Spacecraft Formation Flying

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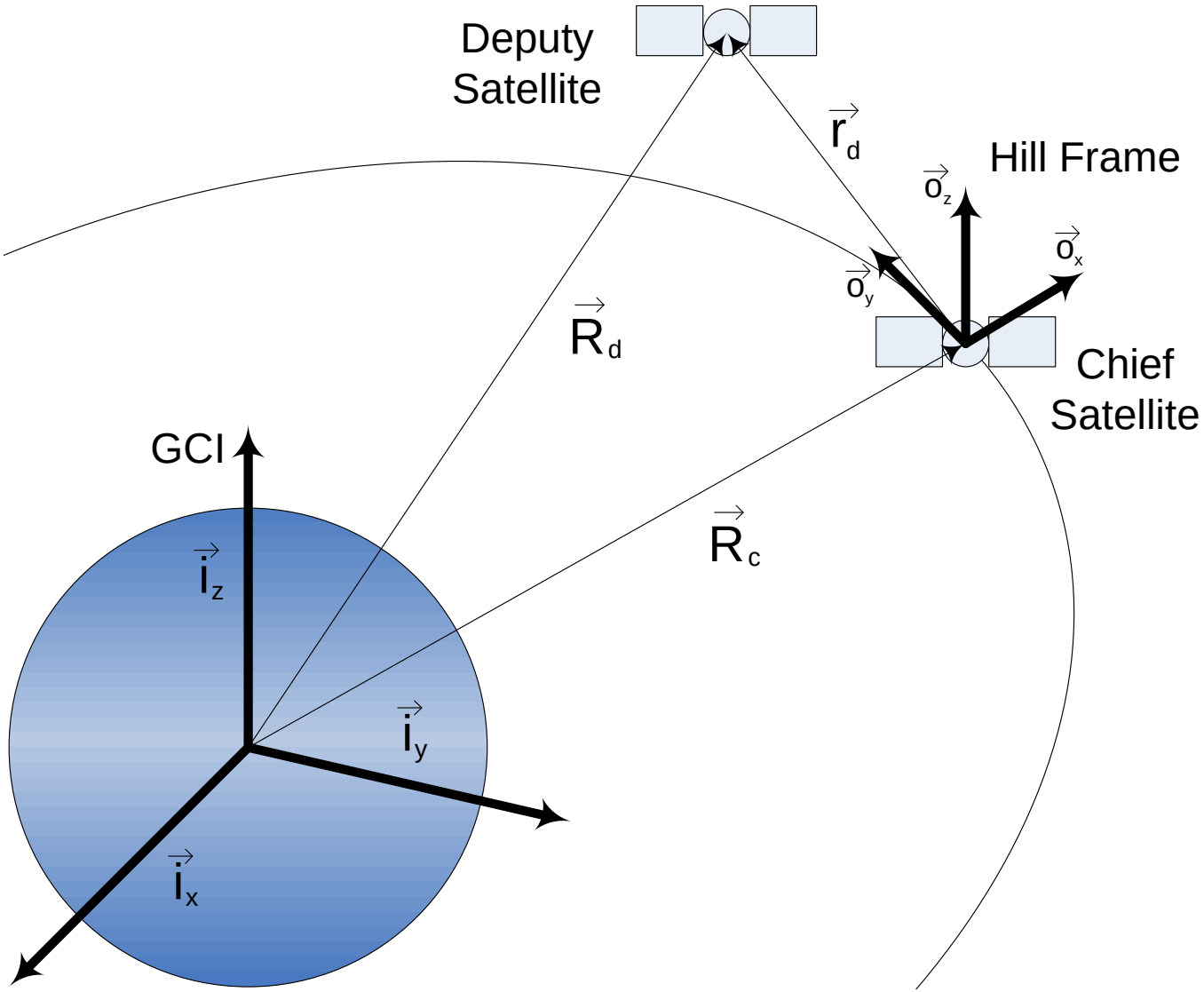
Introduction

- Formation Flying Problem
- Describing Relative Orbits
- Perturbations and Control Systems
- The CanX-4&5 Nanosatellite Mission

