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MASTER THESIS

VLEO Satellites: An Optimized Engineering Design Approach

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ABSTRACT

Satellites operating in Very Low Earth Orbit (VLEO) increase operational capabilities by providing low-latency communications, improved spatial resolution, reduced radiation exposure and natural compliance with de-orbit regulations. However, the enhanced aerodynamic drag at these altitudes poses severe constraints on mission lifetime, requiring innovative propulsion solutions. Among them, air-breathing electric propulsion (ABEP) has emerged as a promising technology, exploiting residual atmospheric particles as propellant to enable sustainable operations. This thesis presents an optimized engineering design approach for VLEO satellites integrating ABEP, combining high-fidelity aerodynamic modeling with surrogate-assisted optimization. First, the environmental characteristics of VLEO are analyzed, including drag forces, radiation environment, intake heating, and feasible flight envelopes. A novel satellite geometry is proposed, consisting of an aerodynamic forebody and dual intake ducts coupled with a rectangular payload section to balance aerodynamic efficiency, manufacturability, and payload capacity.

METHODOLOGY

The aerodynamic behavior is modeled using the NRLMSISE-00 atmosphere, while Direct Simulation Monte Carlo (DSMC) simulations performed with SPARTA quantify drag and scattering coefficients. To overcome the computational cost of exhaustive DSMC evaluations, a surrogate-based methodology is developed, employing screening plans, optimized Latin Hypercube Sampling, Kriging with Partial Least Squares, and adaptive infill strategies. This framework supports a Particle Swarm Optimization (PSO) process targeting the maximization of the thrust-to-drag ratio under realistic geometric and propulsive constraints. Thes tudy validates the feasibility of ABEP-powered missions in VLEO and establishes a robust methodology for future satellite design.

