

Guidance, Navigation, and Control Algorithms for CubeSat Formation Flying



Jason J. Westphal, Christopher W. T. Roscoe, Stephen Lutz, and Trevor Bennett
Applied Defense Solutions, Columbia, Maryland



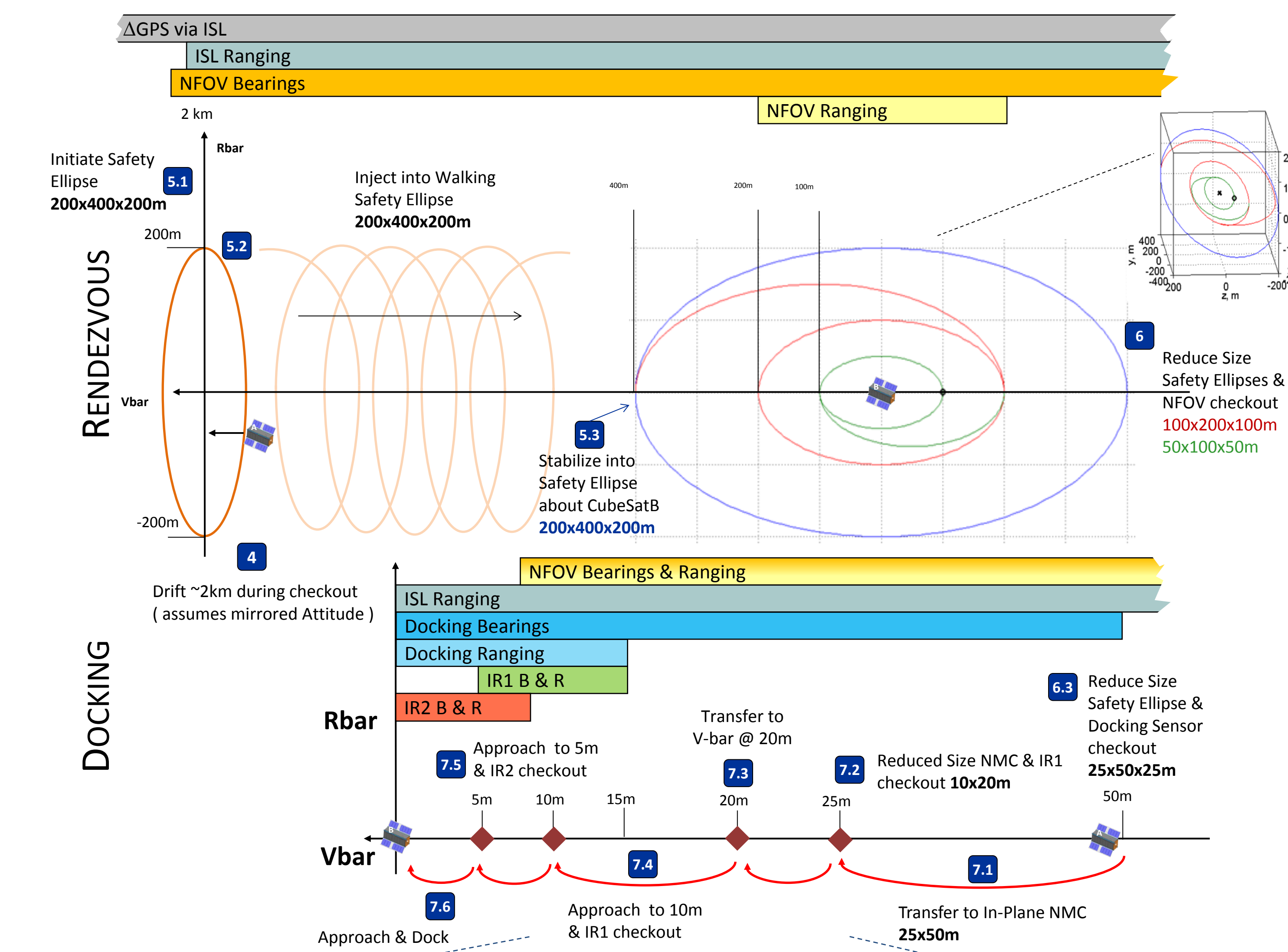
CPOD The CubeSat Proximity Operations Demonstration (CPOD) mission is designed to demonstrate rendezvous, proximity operations, (RPO) and docking with a pair of 3U CubeSats using miniaturized components and sensors.

