AeroCube-7
Proximity Operations CONOPS

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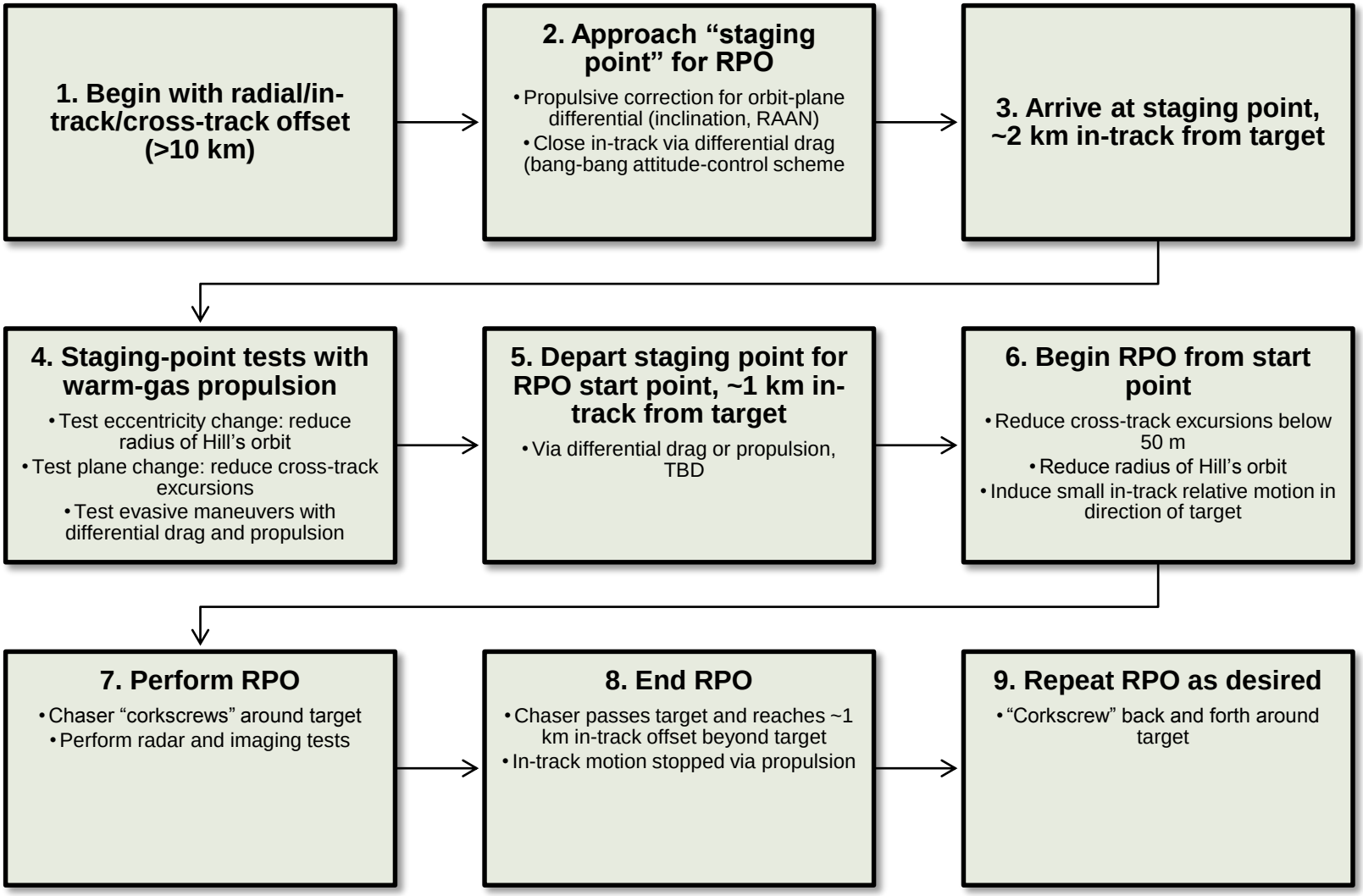
Astrodynamics Department

RPO CONOPS Flow Chart



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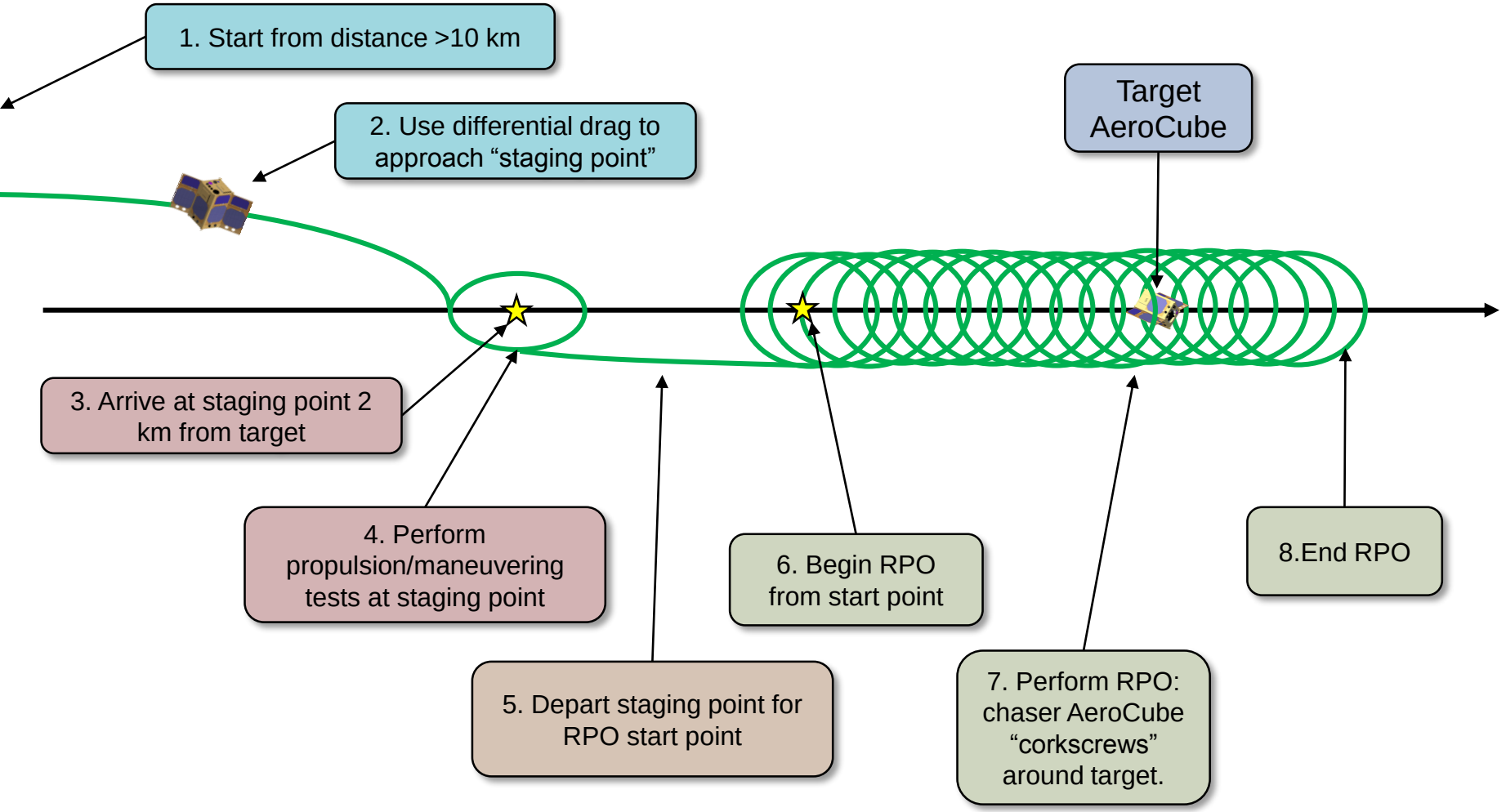
RPO CONOPS Notional Diagram