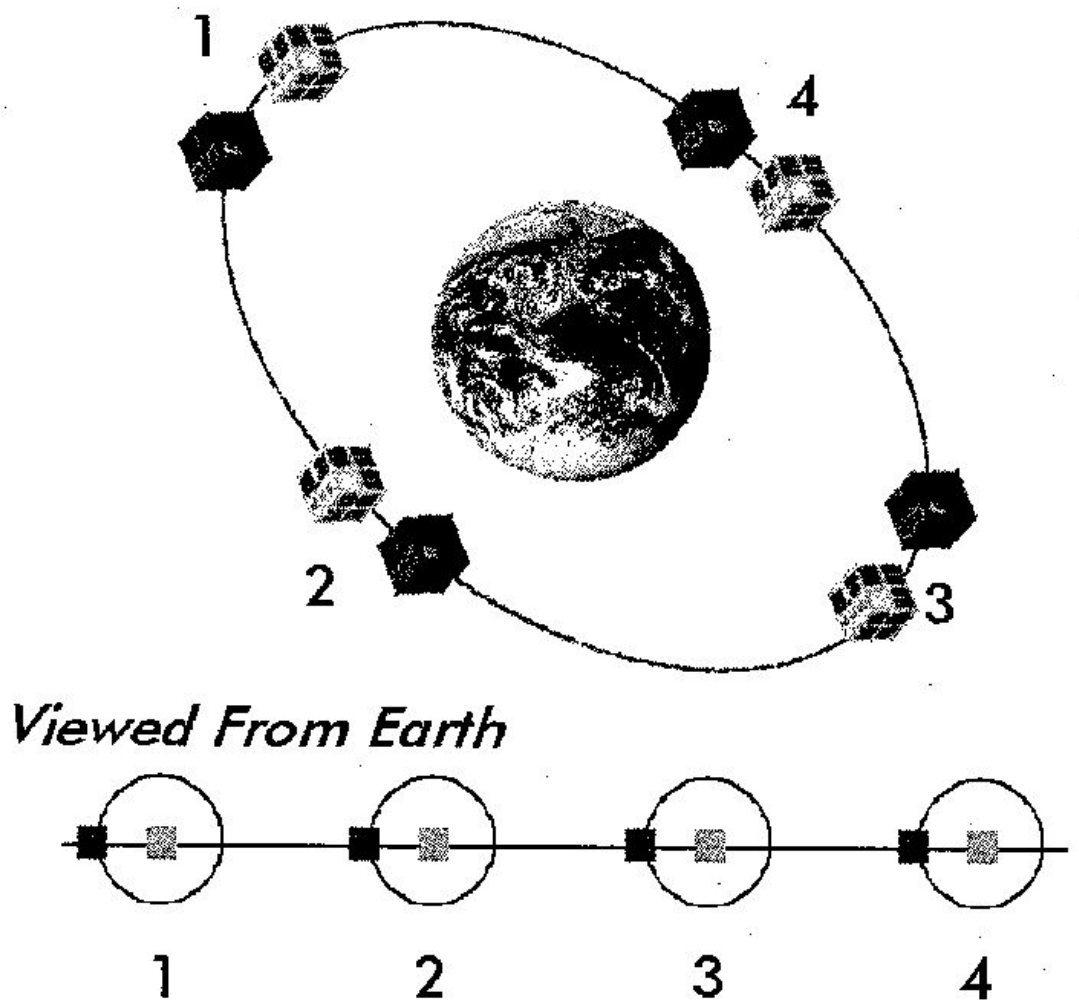
Formation Flying

- **Problem**: Maintain bounded relative motion between 2 or more satellites
- **Motivation**: Accomplish things that one large (expensive) satellite can do with many smaller satellites
- **Advantages**: Inherently redundant
- **Applications**: communications, remote sensing