Large Mass – Mission Application		Rendezvous Demonstrator	
Cygnus COTS	Dragon COTS	DARTS	Orbital Express
Mass >2000 kg Power 3.5 kW Fuel Hydrazine	Mass >4200 kg Power 5 kW Fuel NTO/MMH	Mass 360 kg Power Batteries Fuel Hydrazine	Mass 952 kg Power 1.2 kW Fuel Hydrazine

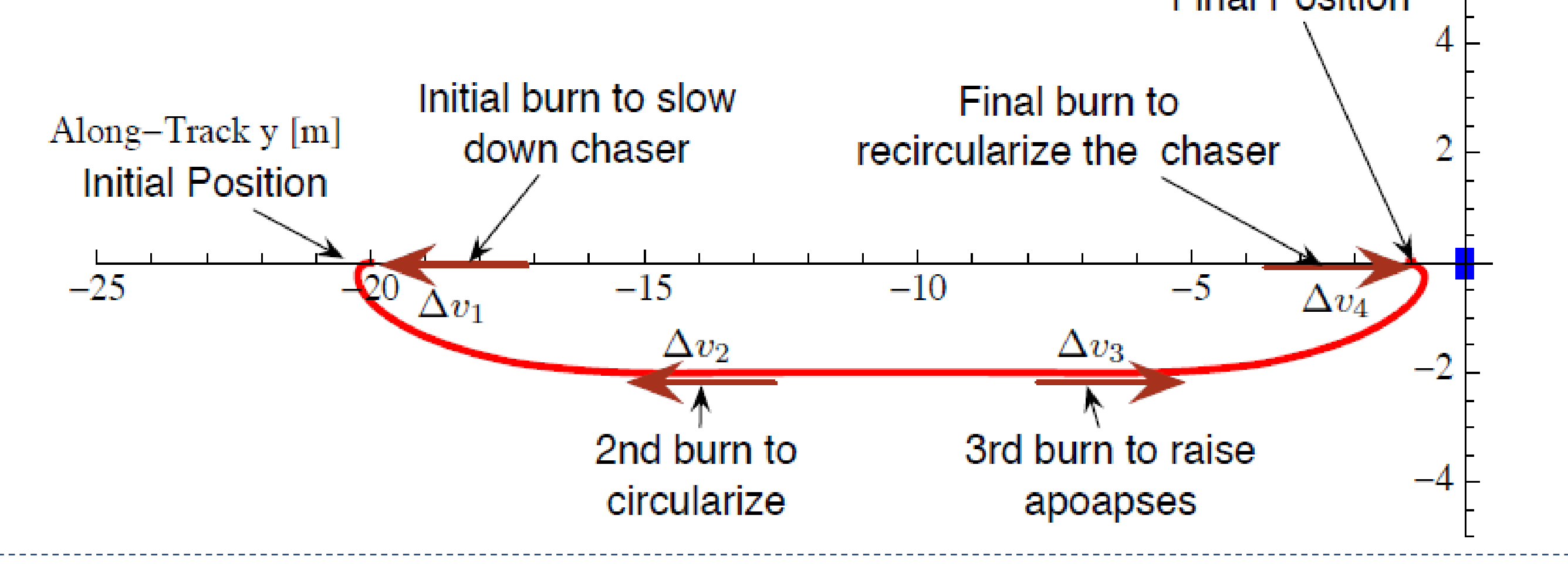
CPOD is Evolving Proximity Operations and Docking to a **Low Mass/Low Power** CubeSat Platform

Mass 5-6 kg Power <50 W Fuel R134a	Navigation Sensors NFOV Camera Docking Camera IR Cameras ISL Ranging GPS	Challenges Processor Limitations Distributed Architecture Sensor and Range Agnostic
--	--	---

