CubeSat Constellation Concept for the Demonstration of Autonomous Docking with a Liquid Apogee Engine

VirginiaTech

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Overview

This research presents ***a modeling tool for the rapid-design of CubeSat rendezvous and proximity operation missions***. The model is applied to a concept for a low Earth orbit CubeSat constellation designed to demonstrate the technological capability of docking with liquid apogee engines.

The model analysis includes:

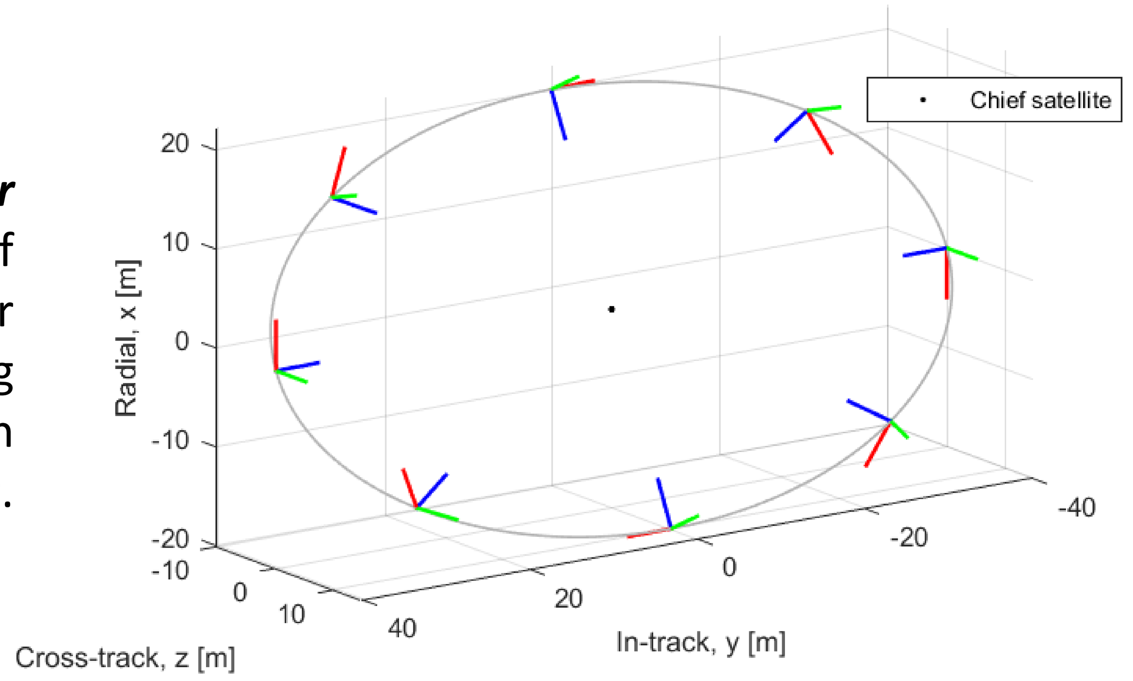
- An open-loop, fuel-optimal maneuver planner capable of generating controls over a complete orbital period
- A closed-loop, model predictive control (MPC) algorithm capable of locally-fuel optimal trajectories with collision-avoidance measures.
- Computer vision algorithms for relative range finding and translational positioning.

Attitude and Sensor Models

The model includes a attitude controller that reacts to automated trajectory design.

- Model-based attitude actuator sizing for pointing requirements

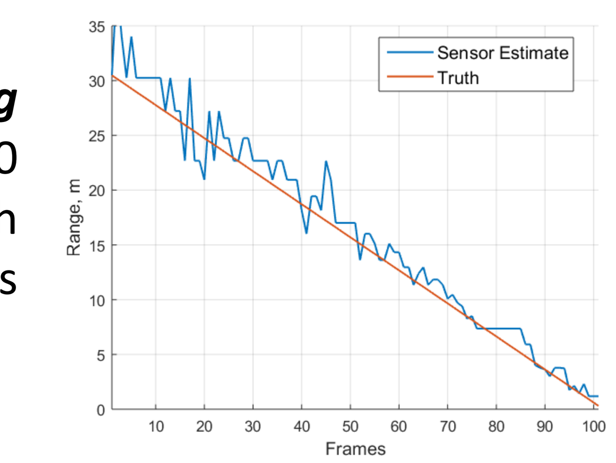
Attitude controller
Attitude concept of operations for chaser satellite maintaining sensor alignment with target spacecraft.

