A Systems Approach to Select a Deployment Scheme to Minimize Re-contact When Deploying Many Satellites During One Launch Mission

Steven J. Buckley, Volunteer Emeritus, Air Force Research Laboratory
Bucklesjs@aol.com, (505) 975-5846

Heather A. Buckley, Student, University of New Mexico, buckley@unm.edu, (505) 264-4485

Dr. Peter W. Wegner, Director Advanced Concepts, Space Dynamics Laboratory,
Peter.wegner@sdl.usu.edu, (435) 713-3130

Agenda

- A Case for Small Satellites
- The Problem
- A Systems Approach To Solving The Problem: Orbital Maneuvers
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  - Adapters
  - Orbital Mechanics
- Radial Tertiary Satellite Deployment Scheme:
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  - Disadvantages
- Radial Tertiary Satellite Deployment Scheme: Things to Consider

A Case for Small Satellites

- Proliferation of small, canisterized satellites has created options to accomplish a variety of space missions
  - Satellite capability is no longer a function of the size and mass of the satellite
- Development of new components for tiny satellites has exploded during the last decade
  - Star Trackers
  - Encryption Systems
  - Momentum Wheels
  - Etc.

Tiny Satellites Can Accomplish Full-capability Missions While Massing 10 Kilograms Or Less: Tiny Satellites Deserve A Priority Based On Mission Not On Size

The Problem

- Multi-payload launch missions present serious architectural problems
    - Protection of primary satellite
        - Must avoid re-contact between primary and all other objects
    - Re-contact between all satellites
        - Small deployment velocity results in essentially common orbits
    - Management of all satellites as they decay
        - All deployed objects are managed as a hazard to navigation after insertion

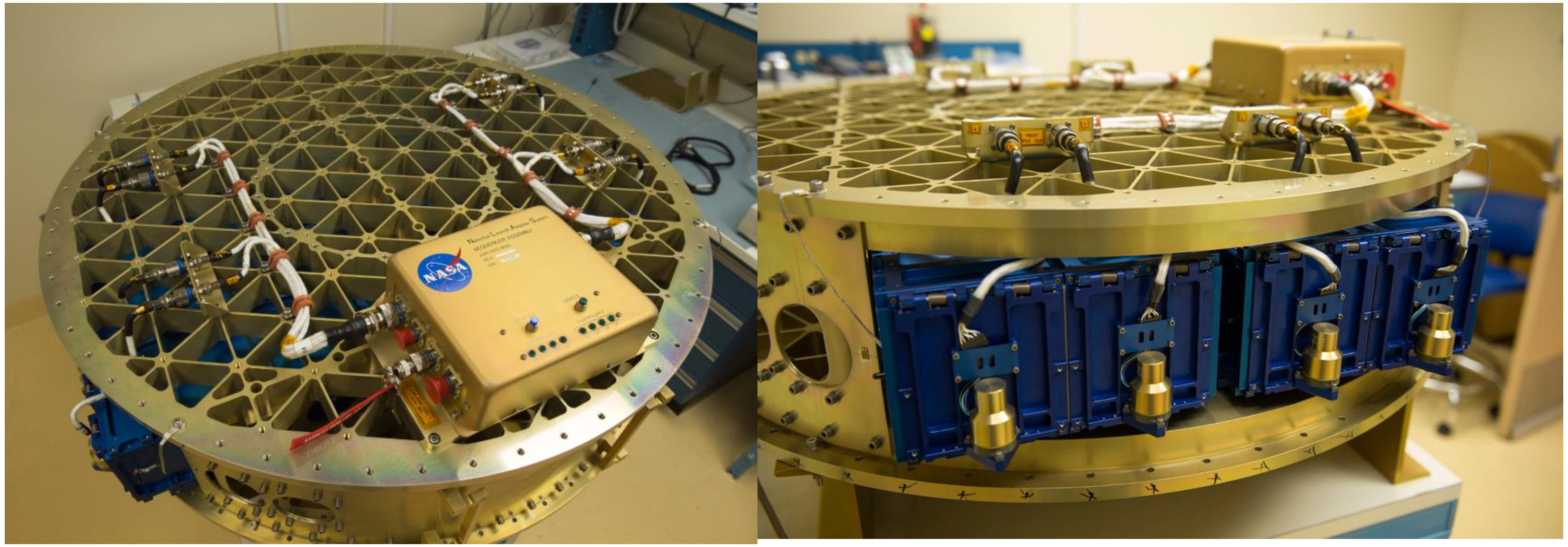
Deployment Scheme Required Capabilities: Launch Vehicle

- Launch vehicles must be able to carry the adapters
  - 38-inch interface is common to several small launch vehicles
- Launch vehicle must be able to orient the adapters during deployment operations
  - Required accuracy is approximately 5-10 degrees
- Launch vehicle must be able to hold orientation of the adapters during the deployment operations
  - Each deployment of a small satellite is an impulsive event and must be countered
- Launch vehicle must be capable of conducting two collision avoidance maneuvers
  - One to deploy primary satellite
  - One to move rocket body from tertiary satellites orbit