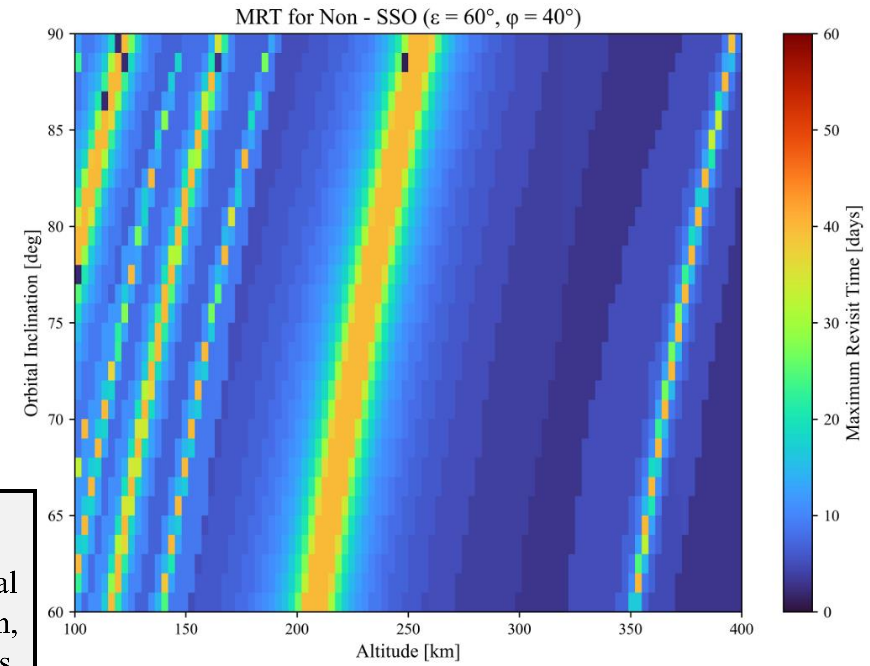

Figure. Maximum revisit time estimation

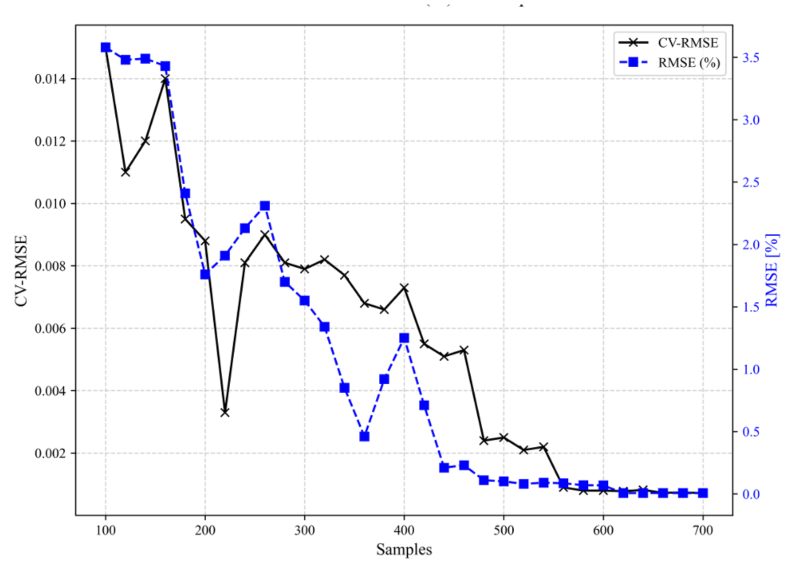

Figure. Surrogate model training errors

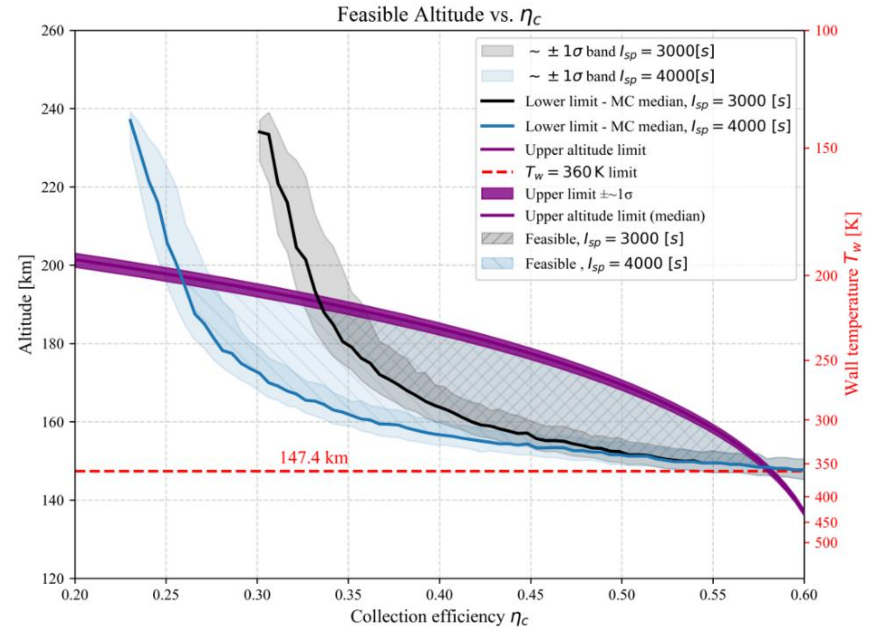

Figure. Feasible operational envelope accounting for geometrical and performance variations

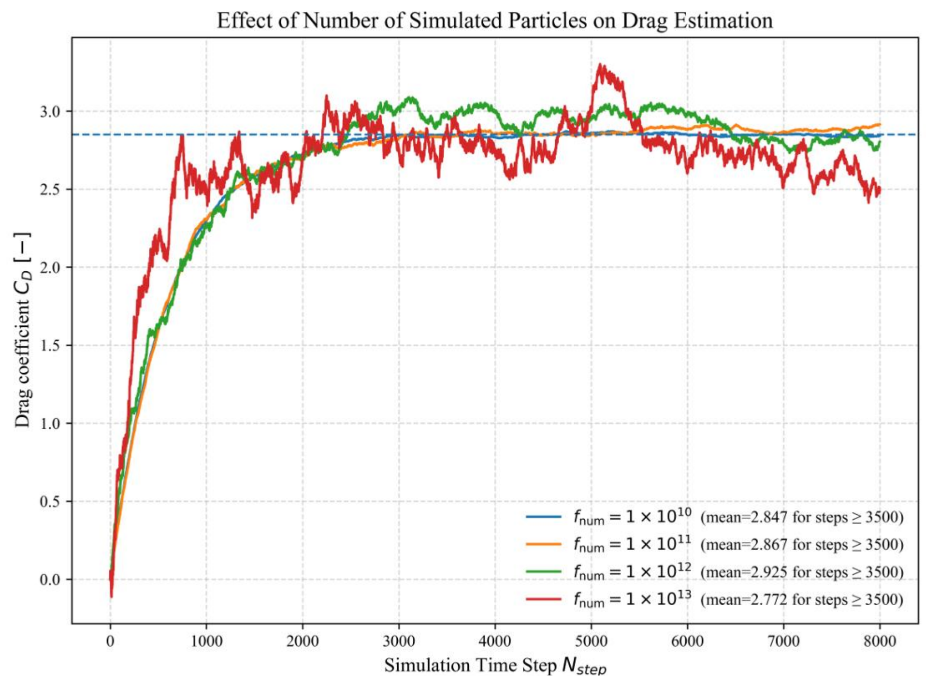

Figure. Effect of number of simulated particles on DSMC drag estimation.

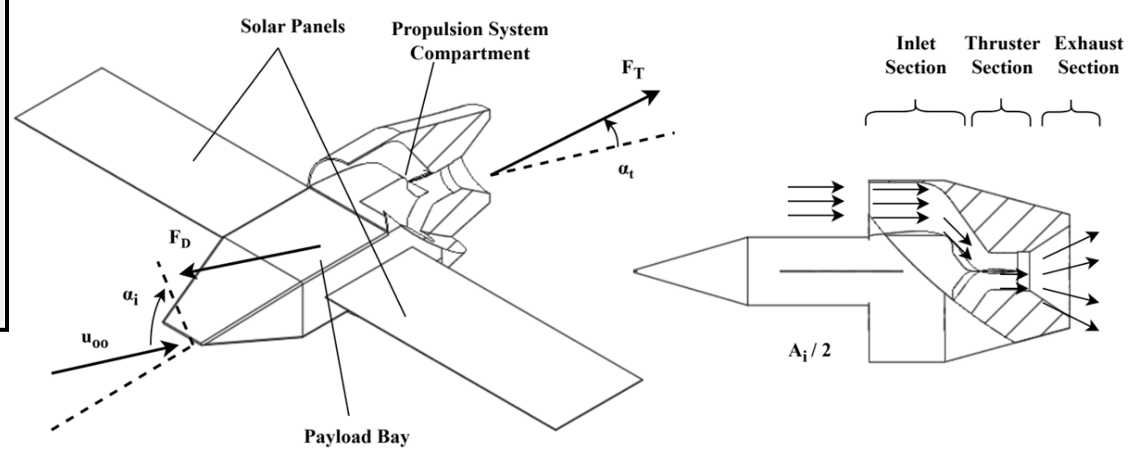

Figure. Schematic of the satellite geometry