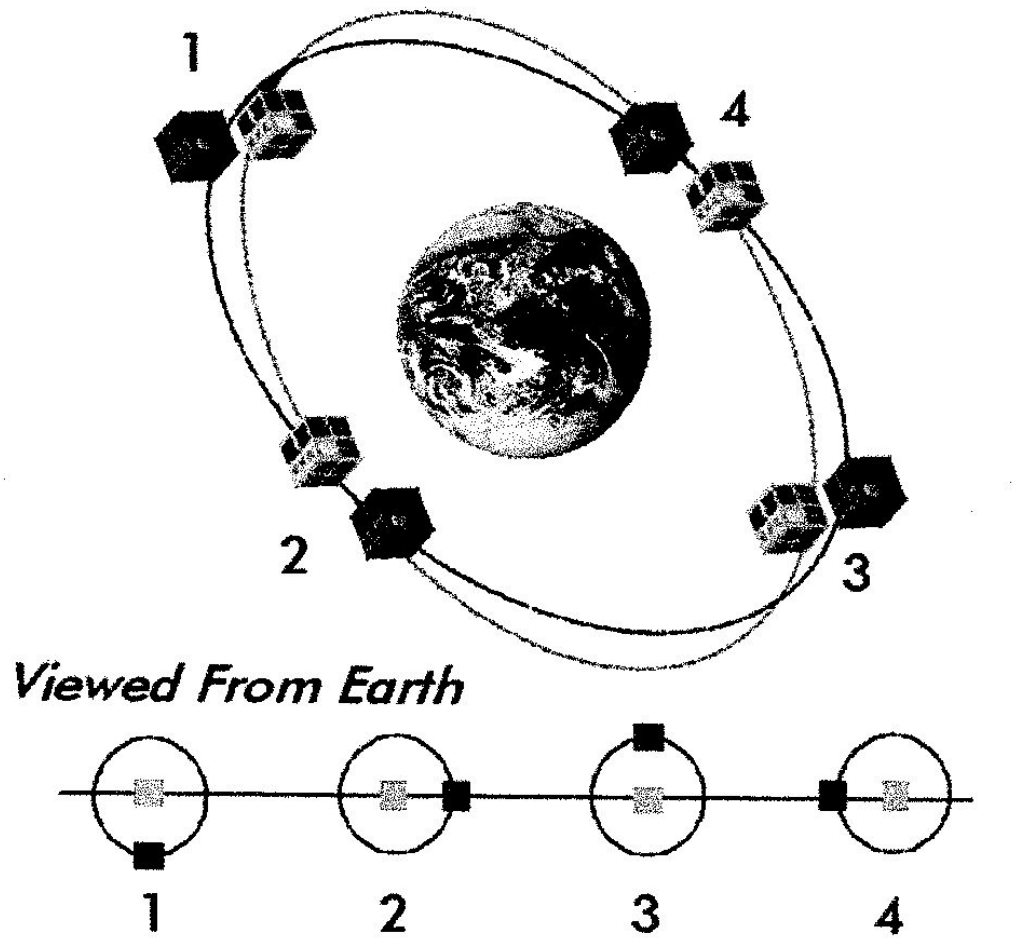
The Basic Setup



The Along Track Orbit (ATO)



The Projected Circular Orbit (PCO)



Perturbations in Low Earth Orbit

Reasons we need a control system:

- the chief is not in a perfectly circular orbit
- oblateness of the Earth (it's fat at the equator)
- differential atmospheric drag

Control System Design

- Place thrusters on the deputy
- Measure the relative position using GPS
- Determine errors: difference between actual relative position and desired relative position
- Use negative feedback: thrust in opposite direction of the errors
- Thrust is proportional to size of the errors

Numerical Example

Chief Orbit

initially circular:

$$\text{radius} = 6378 \text{ km} + 550 \text{ km}$$

Deputy Orbit

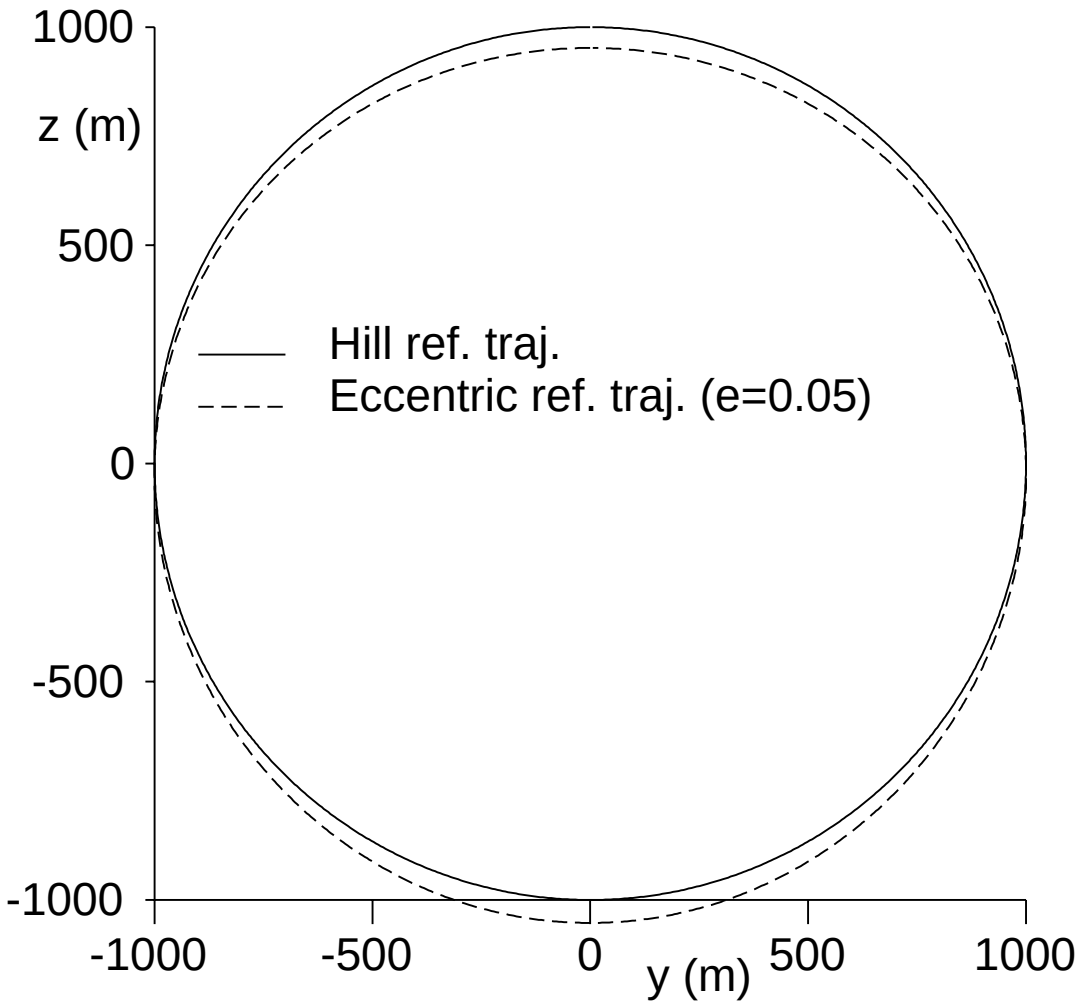
PCO relative initial conditions:

$$\text{radius} = 1000 \text{ m}$$

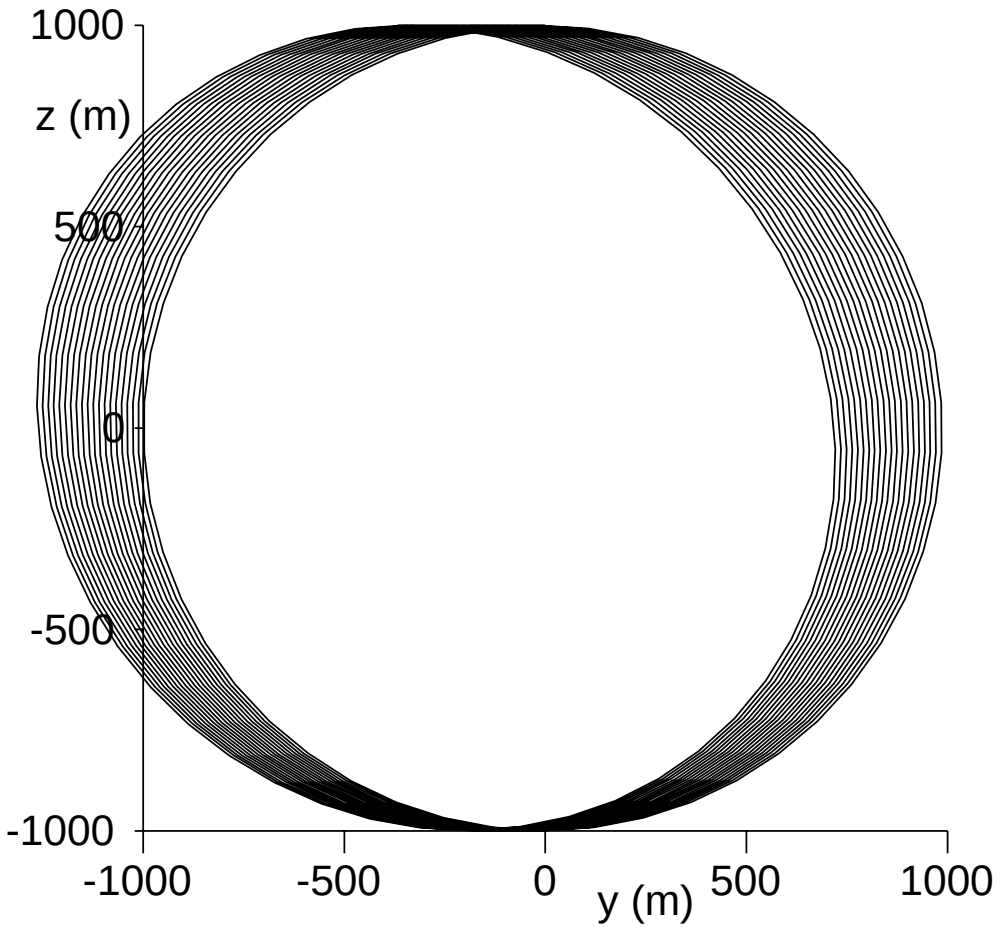
Controller Design

- Try to keep relative position errors less than 1 metre while using as little fuel as possible

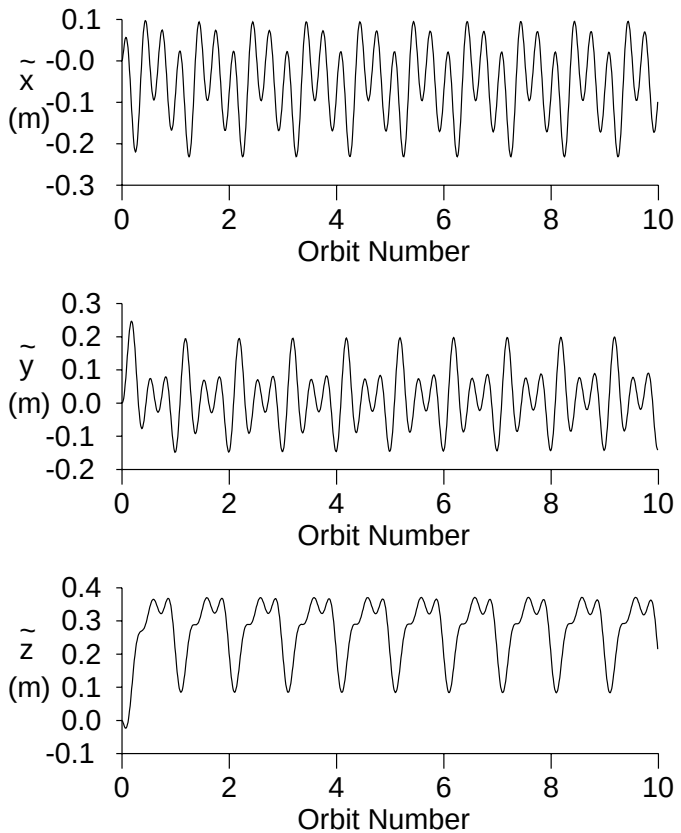
Desired Relative Orbit



Open-Loop Response with Oblateness Perturbation (No Control System)



Closed-Loop Response with Oblateness Perturbation (With Control System)