Deployment Scheme Required Capabilities: Adapters

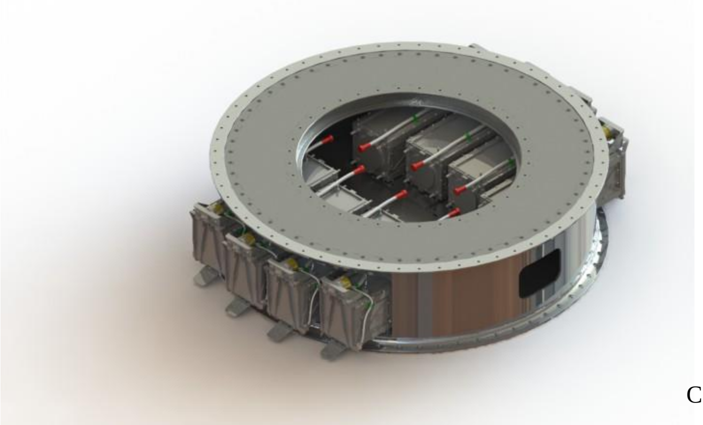
- Multi-payload adapters allow carriage of many small satellites while preserving most of the launch vehicle capability
  - NASA Ames Research Center developed the NASA Ames NanoSat Launch Adapter (NLAS)
    - Can carry eight 3 U equivalent cubesats
  - LoadPath’s CubeStack a development by the Air Force Research Lab
    - Can carry eight 3 U equivalent cubesats
  - These multi-payloads adapters provide small separation velocities to the tertiary payloads (~1.5 m/s)

Multi-Payload Adapters (Wafers)



Courtesy Ames Research Center

NLAS Adapter



Courtesy LoadPath

CubeStack Adapter

Deployment Scheme Required Capabilities: Orbital Mechanics

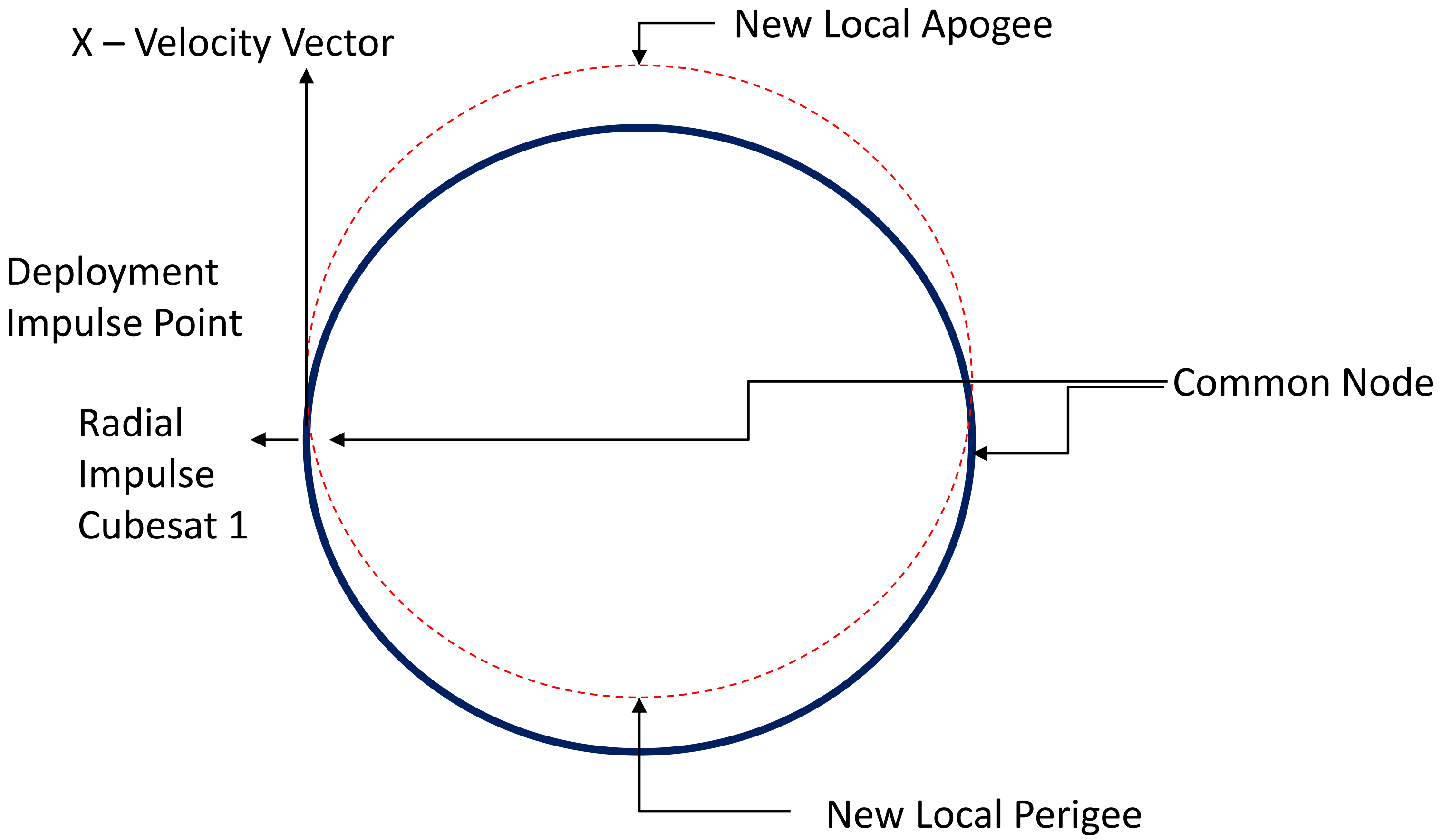
- Small deployment velocity results in near-coincident orbits
  - Satellite pathways are within single-digit meters separation of each other
- Hohlmann Transfer Orbit with small deployment velocities results in very close orbits
- Radial and anti-radial maneuvers allow satellites to be clustered based on deployment attitude of the rocket body
  - All deployments must include an out-of-plane maneuver
- Adequate separation from large targets such as a primary satellite and the rocket body must be accomplished by a clearance maneuver