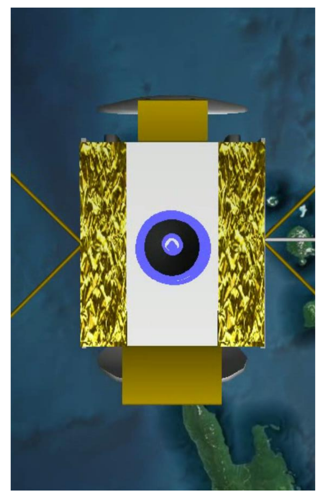


The concept chaser "Active" satellite is equipped with an optical sensor suite and computer vision processor.

- Chaser equipped with a wide and a narrow field of view lens.
- Uses knowledge of the LAE nozzle diameter to scale images to calculate range and relative translational position.
- OpenCV-based computer vision algorithm development.

Optical range-finding
Range testing for 30 meter approach with 70 mm lens





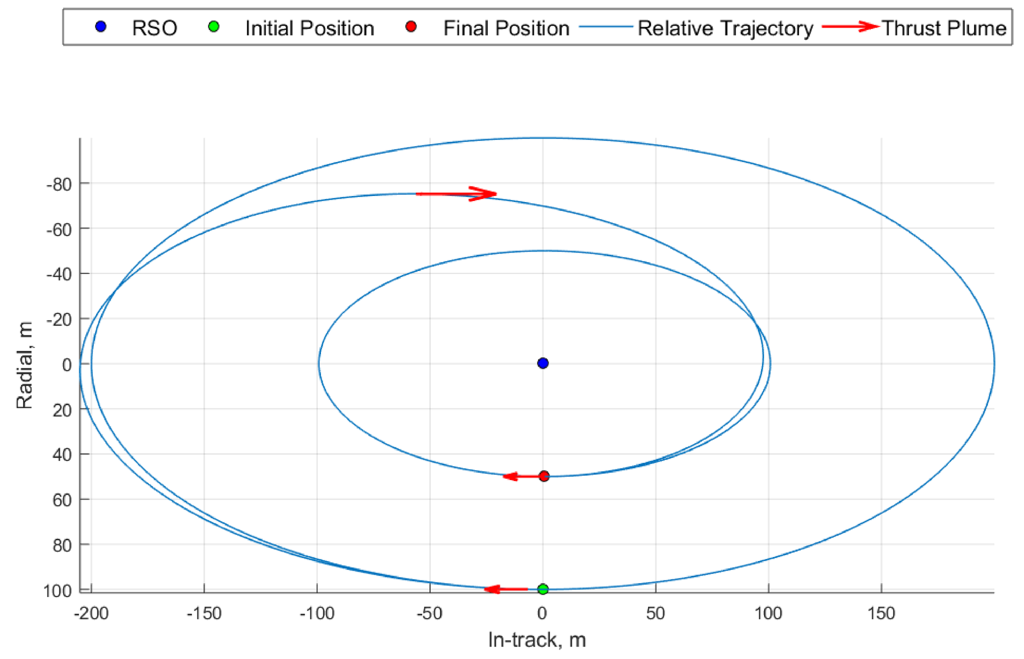
Synthetic testing
Synthetic image testing and algorithm visualization

Trajectory Design

Both guidance methods solve discrete-time fuel minimization problems in the LVLH frame of the chief satellite.

