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

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Agenda

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• The Problem
• A Systems Approach To Solving The Problem: Orbital Maneuvers
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  • Adapters
  • Orbital Mechanics
• Radial Tertiary Satellite Deployment Scheme:
  • Advantages
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• 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)

NLAS Adapter

CubeStack Adapter

Courtesy LoadPath

Courtesy Ames Research Center
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

Deployment Impulse Point

Radial Impulse Cubesat 1

New Local Apogee

Common Node

New Local Perigee

Not To Scale
Effect of Anti-Radial Impulse on Circular Deployment Orbit

X – Velocity Vector

Deployment Impulse Point

Anti-Radial Impulse Cubesat 2

New Local Apogee

Common Node

New Local Perigee

Not To Scale
Effect of Combined Radial and Anti-Radial Maneuvers on Cubesat 1 and 2

Not To Scale
Effect of Combined Radial and Anti-Radial Maneuvers on Cubesat 1 and 2

- Deployment Impulse Point 1
  - 30-120 sec from first

- Radial Impulse Cubesat 1
- Radial Impulse Cubesat 3
- Anti-Radial Impulse Cubesat 4

- New Local Apogee Cubesat 1
- New Local Perigee Cubesat 2

- New Local Apogee Cubesat 2
- New Local Perigee Cubesat 1

- Common Node Cubesats 1 and 2
- Common Node Cubesats 3 and 4

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

Radial Impulse Cubesat 1

Radial Impulse Cubesat 3

Deployment Impulse Point 1

Final position of primary satellite

New Local Apogee Cubesat 1

New Local Perigee Cubesat 2

Final position of rocket body after CCAM

Common Node Cubesats 1 and 2

Common Node Cubesats 3 and 4

New Local Perigee Cubesat 1

New Local Apogee Cubesat 2

Anti-Radial Impulse Cubesat 4

Radial Impulse Cubesat 2

Not To Scale
A Systems Approach To Solving The Problem: Orbital Maneuvers

1. Toward Nadir
2. Orbit Normal
3. Completes RH Frame, Toward Velocity

- 45° (Cube 1 and 3)
- 135° (Cube 6 and 8)
- 225° (Cube 2 and 4)
- 315° (Cube 5 and 7)
Cube 1 to Cube 2 Separation

Separation Distance, Cube 1 to Cube 2 (m)

Closing Velocity, Cube 1 to Cube 2 (m/s)

3 m/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 satellite's 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.