Radial/Anti-Radial Maneuvers, Coupled With an Out-of-Plane Maneuver and the Adapter Architectures Allow Minimal Maneuvering of the Rocket Body While Still Achieving a System of Clustered Satellites With a Lower Probability of Re-Contact

Sequence of Deployment Maneuvers for All Orbital Bodies

1. Separate primary satellite
    - Establishes final primary satellite orbit
2. Accomplish clearance avoidance maneuver on rocket body
    - Establishes deployment orbit for tertiary satellites
    - Minimizes re-contact with primary satellite
3. Accomplish series of paired deployments of tertiary satellites
    - Deploy on short (30-120 second) intervals
    - Establishes system of tertiary satellite orbits
    - Minimizes re-contact possibility between all tertiary satellites
4. Accomplish clearance avoidance maneuver on rocket body
    - Minimizes re-contact possibility between rocket body and tertiary satellites
    - Provides further separation between rocket body and primary satellite

Effect of Radial Impulse on Circular Deployment Orbit



X – Velocity Vector

New Local Apogee

Deployment
Impulse Point

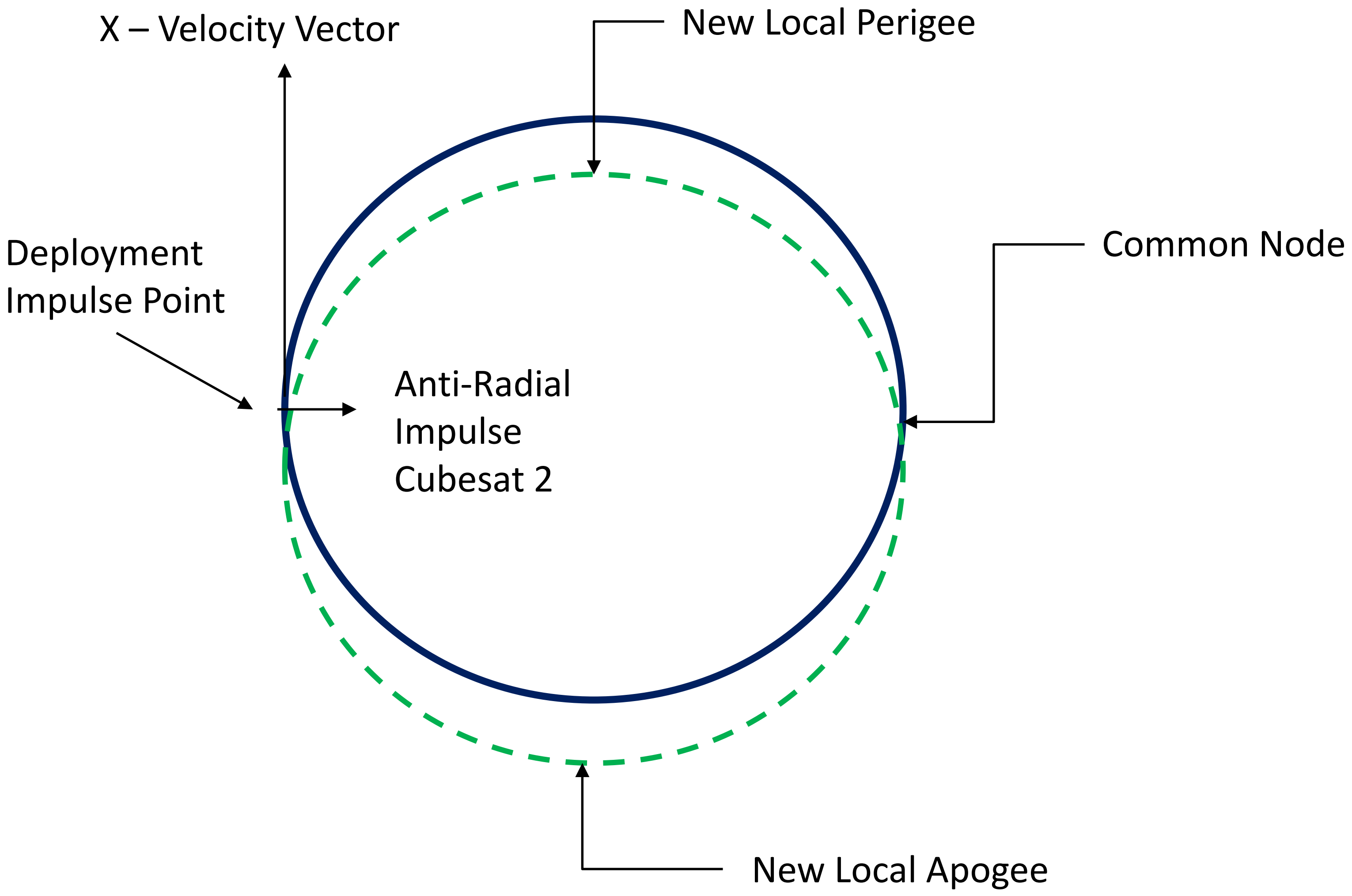
Radial
Impulse
Cubesat 1

Common Node

New Local Perigee

Not To Scale

Effect of Anti-Radial Impulse on Circular Deployment Orbit



X – Velocity Vector

