Technology Demonstration Missions for Orbit and Attitude Control of Nanosatellites

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Presentation Summary

- Introduction
- Satellite Formation Flying Using Solar Radiation Pressure and Aerodynamic Drag
- Fault Tolerant Control of Satellite Attitude In the case of Reaction Wheels' Failures
- Conclusions

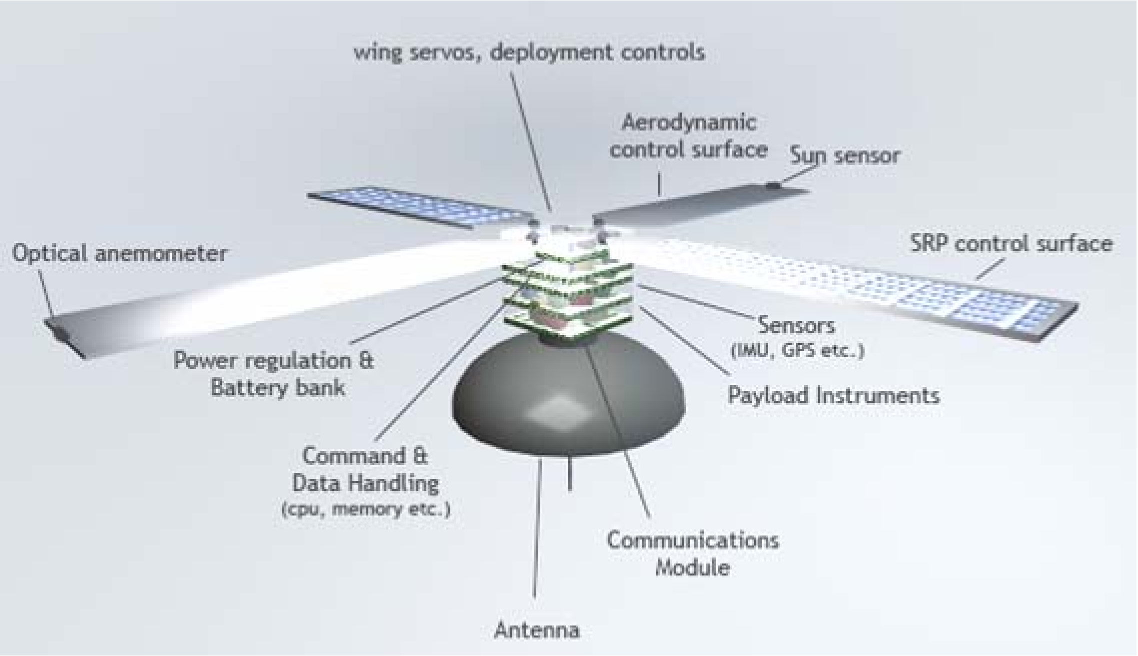
Introduction

- Autonomous station-keeping, formation maintenance and attitude control of nanosatellites using minimum fuel represents one of the most important future space technologies.

- “Propellant-less” method includes use of Solar Radiation Pressure (SRP) and Aerodynamic forces for orbit and attitude control.

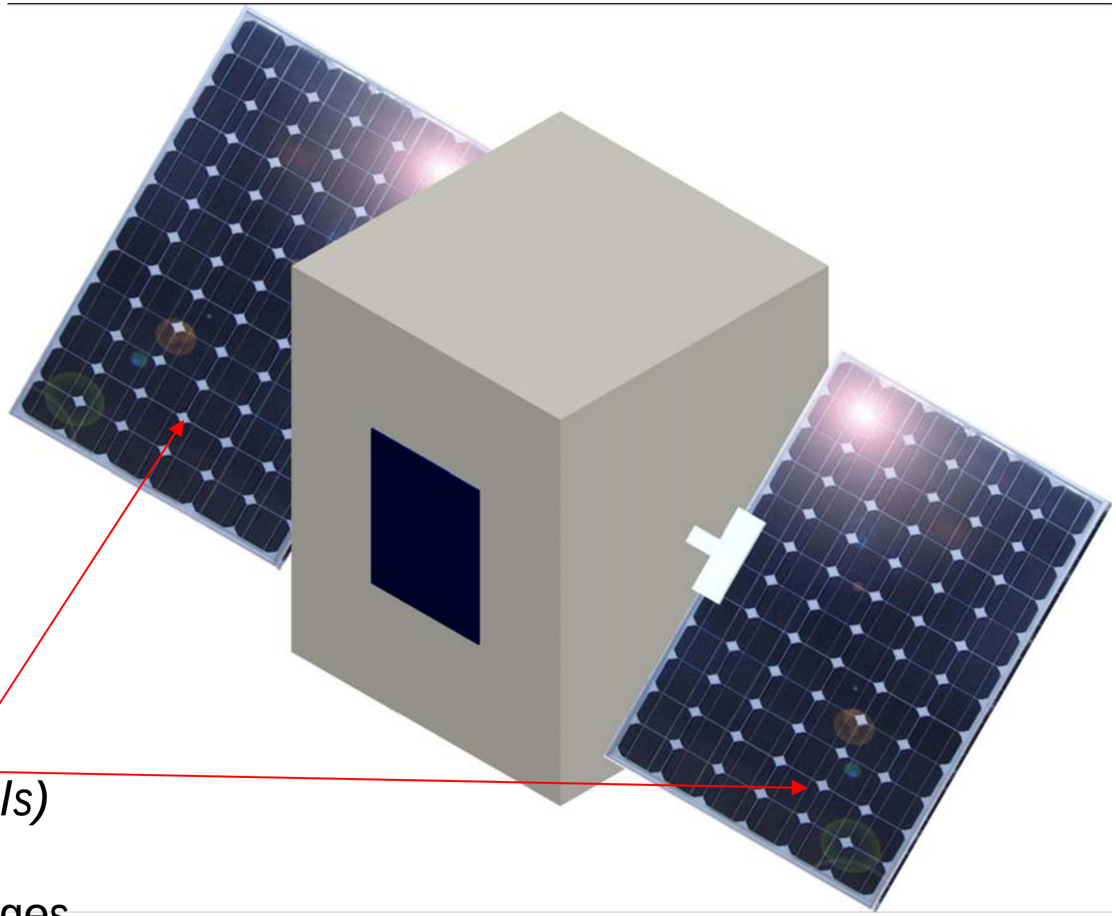
- Fault-tolerant control algorithms ensure mission safety in the case of sensor or actuator failure (for example, failure of reaction wheels)