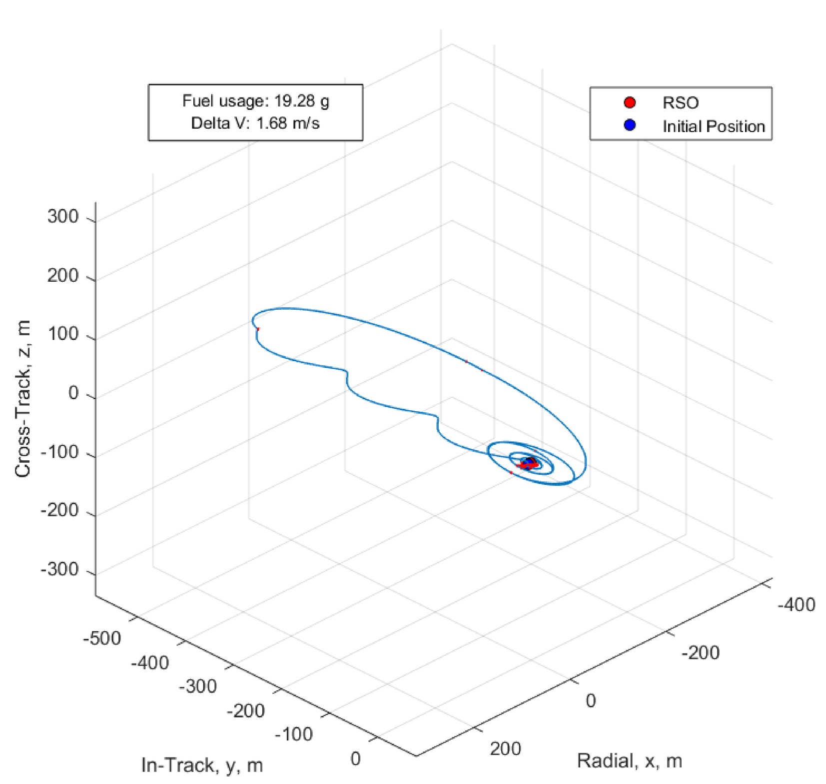
An open-loop trajectory planner is capable of:

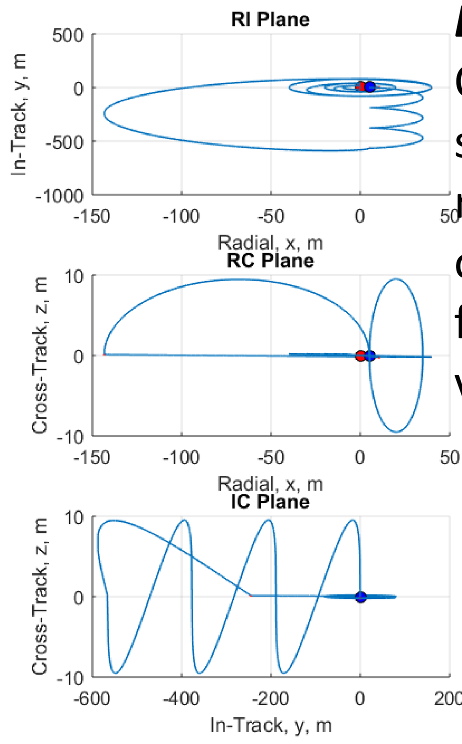
- ***Fuel-optimal maneuver planning*** for relative ellipse resizing



Ellipse resizing
100 m to 50 m radial axis ellipse resizing maneuver. The discrete-time result converges to a three-burn maneuver.