New Local Perigee

Deployment
Impulse Point

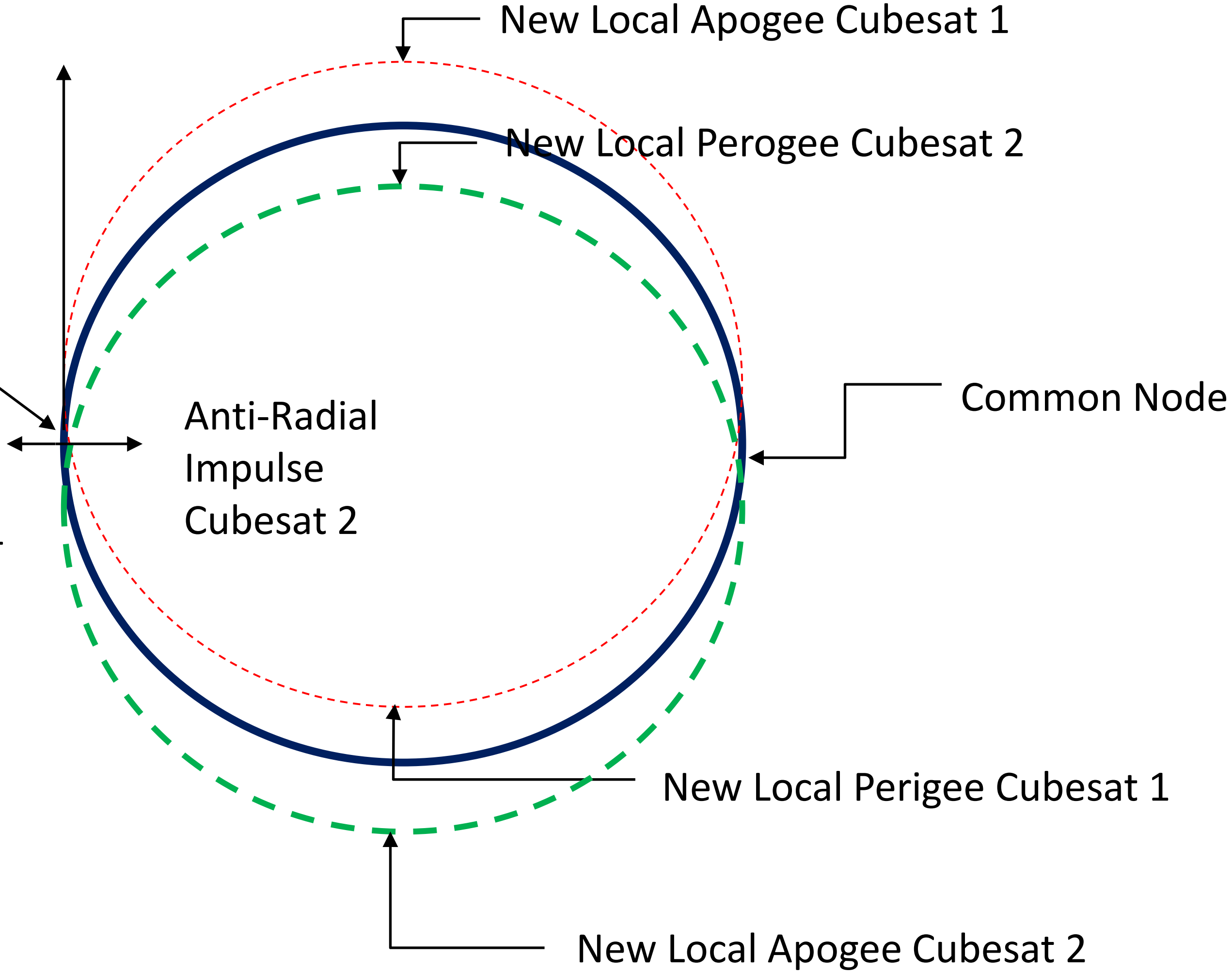
Common Node

Anti-Radial
Impulse
Cubesat 2

New Local Apogee

Not To Scale

Effect of Combined Radial and Anti-Radial Maneuvers on Cubesat 1 and 2



New Local Apogee Cubesat 1

New Local Perogee Cubesat 2

Deployment
Impulse Point

Radial
Impulse
Cubesat 1

Anti-Radial
Impulse
Cubesat 2

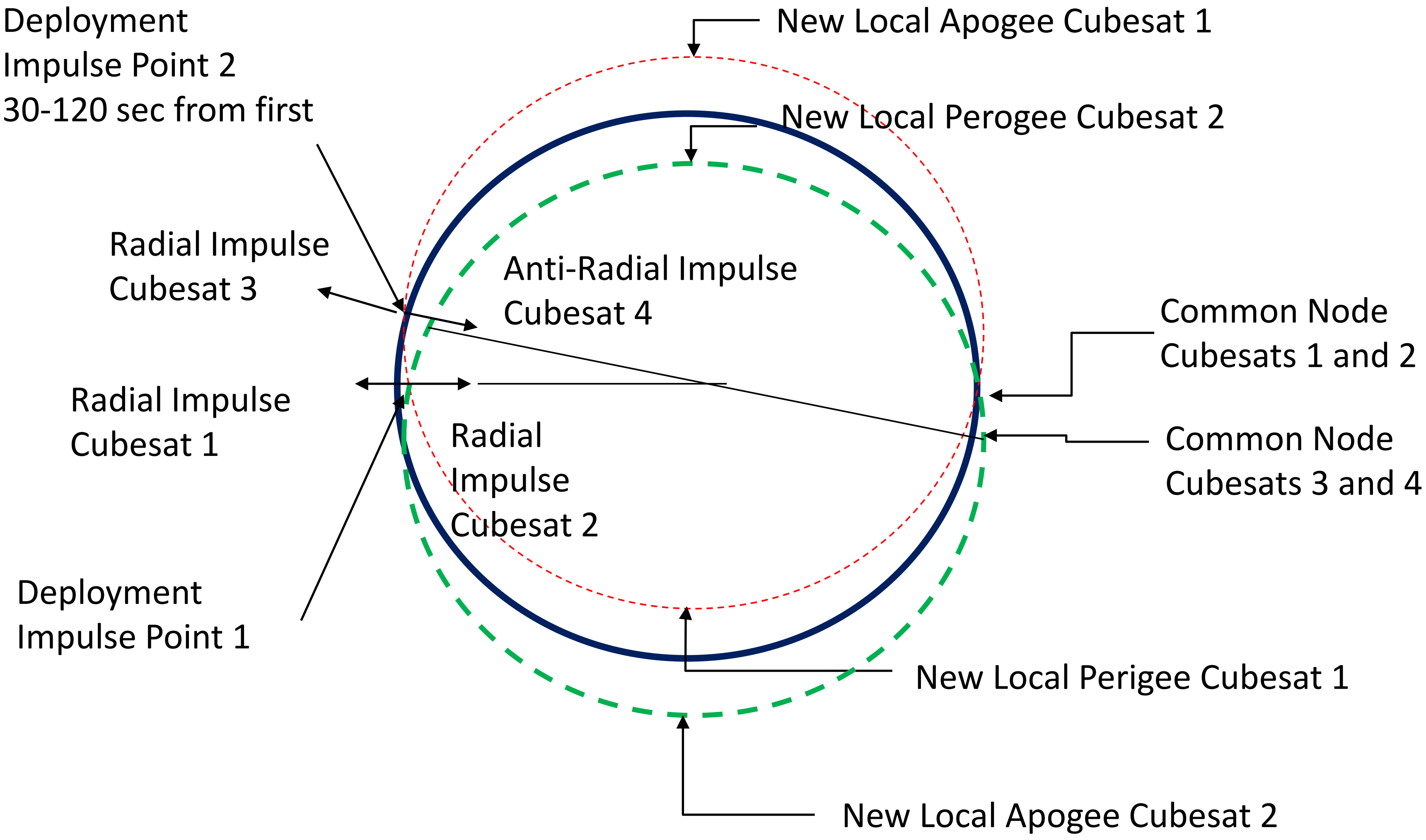
Common Node

New Local Perigee Cubesat 1

New Local Apogee Cubesat 2

Not To Scale

Effect of Combined Radial and Anti-Radial Maneuvers on Cubesat 1 and 2



Deployment
Impulse Point 2
30-120 sec from first

New Local Apogee Cubesat 1