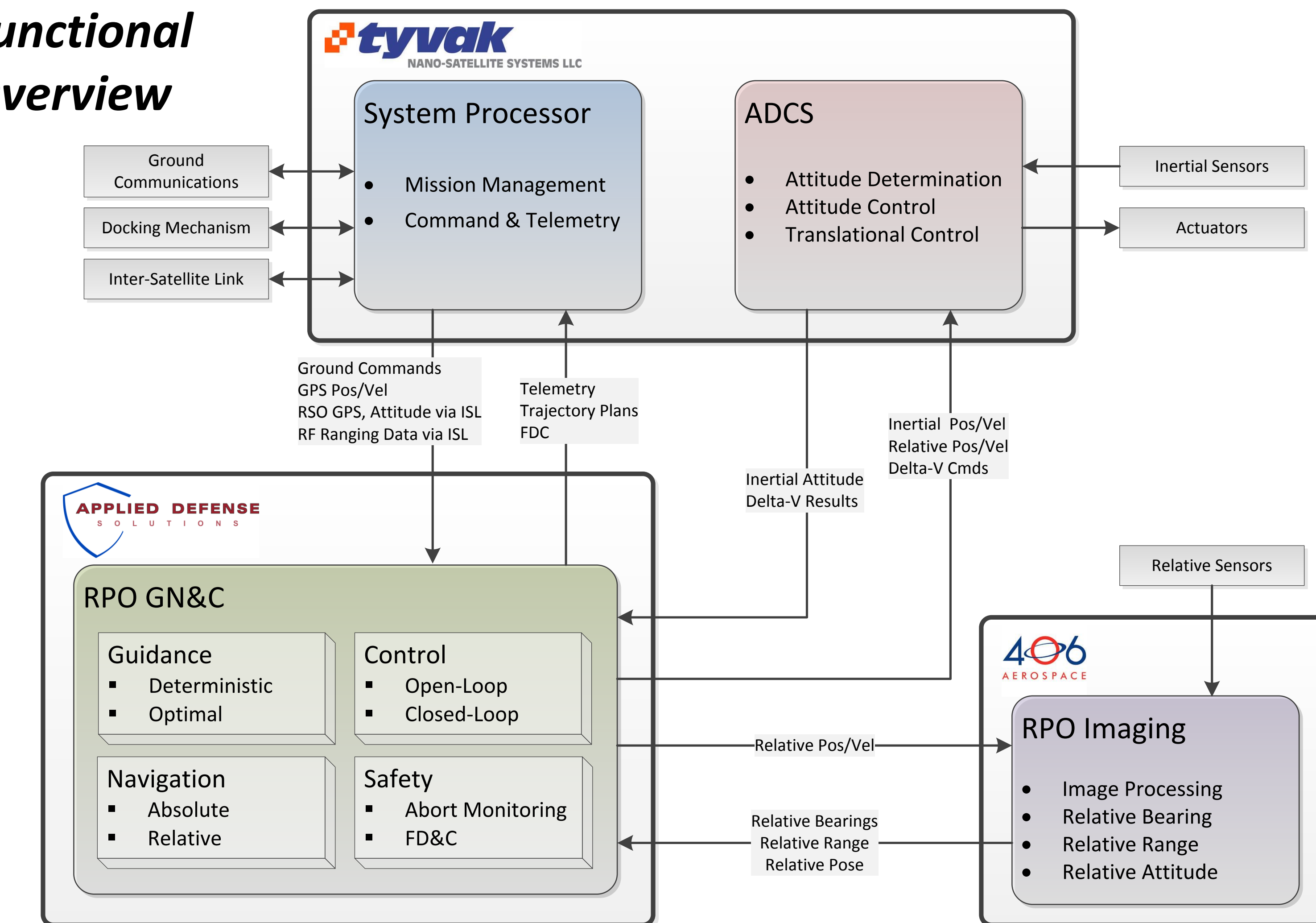
Concept of Operations



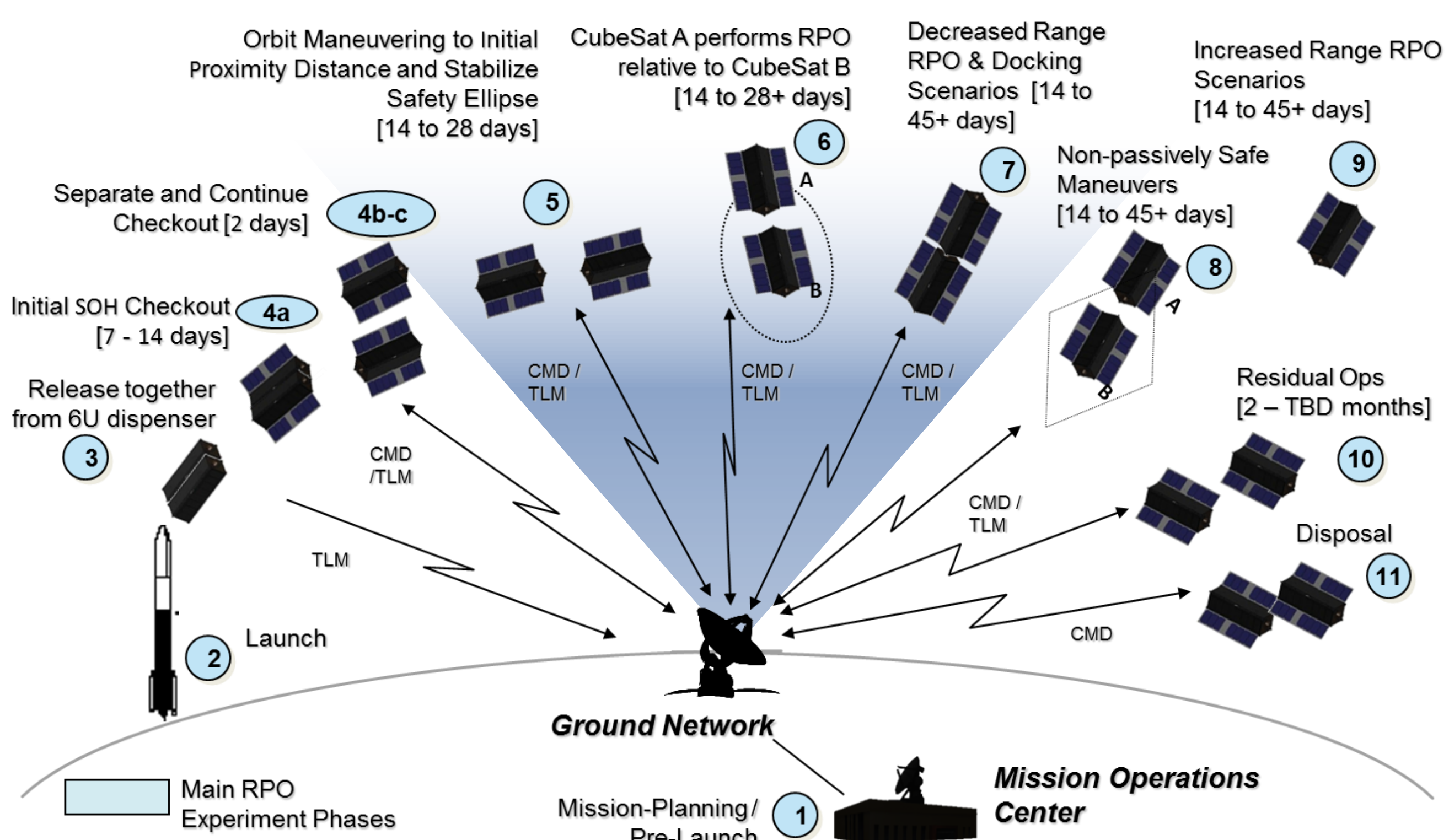
Nominal trajectory – 4-burn sequence
Radial offset provides safety in case of abort



