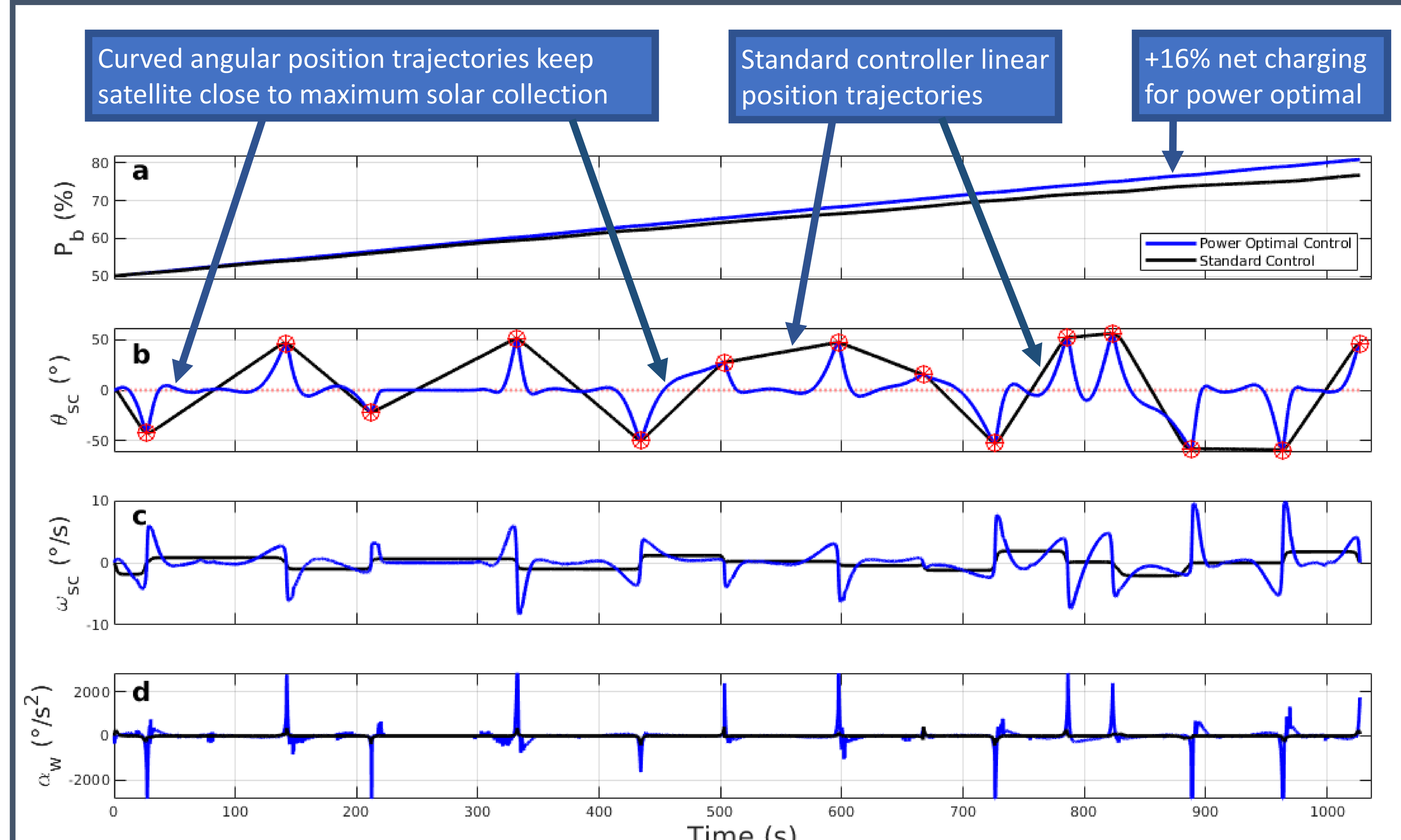


Zero and Back: Satellite slews away from target to maximize charging.
➢Start at 45°
➢Target at 180°

Skip Zero: Satellite slews directly to target due to insufficient time for charging.
➢Start at 45°
➢Target at 180°



Results: Collection Operation



Conclusions

- The power state optimal controller reduces the need for operator decisions by integrating power collection with imaging tasks.
- The power state optimal controller always collected equal or greater solar power than the standard controller.
- Sufficient time between targets is necessary to benefit from power optimization.
- The power state optimal controller required greater maximum input acceleration.
- Power optimization is more computationally expensive (27x of standard controller for the case study collection plan).