New Local Perogee Cubesat 2

Radial Impulse
Cubesat 3

Anti-Radial Impulse
Cubesat 4

Common Node
Cubesats 1 and 2

Radial Impulse
Cubesat 1

Radial
Impulse
Cubesat 2

Common Node
Cubesats 3 and 4

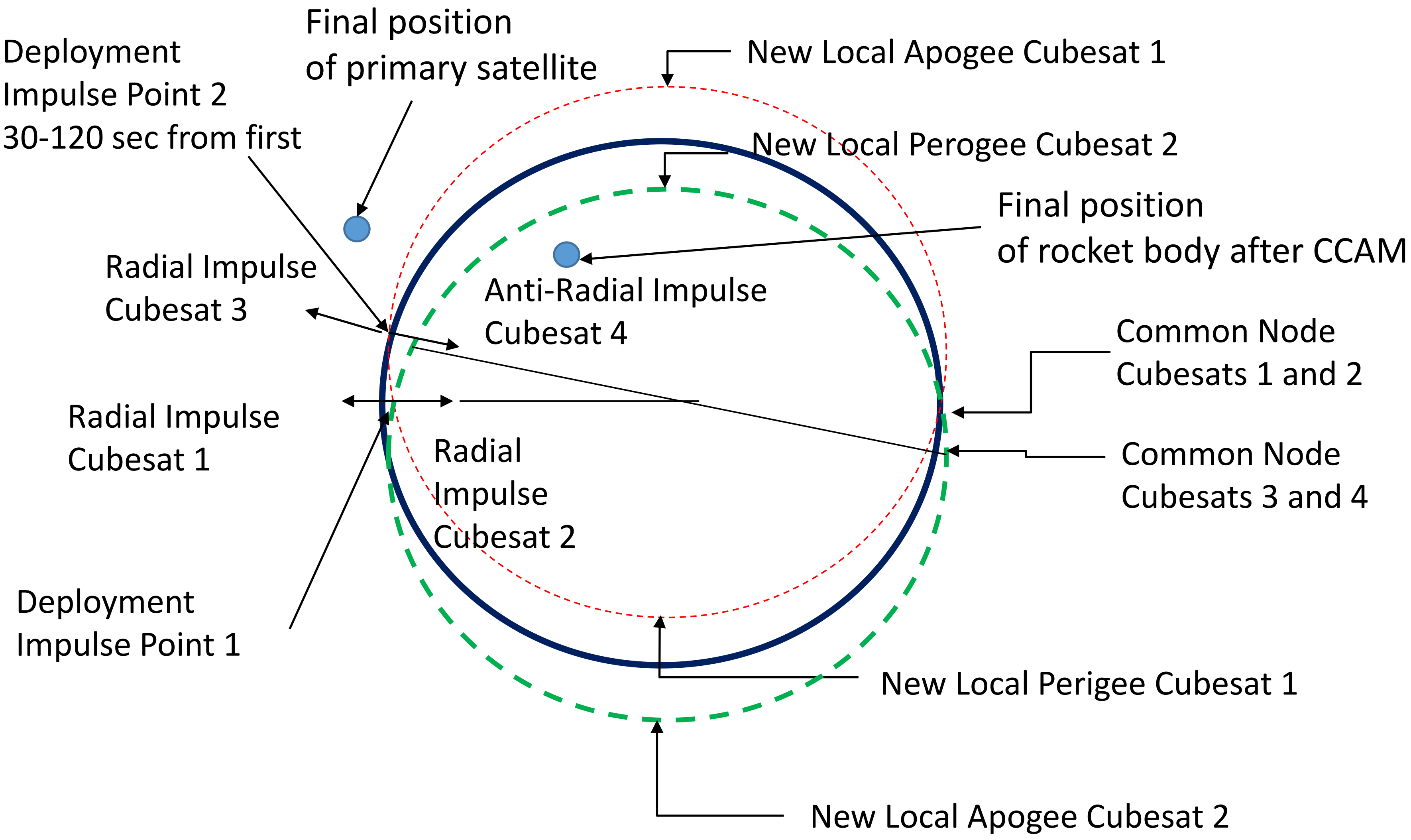
Deployment
Impulse Point 1

New Local Perigee Cubesat 1

New Local Apogee Cubesat 2

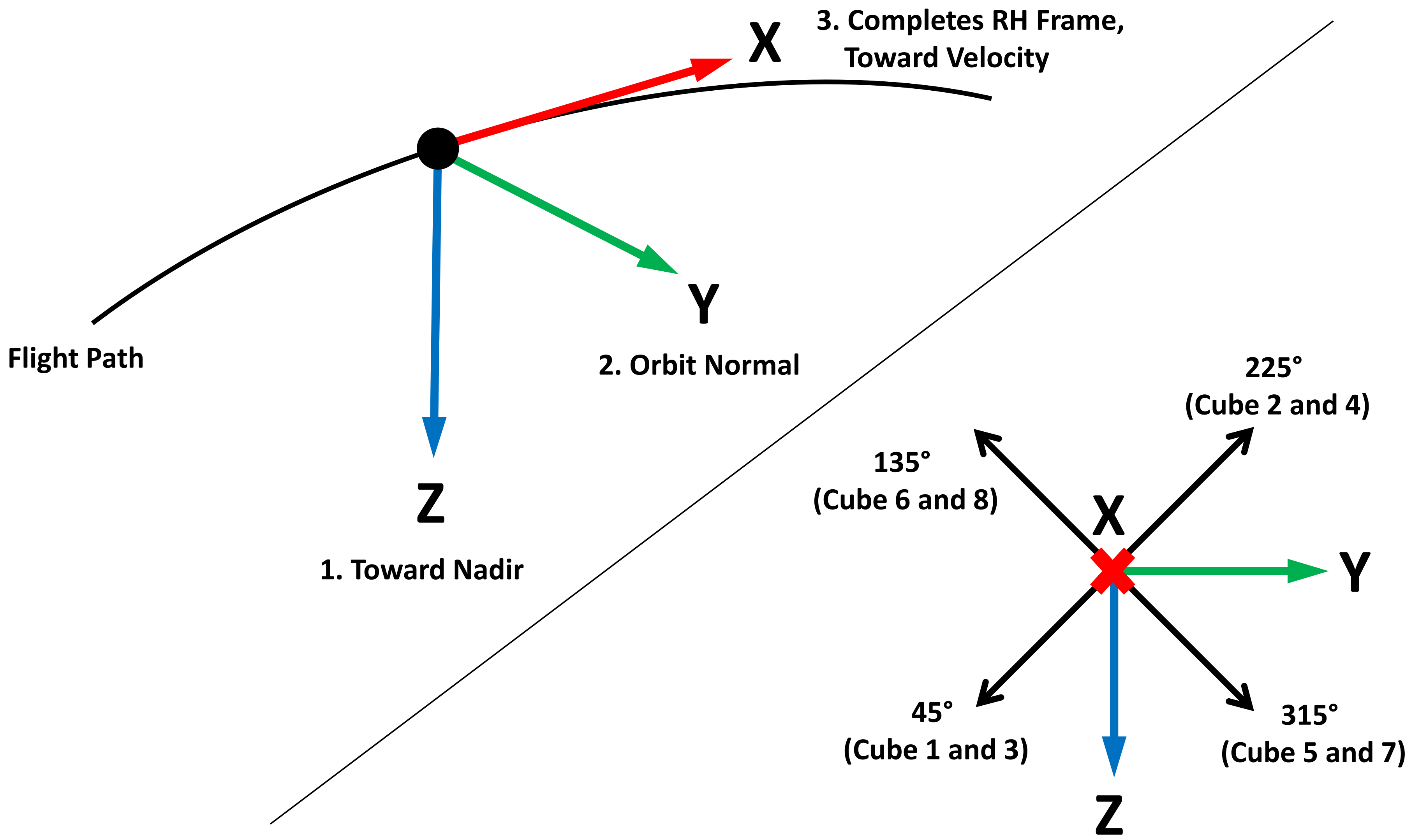
Not To Scale

Effect of Combined Radial and Anti-Radial Maneuvers on Cubesat 1 and 2



Not To Scale

A Systems Approach To Solving The Problem: Orbital Maneuvers



X

3. Completes RH Frame, Toward Velocity

Y

2. Orbit Normal

Flight Path

Z

1. Toward Nadir

225°
(Cube 2 and 4)

135°
(Cube 6 and 8)