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Initial Conditions

- After deployment and during checkout, AeroCubes will drift due to initial deployment dispersions and checkout activities.
- Begin RPO with substantial (>10 km) in-track separation between AeroCubes, plus some radial and cross-track separation
  - *Will use differential drag during checkout if available to minimize in-track separation as much as possible*
- Assumptions for this analysis:
  - *Orbit is 500 km circular, 65 deg inclination*
  - *Min drag area: 150 cm^2*
  - *Max drag area: 500 cm^2*
  - *Mass: 2 kg*

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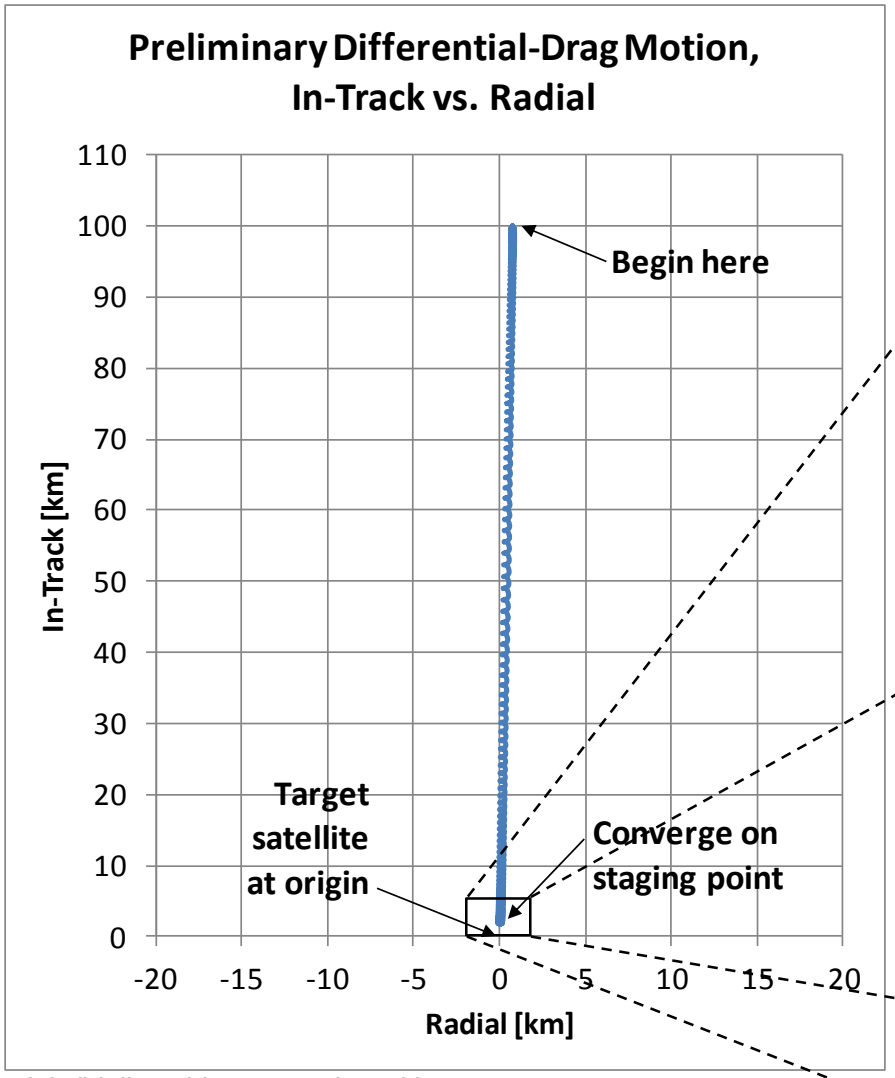
Approach Staging Point