Functional Overview

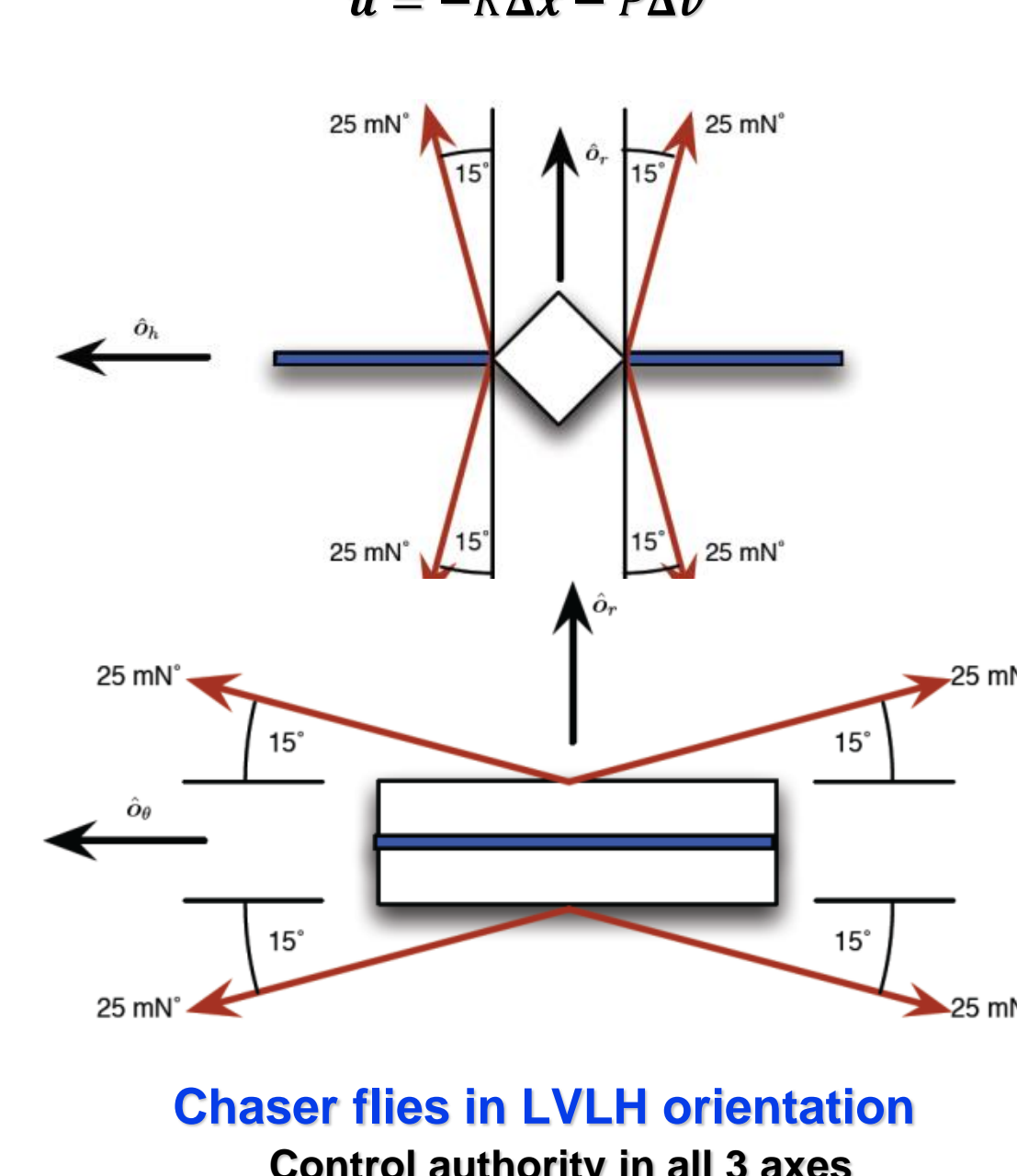


Mission Overview



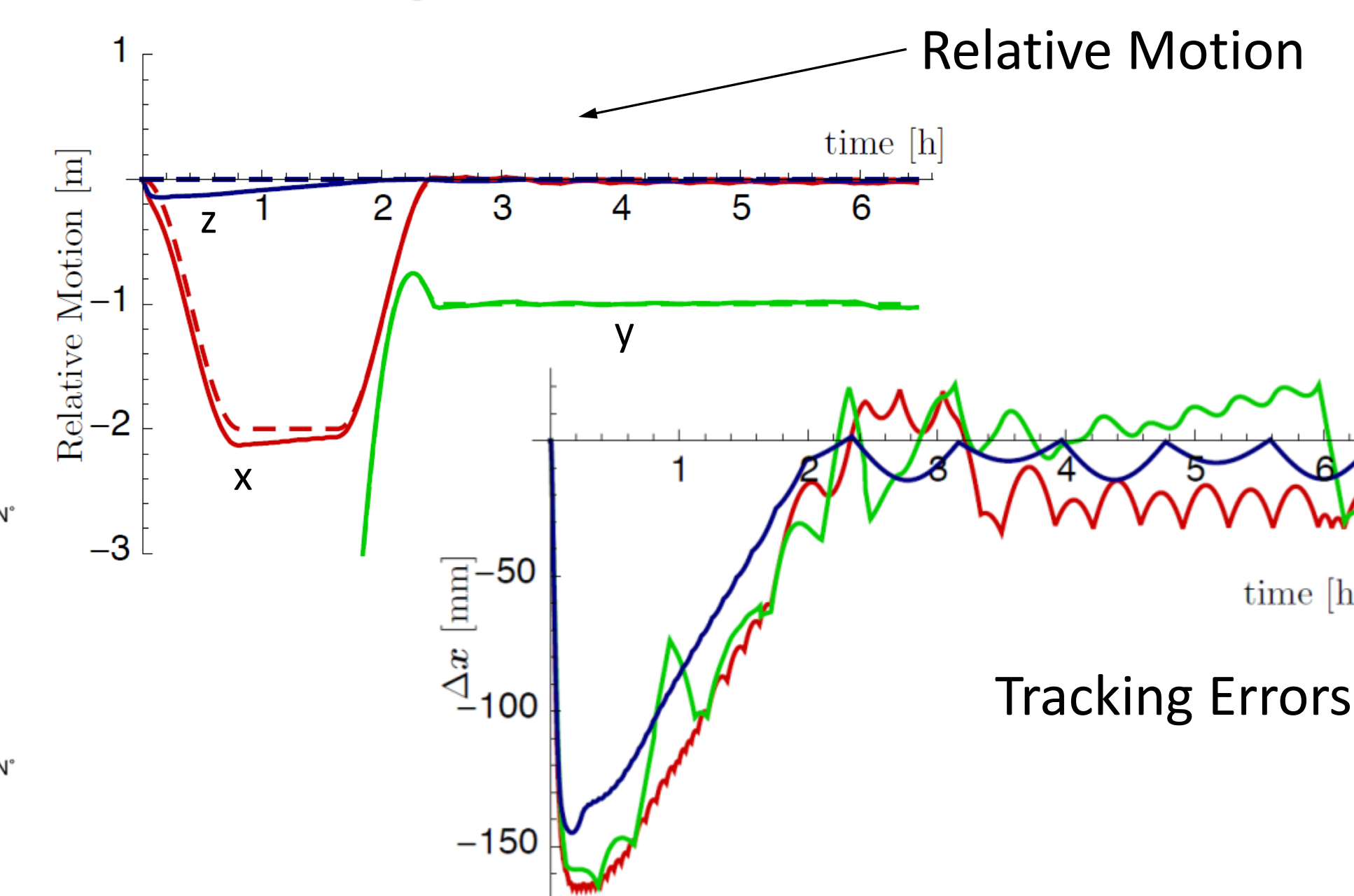
Closed-Loop Control

Closed-loop control feeds back position and velocity tracking errors
 $u = -K\Delta x - P\Delta v$