X

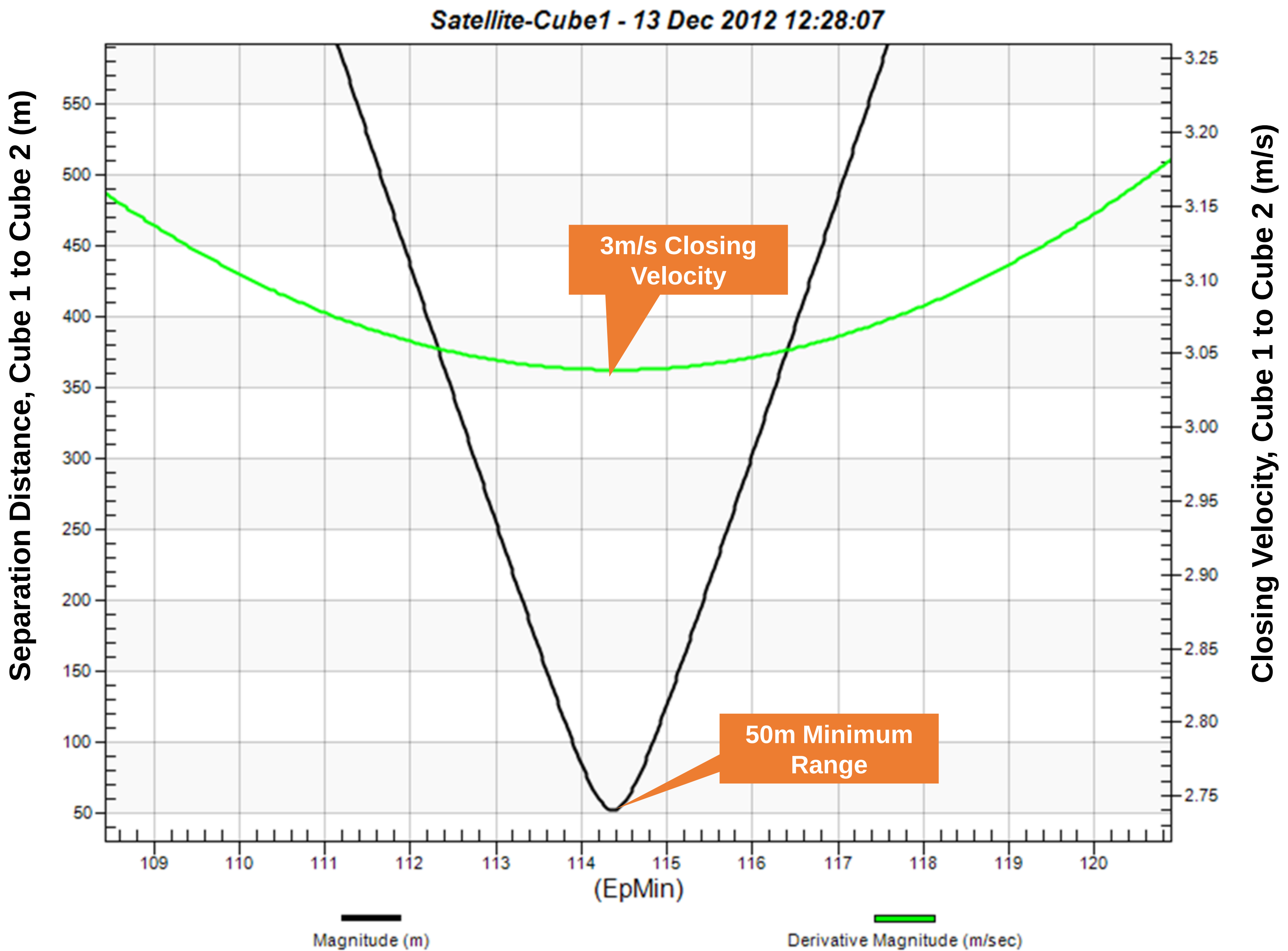
Y

45°
(Cube 1 and 3)

315°
(Cube 5 and 7)

Z

Cube 1 to Cube 2 Separation



3m/s Closing Velocity

50m Minimum Range

Radial Tertiary Satellite Deployment Scheme: Advantages

- Relatively stable orbits achieved at deployment
  - Satellites deployed in common direction maintain relative positions
  - Stable until perturbations take effect
- Satellites deployed in opposite directions maintain adequate separation
  - Miss distances cycle between tens of meters and kilometers
  - Stable until perturbations take effect
- Maximum closing velocities of satellites are single digit m/s (similar to 18” drop to ground)
  - These impacts would not create orbital debris!
- Care must be taken to completely eliminate the rocket body and primary satellite orbits from the common tertiary satellite orbits

Radial Tertiary Satellite Deployment Scheme: Disadvantages

- Not suitable for spacing satellites in a beads-on-a-string constellation
  - Rocket body does not have attitude control system life-time or accuracy to position large number of tertiary satellites on custom vectors
  - Satellites deployed in the same direction are stable with relatively close separation distances (tens of meters)
  - Satellites deployed in opposite directions come relatively close to each other at the original deployment point in the orbit
- All bets are off several months into the mission when perturbations take effect
  - Satellite perturbations of the constellation are indeterminate

Radial Tertiary Satellite Deployment Scheme: Things to Consider

- No deployment scheme is fool-proof
  - This scheme only minimizes the probability of re-contact
  - Does allow tertiary satellites to orbit as a disciplined system
  - Perturbations are impossible to predict exactly
- Relative stability of this deployment scheme offers an opportunity to treat the tertiary satellites as a single orbital system