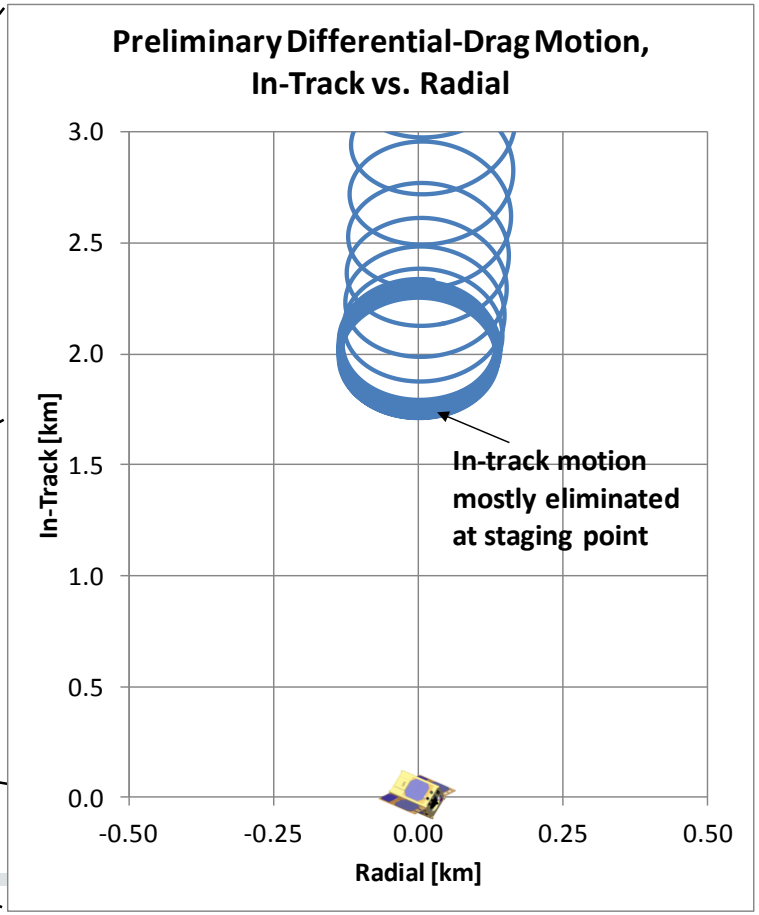
- RPO process begins with approach to a “staging point” to ensure control of the spacecraft and efficacy of planned maneuver schemes.
- Use on-board propulsion to correct plane differences between AeroCubes:
  - *Based on AeroCube-4 experience, as much as 0.002 deg of inclination change, costing 30 cm/s of ΔV.*
  - *As much as 0.005 deg of RAAN change, costing 75 cm/s.*
  - *Budget 2 m/s total, performed in small amounts over many orbits.*
  - *Can perform plane change maneuvers at any time.*
- Use differential drag with a bang-bang attitude-control scheme to approach the target AeroCube within 2 km in-track. This is the “staging point.”
  - *At end of differential drag process, mean motion of chaser and target are matched.*

Approach Staging Point, In-Plane Motion



High-fidelity orbit propagation with TRACE

Differential drag with a bang-bang attitude-control scheme brings the spacecraft together within 2 km and holding



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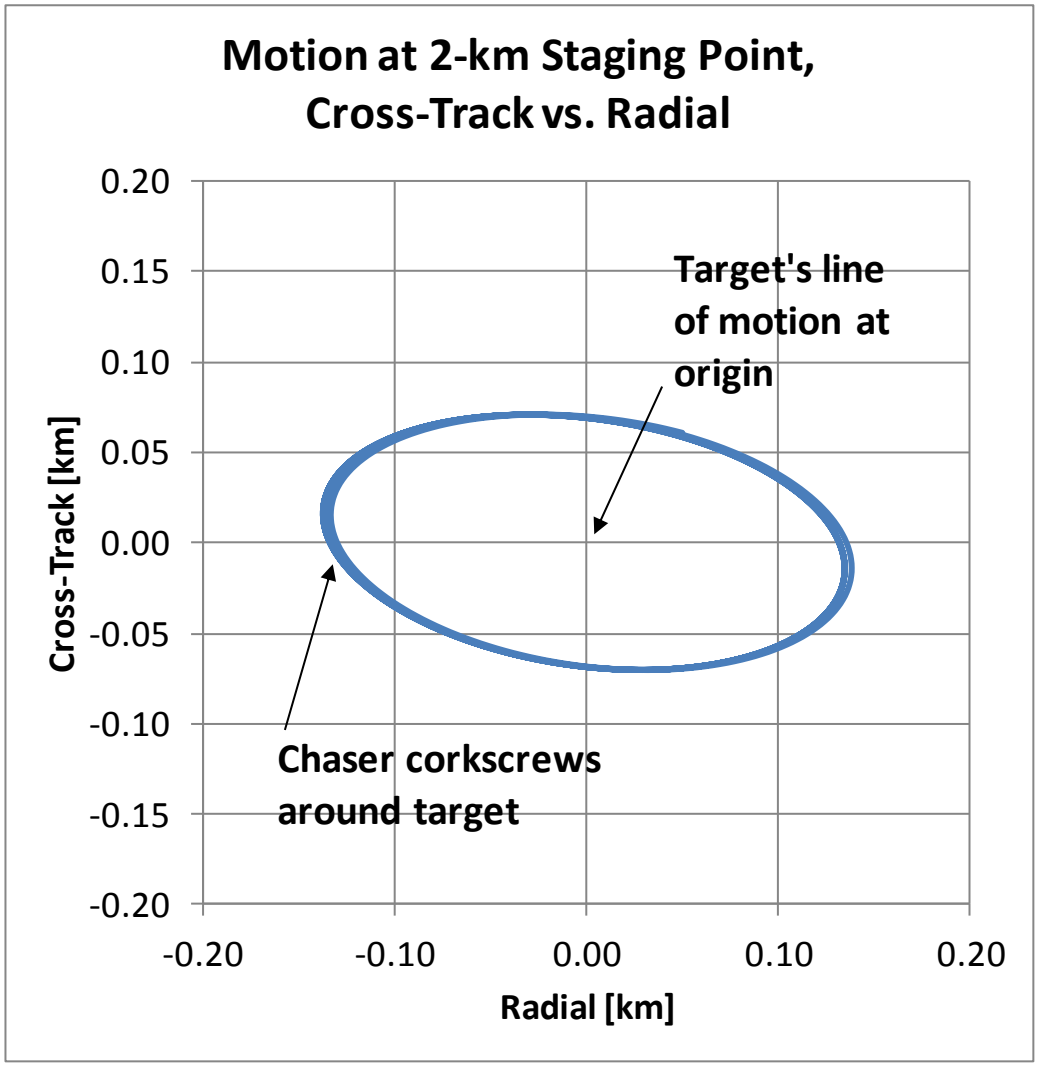
Approach Staging Point, Out-of-Plane Motion

At the staging point, the target has some cross-track motion.