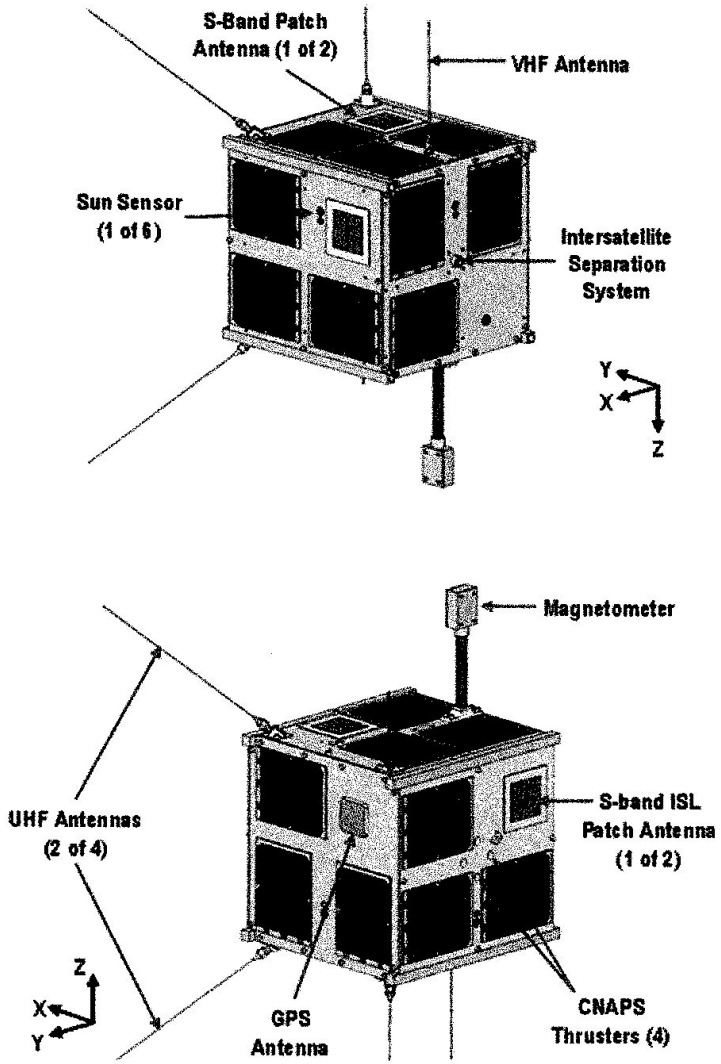


The CanX-4&5 Mission

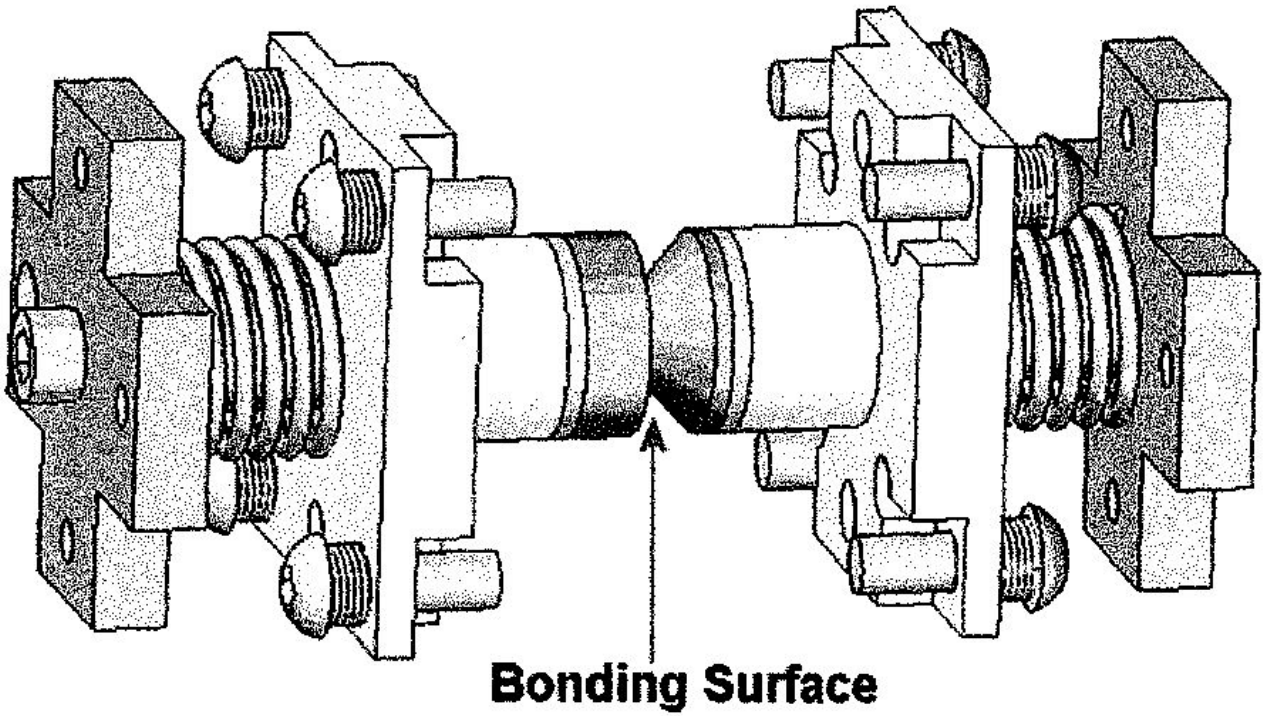
CanX = Canadian Advanced Nanosatellite eXperiment