  - Facilitates hazards-to-navigation management of the swarm
- All large targets must be deconflicted from the tertiary satellite orbital swarm

This Paper is Intended to Define a Deployment Scheme Methodology. The orbital designer must consider all hardware/software/orbital factors when designing a custom deployment scheme for a particular mission. You must do the analysis yourself!

Acronyms And Definitions

1. CubeStack: Multi-payload adapter used to support up to eight 3U cubesats as tertiary payloads.
2. Hohmann Transfer Orbit (HTO): Method to transfer from one orbit to another using velocity vector and anti-velocity vector maneuvers.
3. NASA Ames NanoSat Launch Adapter (NLAS): Multi-payload adapter used to support up to eight 3U cubesats as tertiary payloads.
4. Out-of-Plane Maneuver: Using impulses normal to the plane of the orbit to change the inclination of the satellite.
5. Primary Satellite: Large satellite constituting the primary payload on a given launch. This satellite pays most of the cost of the launch, as well as defining most mission requirements.
6. Radial/Anti-Radial Maneuver: Using impulses in the radial and anti-radial directions (straight up and straight down) to change the satellites orbit.
7. Resident Space Objects (RSOs): Satellites and other objects in permanent Earth orbit.
8. Rocket Body: The last stage of a launch vehicle that deploys all primary, secondary, and tertiary satellites and remains on orbit after the deployment event.
9. Secondary Satellite: Large satellite flying as an auxiliary payload on a given launch. This satellite pays a significant part of the cost of the launch, as well as defining some mission requirements.
10. Tertiary Satellite: Small satellites flying as launch vehicle mass on a given launch. This satellite pays almost none of the cost of the launch, as well as defining no mission requirements.
11. Velocity Vector/Anti-Velocity vector maneuver: One-half of a Hohmann Transfer Orbit.