The line of motion (the orbit velocity vector) of the target AeroCube goes into/out of the screen in this plot. The chaser AeroCube "orbits" around that line of motion

Risk mitigation: by following this trajectory, the chaser ***never*** crosses the path of the target, preventing collisions.



High-fidelity orbit propagation with TRACE

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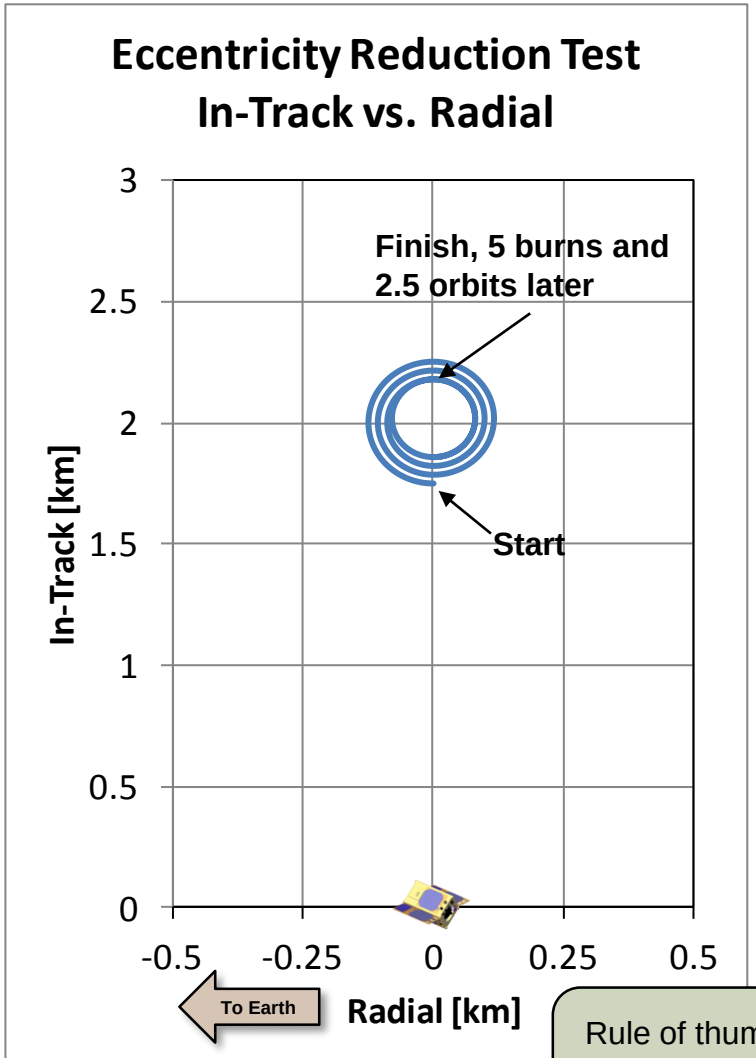
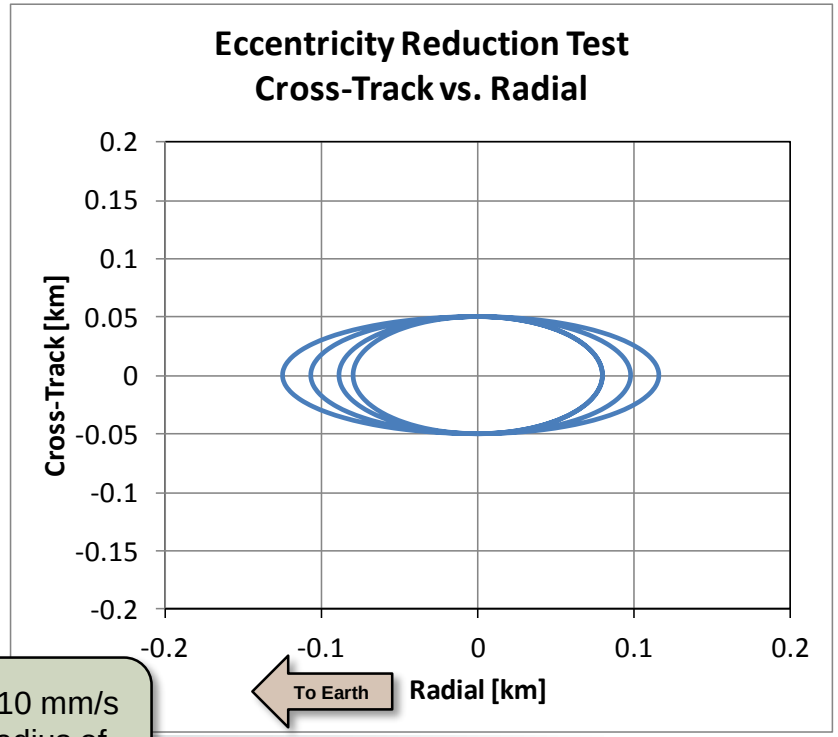
Tests at Staging Point: Eccentricity Reduction



Small burns (~10 mm/s) performed in the radial direction reduce the radius of the Hill's orbit (left). These burns can occur as often as every half-orbit. In practice, will use longer lead times. Note that the cross-track motion (below) is not affected; the chaser still never crosses the path of the target.



Rule of thumb: ~10 mm/s of DV reduces radius of Hill's orbit by ~20 m.