- Complex ***concept of operations design***



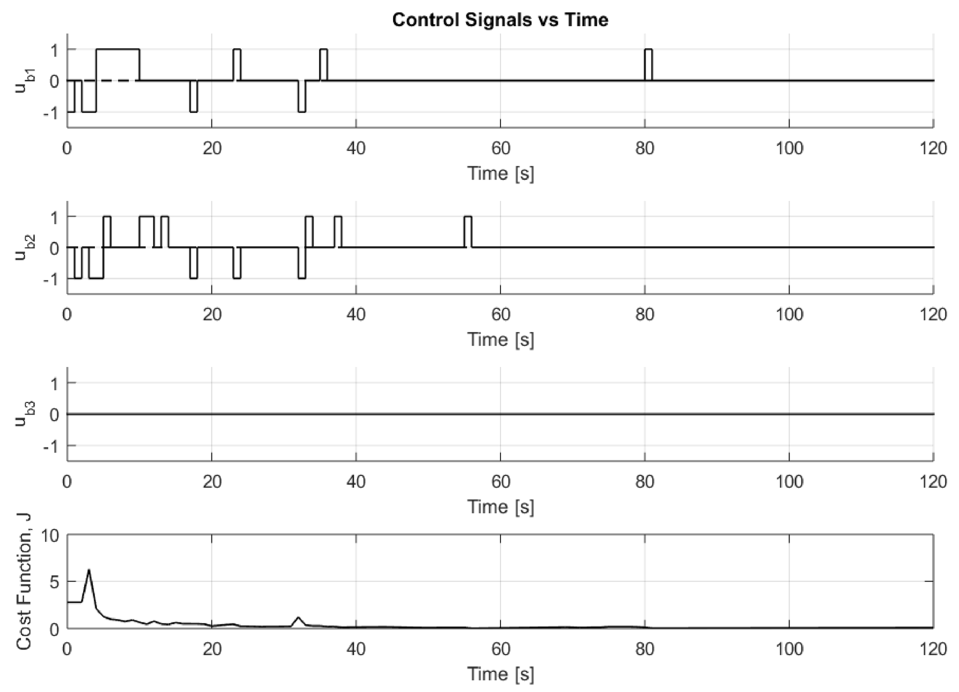


End-to-end simulation
Complete trajectory and attitude simulation of detumble, rendezvous, and proximity operations. Exports ephemeris files for post process visualization.

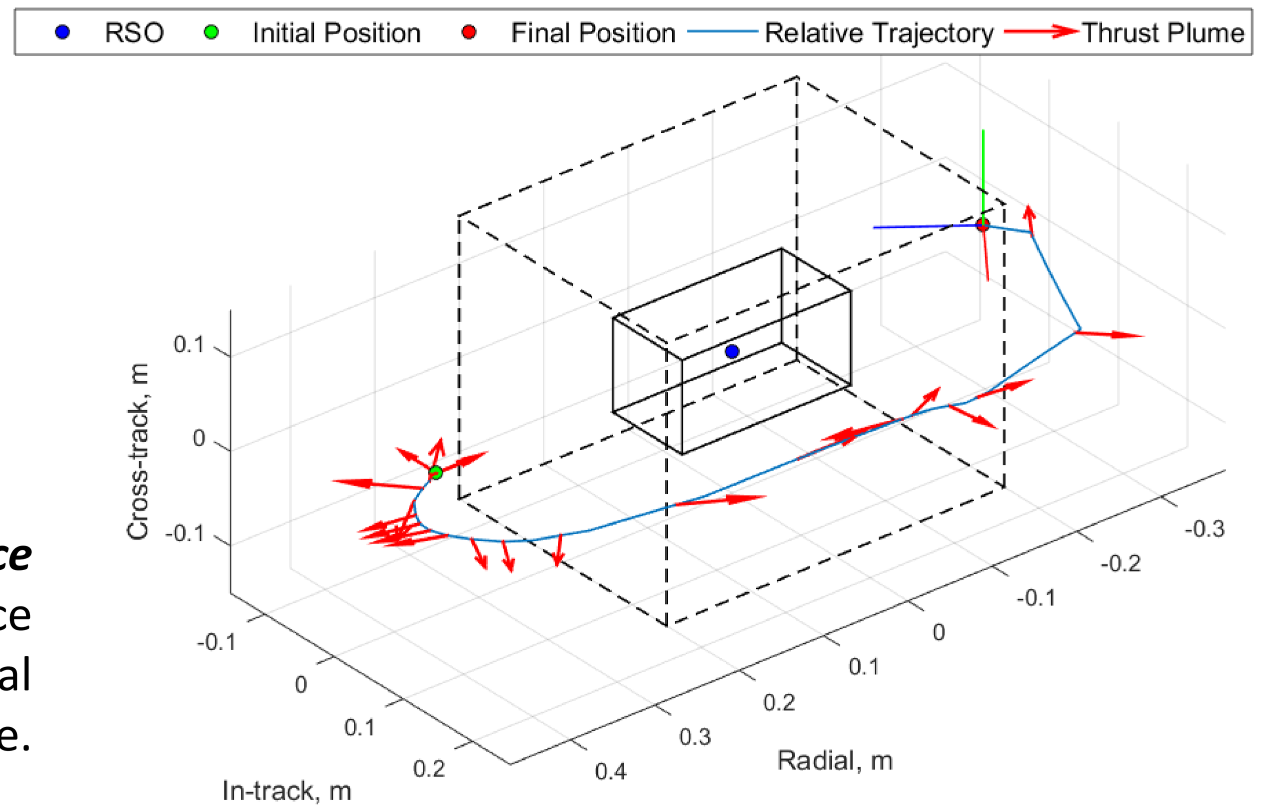
Model predictive control is used for closed-loop control during close-proximity operations and docking with the apogee engine.