- two identical 6.85 kg nanosatellites
- 20 cm cubes
- position error requirement: $<$1 m
- position determination: $<$10 cm
- total Δv: 14 m/s
- thrust: 5 mN

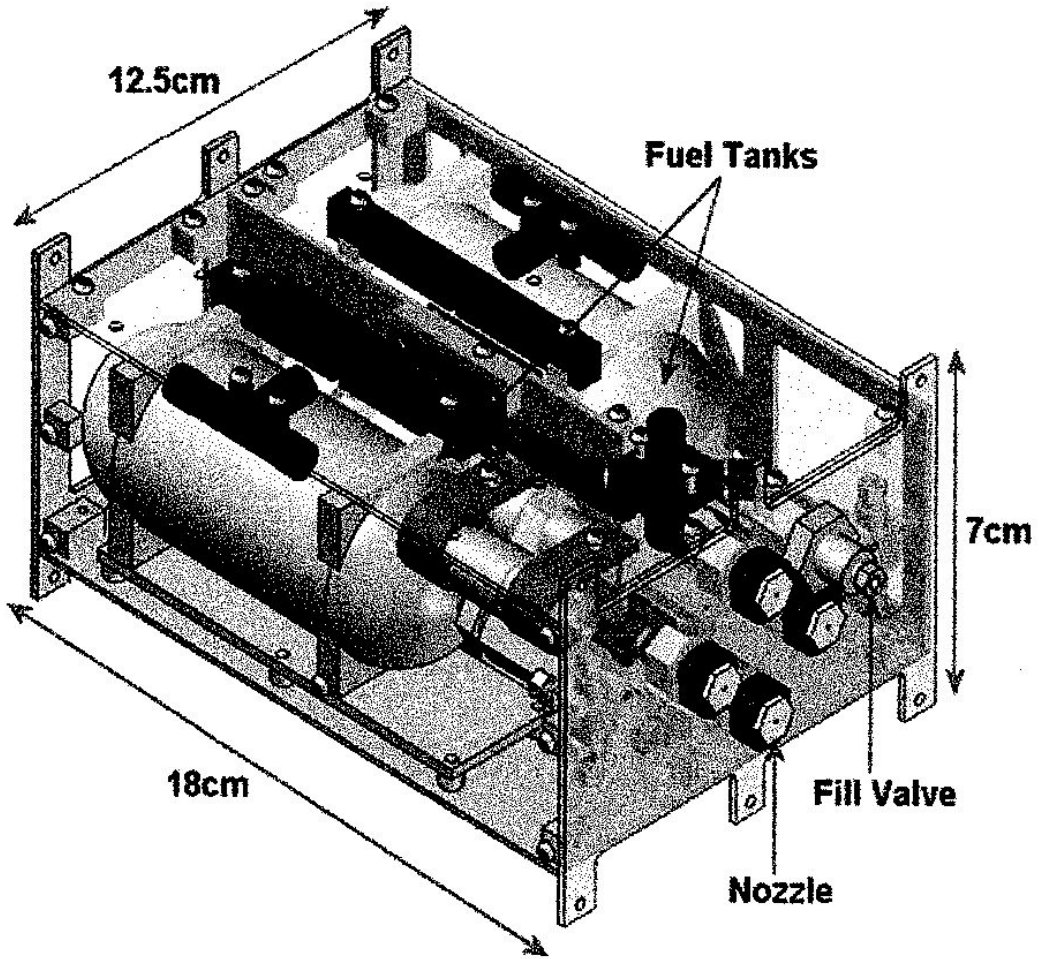
The CanX-4&5 Spacecraft



Intersatellite Separation System



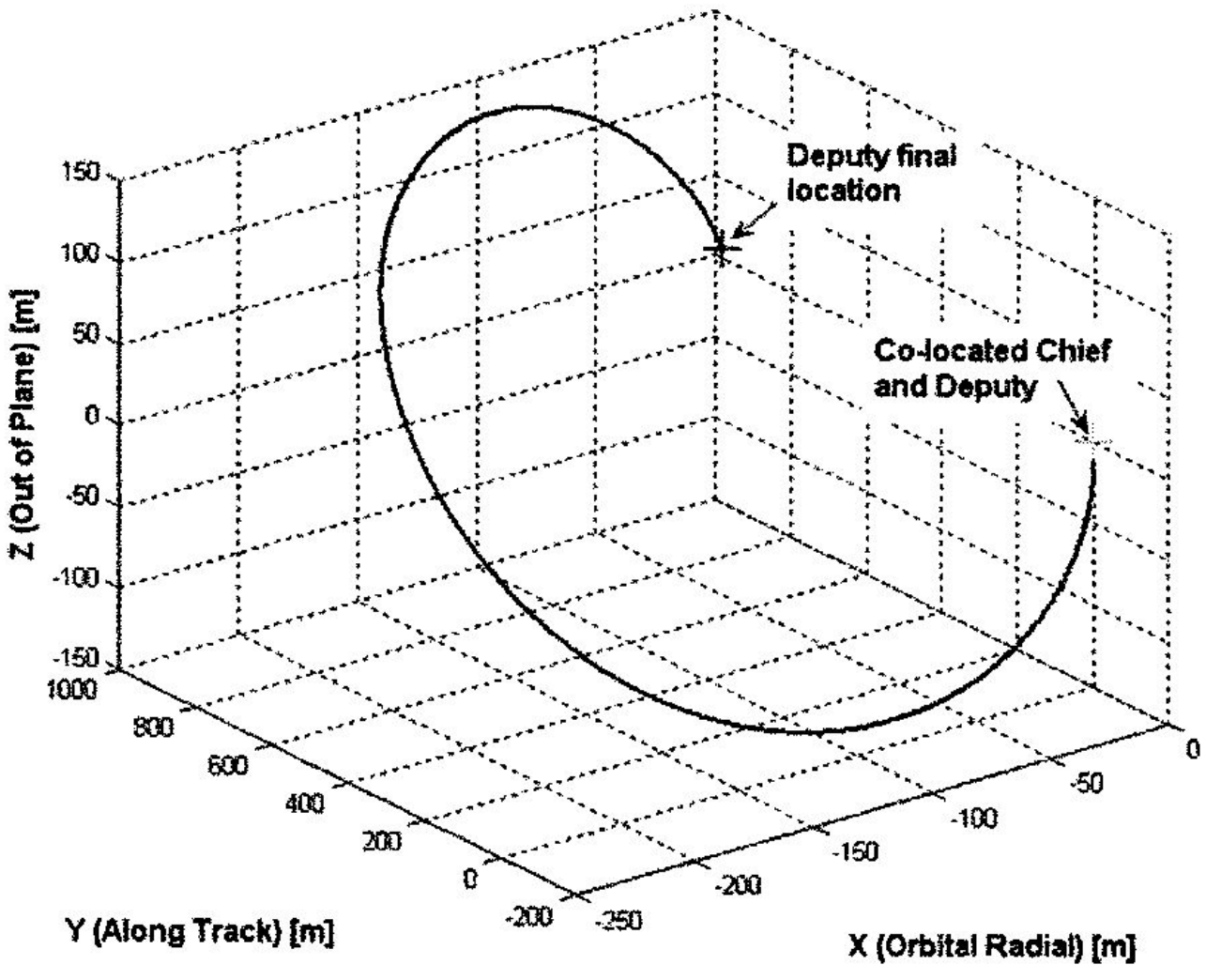
Canadian Nanosatellite Propulsion System



CanX-4&5 Mission Sequence

- Separation Sequence
- **1000 m ATO** (50 orbits)
- ATO-to-ATO reconfiguration
- **500 m ATO** (50 orbits)
- ATO-to-PCO reconfiguration
- **50 m PCO** (50 orbits)
- PCO-to-PCO reconfiguration
- **100 m PCO** (50 orbits)

Separation Maneuver



Concluding Remarks

- Formation Flying is an interesting problem in spacecraft dynamics and control
- ATO and PCO relative orbits are useful in applications
- CanX-4&5 will demonstrate autonomous formation flying in low Earth orbit using a pair of nanosatellites