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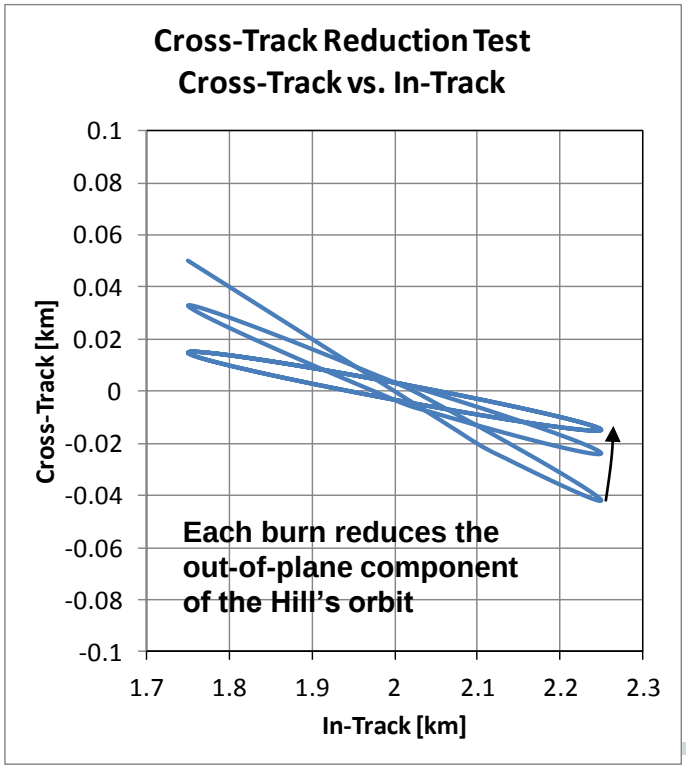
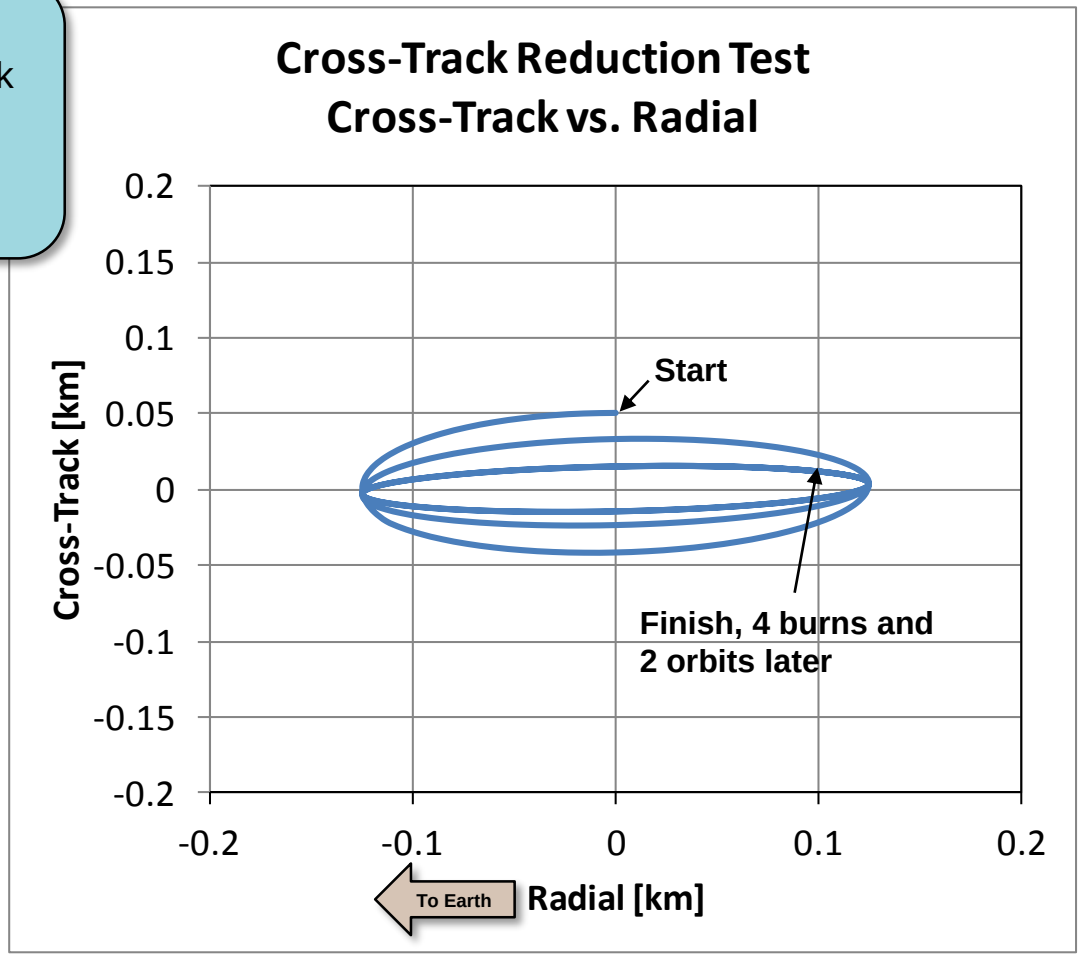
Tests at Staging Point: Cross-Track Reduction

Small burns (~10 mm/s) performed in the cross-track direction reduce the cross-track excursions of the Hill's orbit. These burns can occur as often as every half-orbit. In practice, will use longer lead times.





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Note on Risk from Staging-Point Tests

- In the event that a test burn is misaligned entirely in the in-track direction, the chaser will continue to corkscrew around the line of motion of the target due to cross-track motion. Closest approach to target's line of motion >50 m.
- If a test burn is misaligned in the cross-track direction, the change in cross-track motion is minimal.
- No individual burn is sufficient to put the chaser AeroCube on a collision course with the target.
  - *Until we have high confidence in the performance of the thruster later in the mission, each burn will be followed by orbit determination and thruster-performance analysis to ensure that the new desired orbit was achieved.*
  - *In the event of an anomaly or undesired behavior, no further burns will be performed to ensure the safety of both spacecraft.*