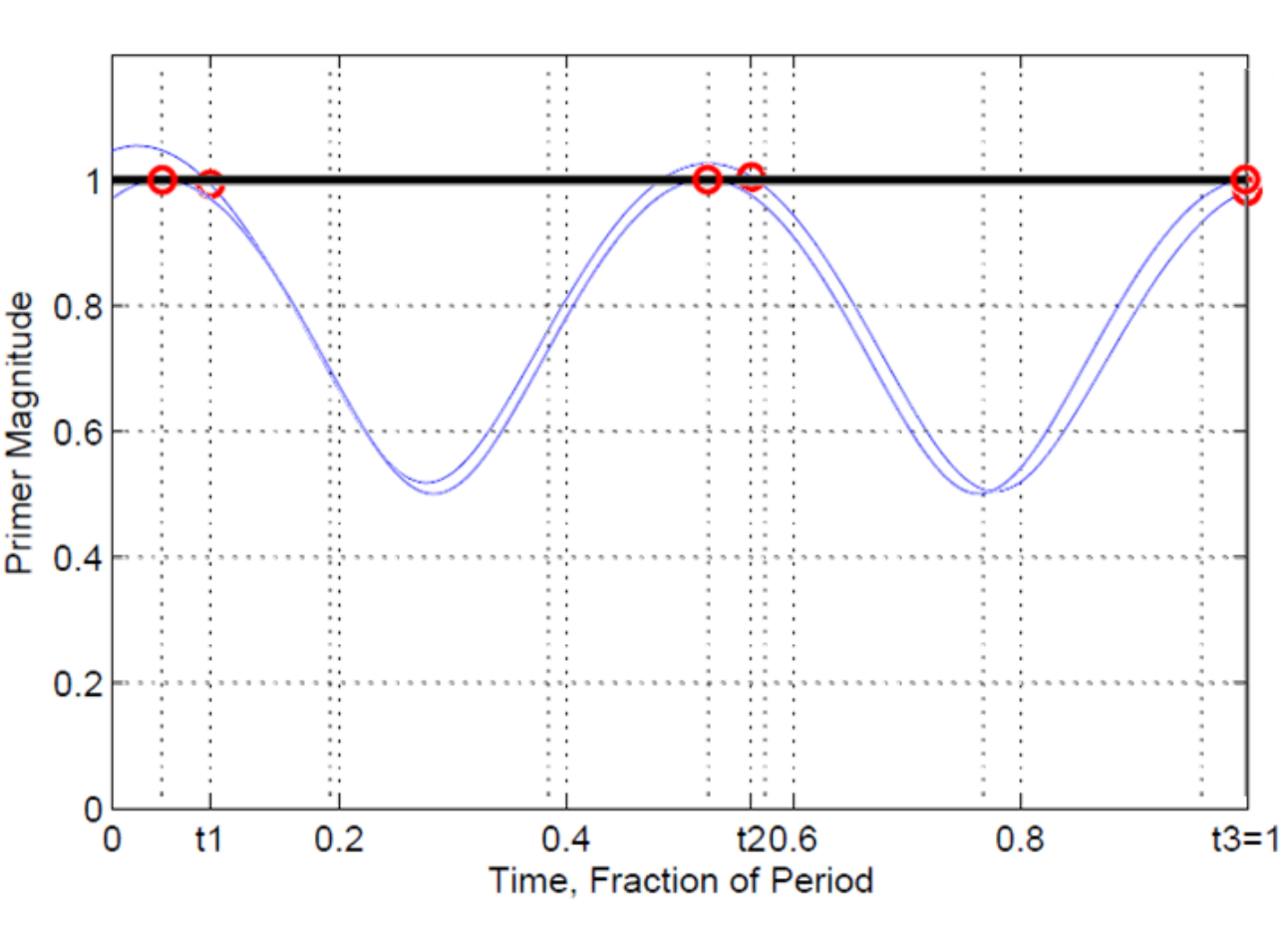
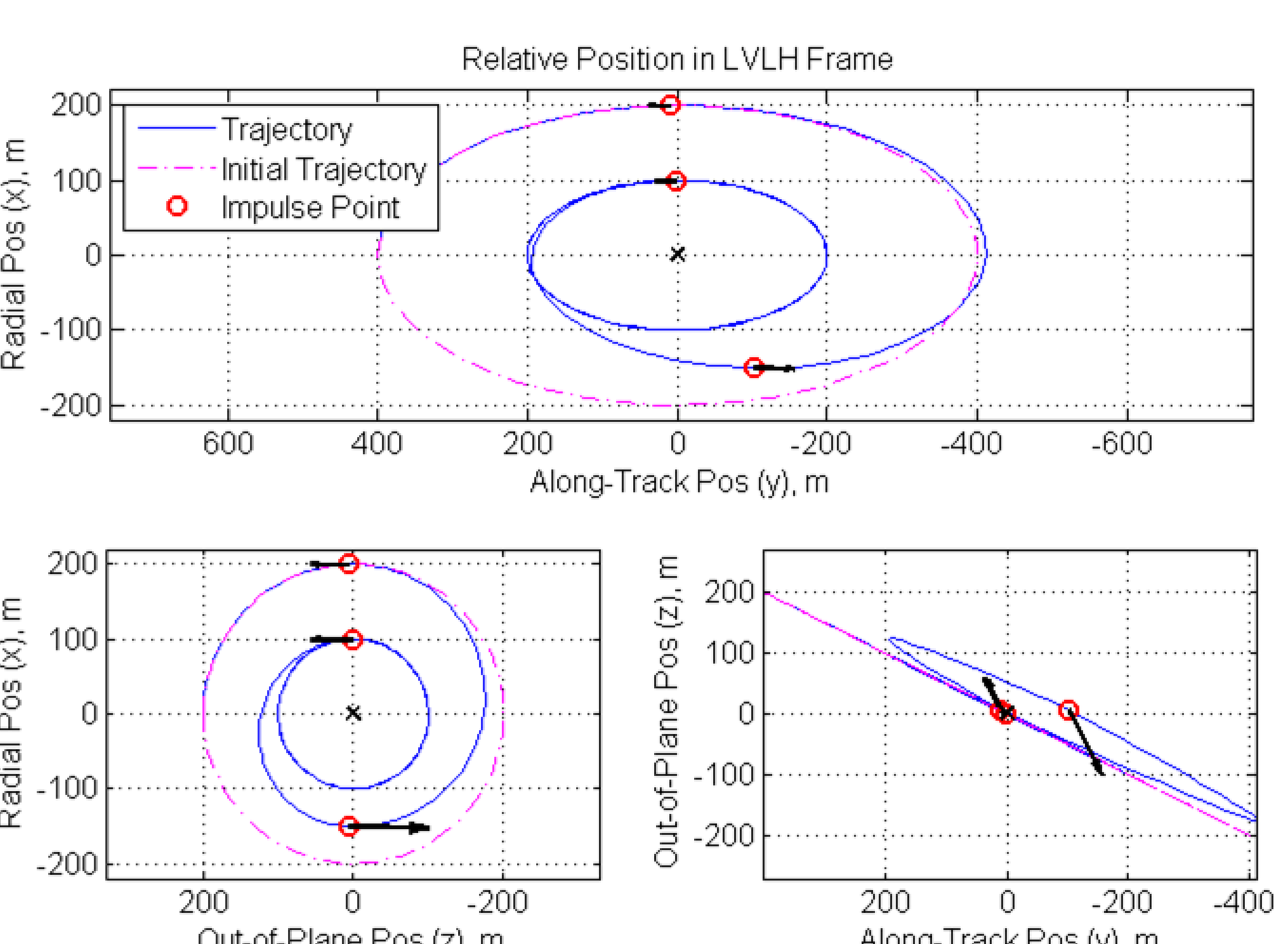
No feedback during open-loop impulse
Controller is robust to expected:

- Control update period
- Thruster magnitude & attitude errors
- Navigation errors



Guidance Solution

Example Maneuver - Sequence 6.1
Reduce size of safety ellipse to: 100 m (x) x 200 m (y) x 100 m (z)

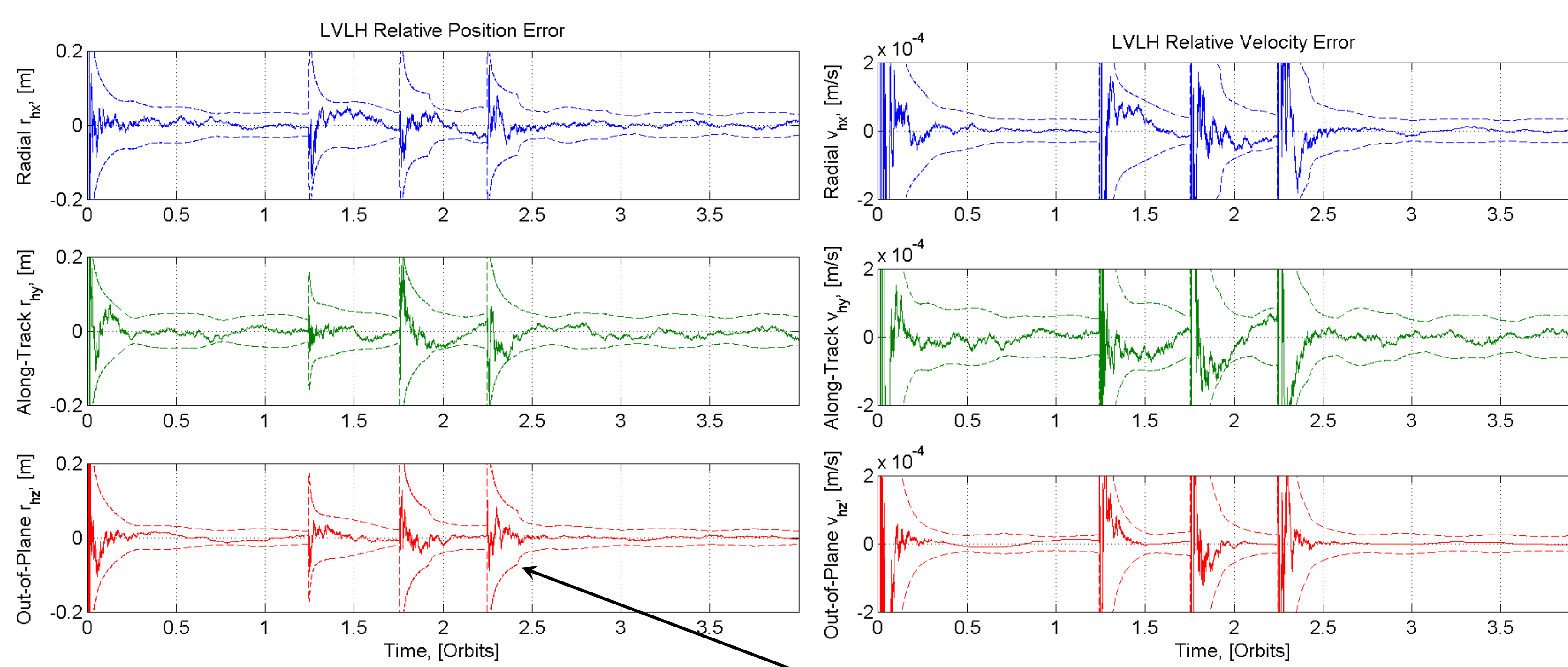
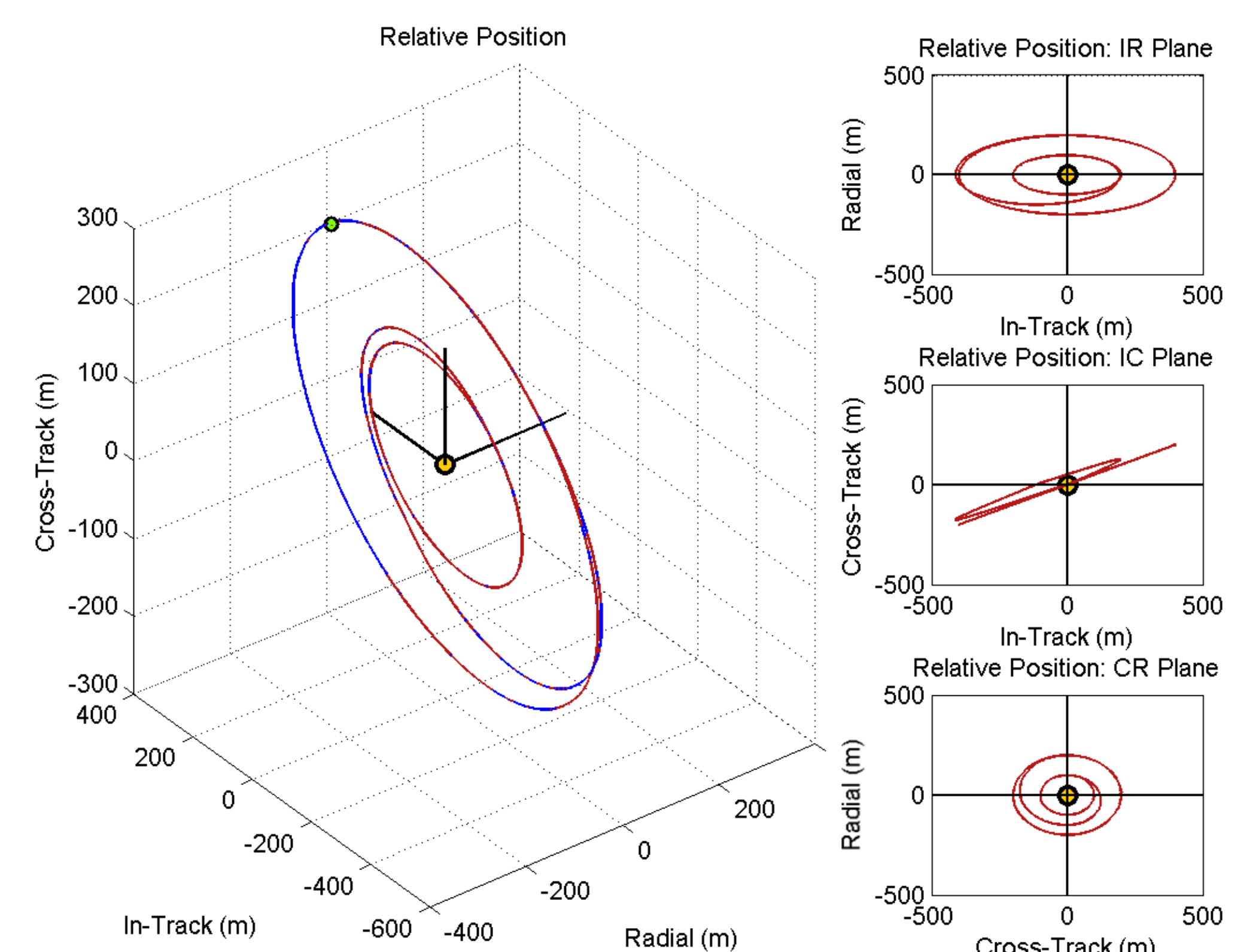


Fuel-Optimal n-Impulse Maneuver Targeting

- Valid for circular, eccentric orbits, including J2
- Impulse times determined by primer vector history
- Optimization uses iterative solution, low computational burden
- Solves n-impulse optimization but avoids implementing nonlinear numerical solver
- Fuel cost is much lower than traditional 2- or 3-impulse analytical methods

Navigation Solution

Extended Kalman Filter (EKF)
Dual Inertial State Vector:
Chaser and RSO spacecraft Position and Velocity



Maneuver Feed-Forward: Robust to time/magnitude uncertainty and biases.