- ***Multi-objective cost function*** to allow for greater control over the behavior of the deputy spacecraft in proximity operations.

Model predictive control. Control signals and cost function for the collision avoidance example below.



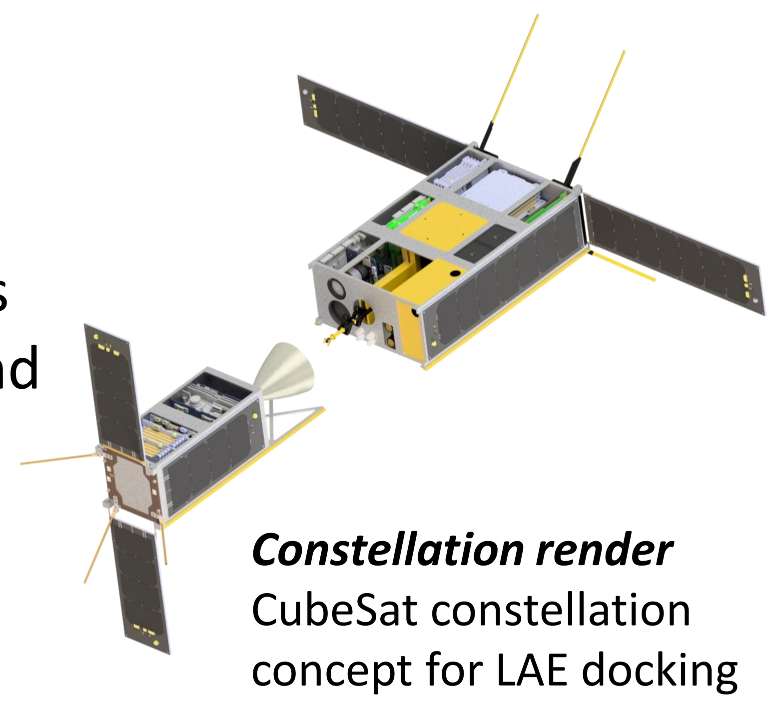
- Mixed-integer linear programming for binary constraints allows for ***binary-thrust control*** and ***collision avoidance***



Collision avoidance
Automated collision avoidance while repositioning along the radial access of the Target satellite.

Constellation Design Concept

- 3U "target" CubeSat with an onboard liquid apogee engine representation
- 6U "active" satellite which acts as the chaser with RPO capability and demonstration technologies.
- Using a cold-gas propellant tank and the presented guidance methods, the 6U is ***capable of a large rendezvous and several docking attempts.***



Constellation render
CubeSat constellation concept for LAE docking demonstration.

Summary and Future Work

This work provides the user with the ability to:

- Rapidly design microsatellite RPO concept of operations.
- Evaluate different thruster performance on mission ability.
- Calculate Δv and fuel usage for constrained station keeping.

Future improvements and additions to this work include:

- Migration of the work to a system programming language is necessary to benchmark the performance.
- Implementation of a method to convert discrete-time outputs in continuous-time control signals.
- High-precision propagation with corrective measures using similar techniques