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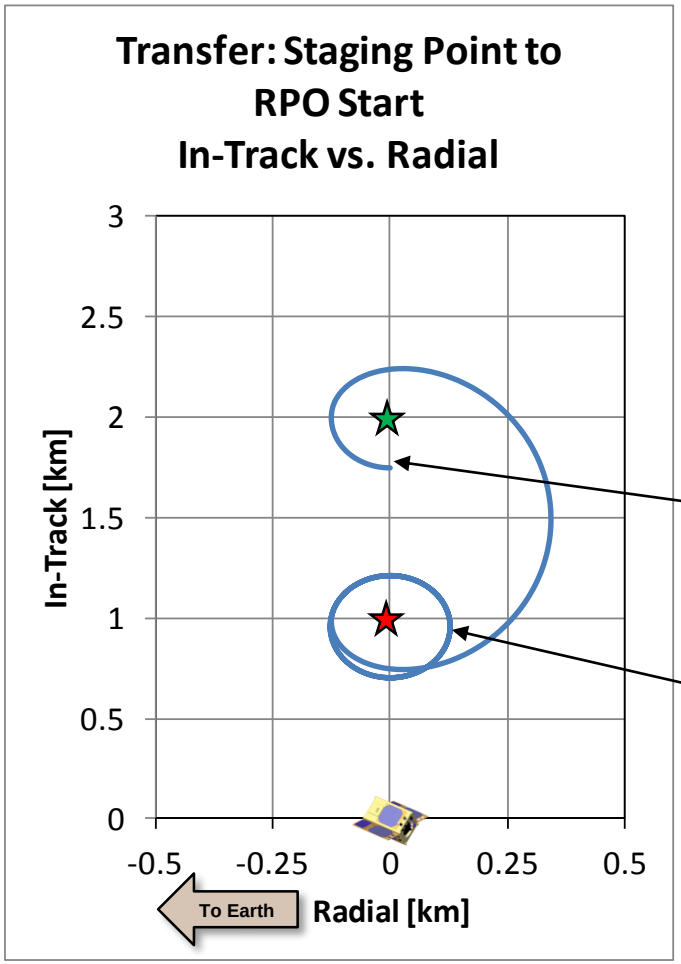
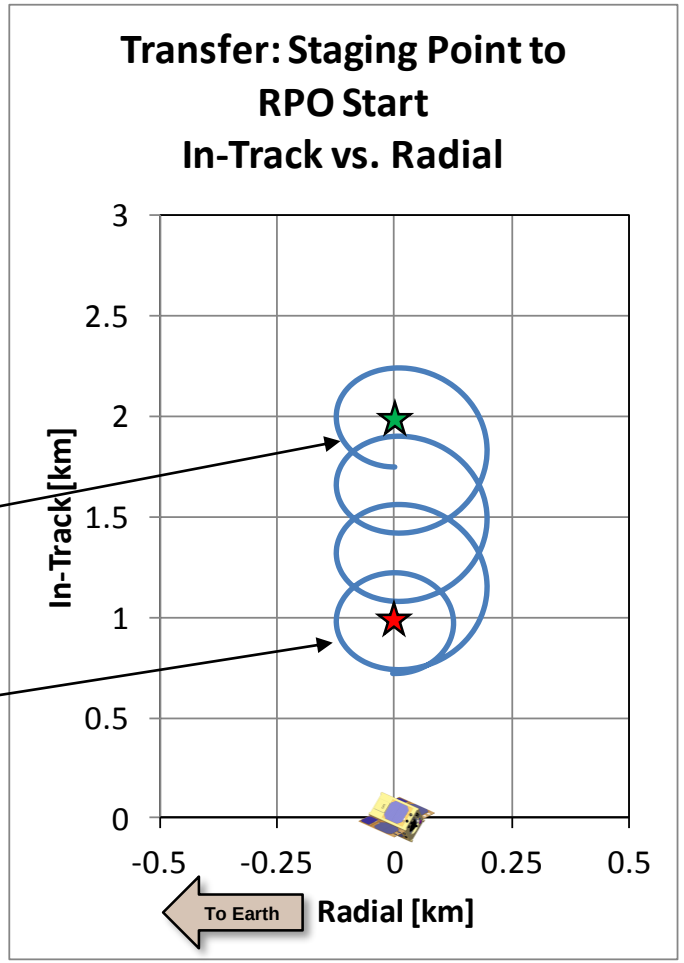
Transfer: Staging Point to RPO Start Point



Transfer from the staging point to the RPO start point can occur over different timescales. The longer the transfer takes, the cheaper it is in ΔV.

Start: Staging point

End: RPO start point



1 orbit transfer, ΔV = 12 mm/s

3 orbit transfer, ΔV = 4 mm/s

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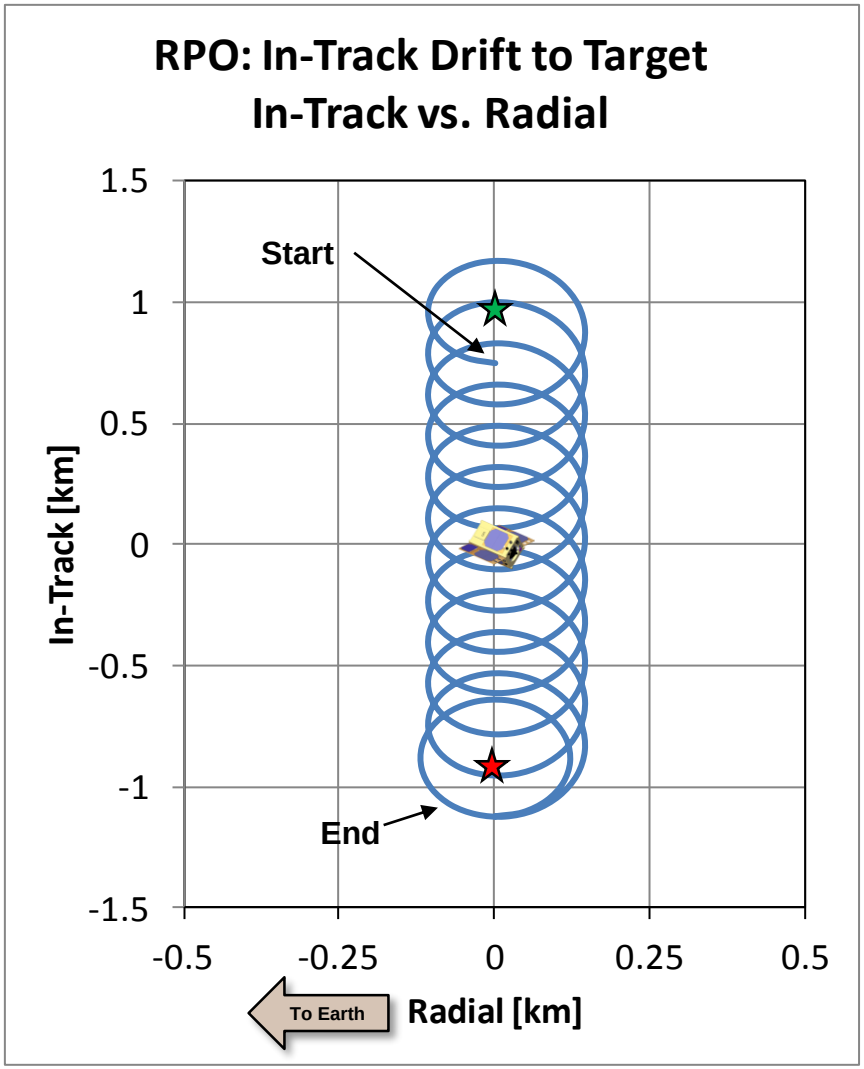
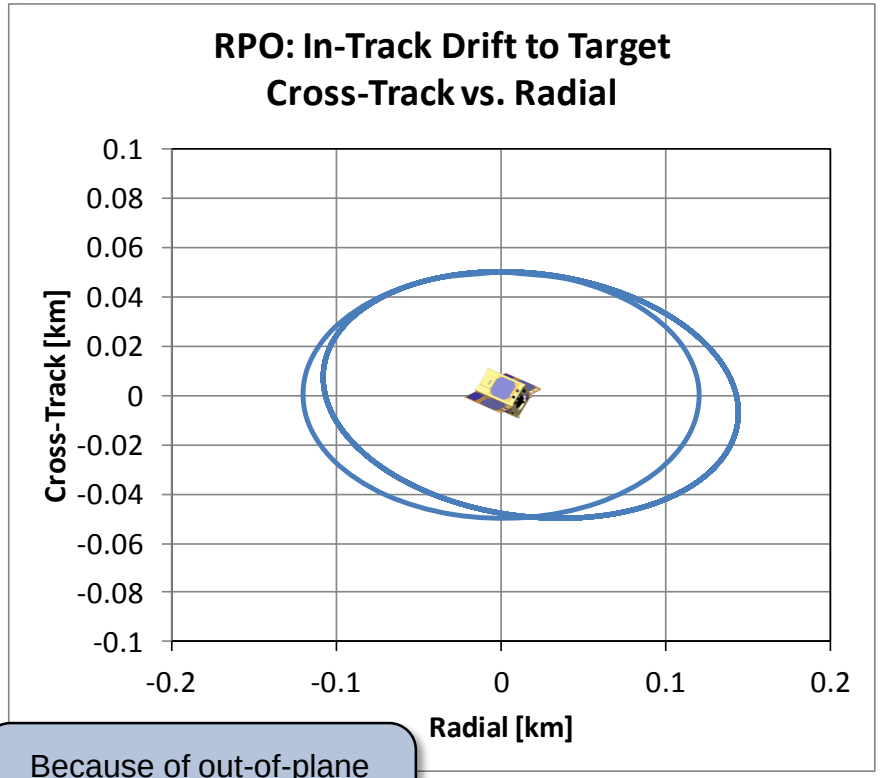
AEROSPACE

RPO: Initiate In-Track Drift and Approach Target



A small burn (~10 mm/s) induces in-track motion relative to the target. The chaser corkscrews around the target over the course of several orbits, passes the target, and then performs another burn (~10 mm/s) to stop 1 km beyond the target.



Because of out-of-plane motion, the chaser never crosses the target's path.

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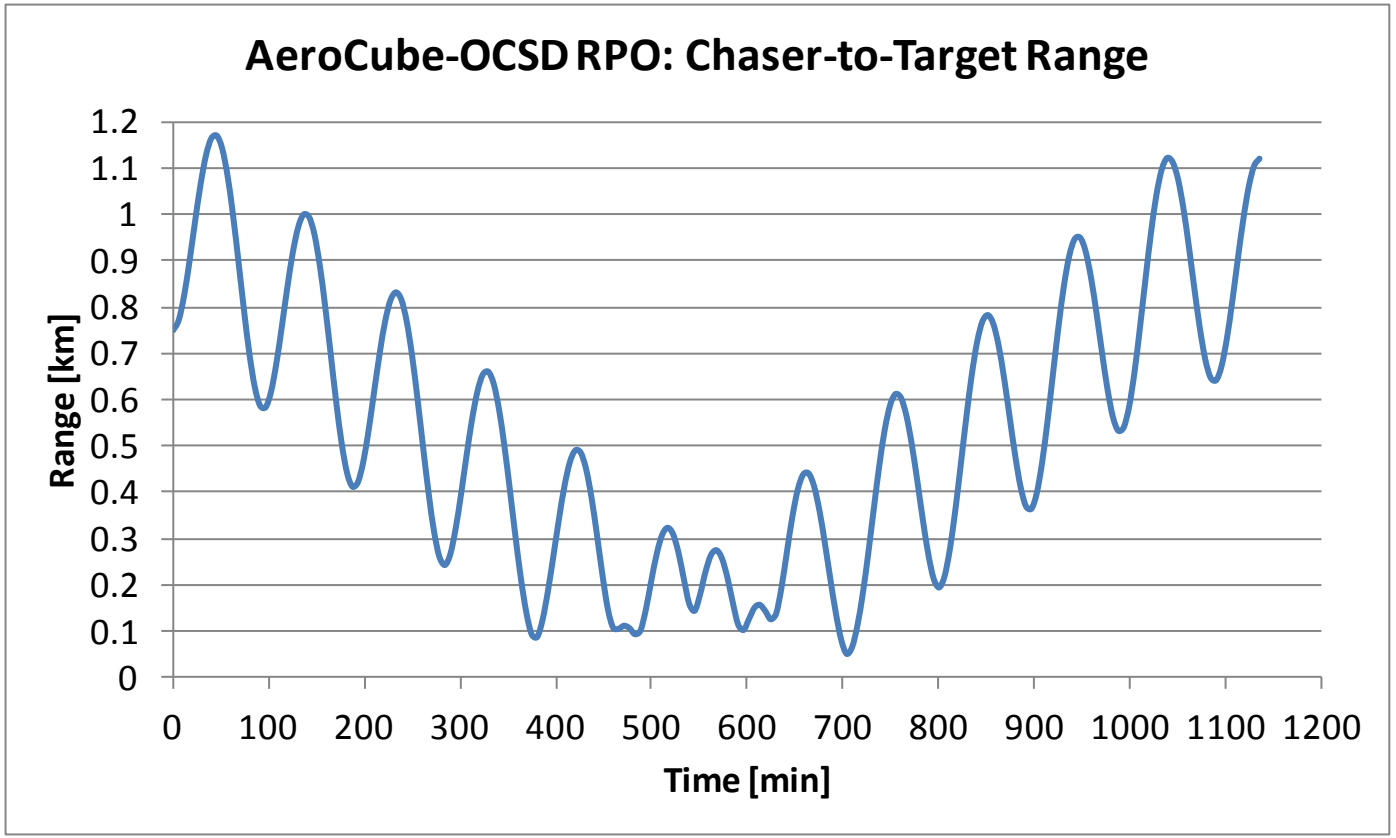
RPO: Chaser-to-Target Range

The duration of the RPO depends on the amount of in-track drift induced. For this ΔV = 20 mm/s (start and stop) example, the RPO takes about one day, with closest approach halfway.



In this example the closest approach is ~50 m. As confidence grows, the radius of the Hill's orbit will be reduced.

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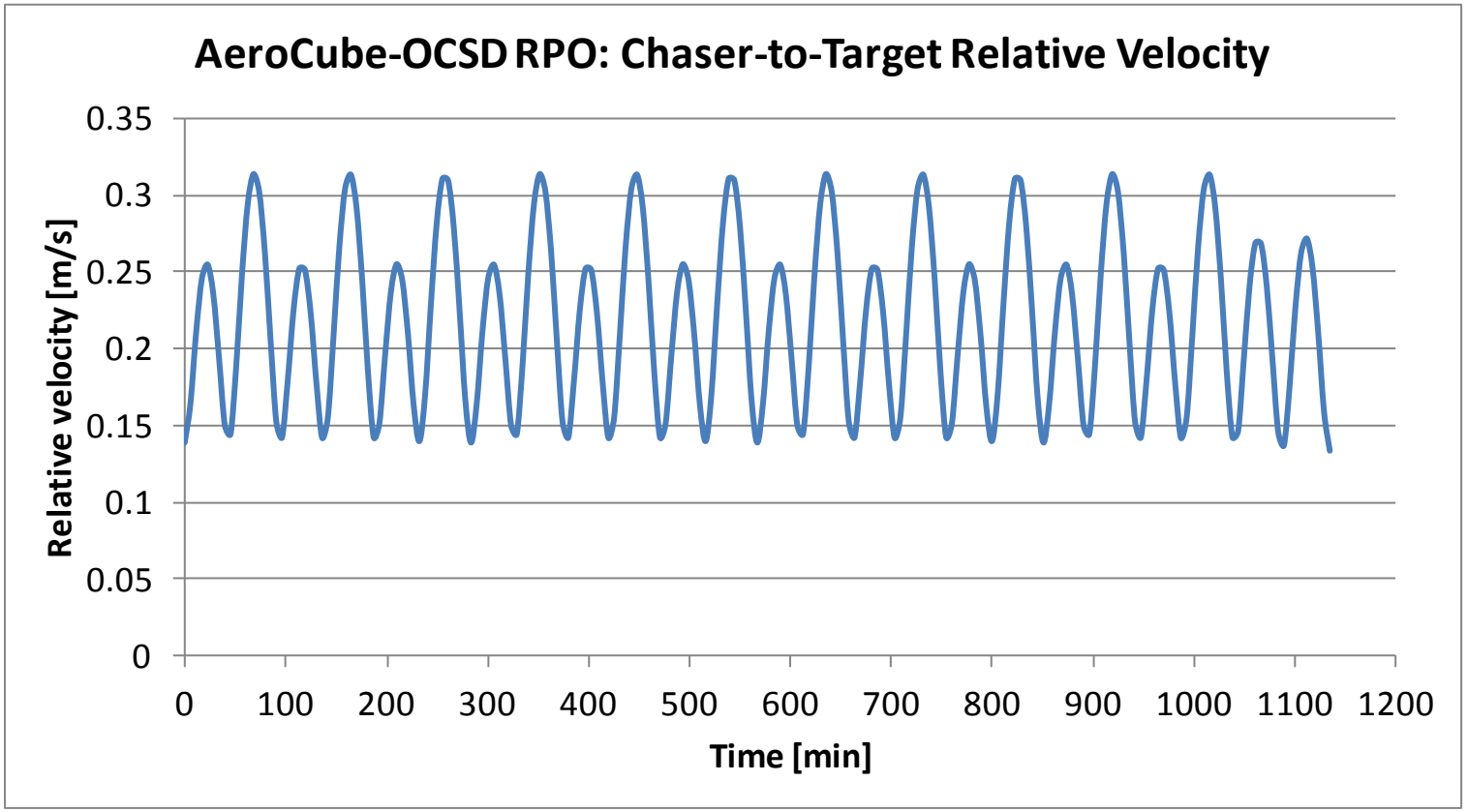
RPO: Chaser-to-Target Relative Velocity

In this example, the relative velocity between the chaser and target does not exceed 0.35 m/s (<1 mph).



Even is a collision did happen, these relative velocities are not high enough to cause fragmentation or a catastrophic breakup.

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ΔV Budget

Event	ΔV [m/s]	Comment
Plane corrections	2	
Staging-point test: eccentricity reduction	0.1	~10 mm/s per maneuver
Staging-point test: cross-track reduction	0.1	~10 mm/s per maneuver
Transfer from staging point to RPO start point	0.12	Maximum possible cost (for transfer in 1 orbit)
RPO: start and stop in-track drift	0.02	
RPO: modify radius of Hill's orbit	0.01	Changes radius by ~20 m

A full RPO cycle, including Hill's orbit modifications, costs ~30 mm/s.

Even with this conservative DV budget, the 10 m/s capacity of the AeroCube-7 system should permit dozens of RPO cycles with considerable propellant margin.

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Summary

- The AeroCube-7 RPO CONOPS has been designed to minimize risk to both vehicles and to build maximum confidence via incremental testing of maneuver schemes.
  - *"Dress rehearsal" maneuvers at a staging point will characterize control authority on chaser AeroCube without risk to target.*
  - *Cross-track amplitude is always maintained to ensure that the chaser AeroCube never crosses the path of the target, preventing collision.*
    - During RPO, chaser "corkscrews" around target
  - *Radius of Hill's orbit will be reduced incrementally over several RPO cycles.*
- ΔV budget has considerable margin
  - *Each RPO cycle costs ~30 mm/s*
  - *Can perform dozens of RPO cycles*