Formation Flying of Satellites Using SRP and Aerodynamic Drag



Satellite with SRP wings and AERO wings

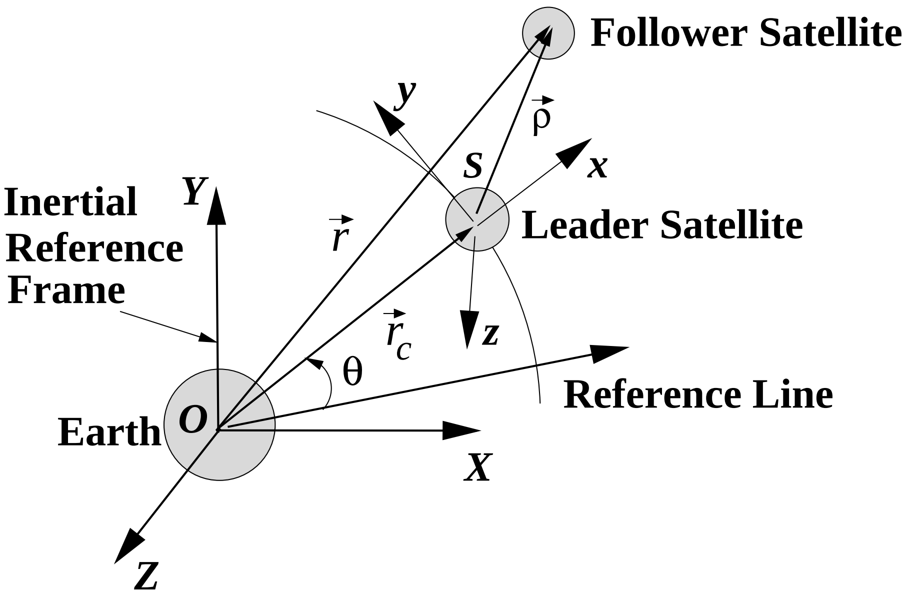
Panel Rotations



Aerodynamic Panels
(shown here as solar panels)

Rotating these panels changes the effective drag area of the Spacecraft

System Model



Leader satellite equations of motion

$$\ddot{r}_c = r_c\dot{\theta}^2 - \frac{\mu}{r_c^2}$$

$$\ddot{\theta} = -\frac{2\dot{\theta}\dot{r}_c}{r_c}$$

Relative Equations of motion

$$\ddot{x} = x\dot{\theta}^2 + y\ddot{\theta} + 2\dot{y}\dot{\theta} - \frac{\mu(r_c + x)}{r^3} + \frac{\mu}{r_c^2} + f_x + f_{dx}$$

$$\ddot{y} = y\dot{\theta}^2 - 2\dot{x}\dot{\theta} - x\ddot{\theta} - \frac{\mu y}{r^3} + f_y + f_{dy}$$

$$\ddot{z} = -\frac{\mu z}{r^3} + f_z + f_{dz}$$

SRP force model

- The force acting on a plate due to solar radiation pressure is

$$\vec{F}_s = pA\left|\vec{s}\ .\ \vec{n}\right|\left\{\left(1-\rho_s-\rho_t\right)\vec{s} + \left[2\rho_s\left(\vec{s}\ .\ \vec{n}\right) + \frac{2}{3}\rho_d\right]\vec{n}\right\}$$

$$\Downarrow$$

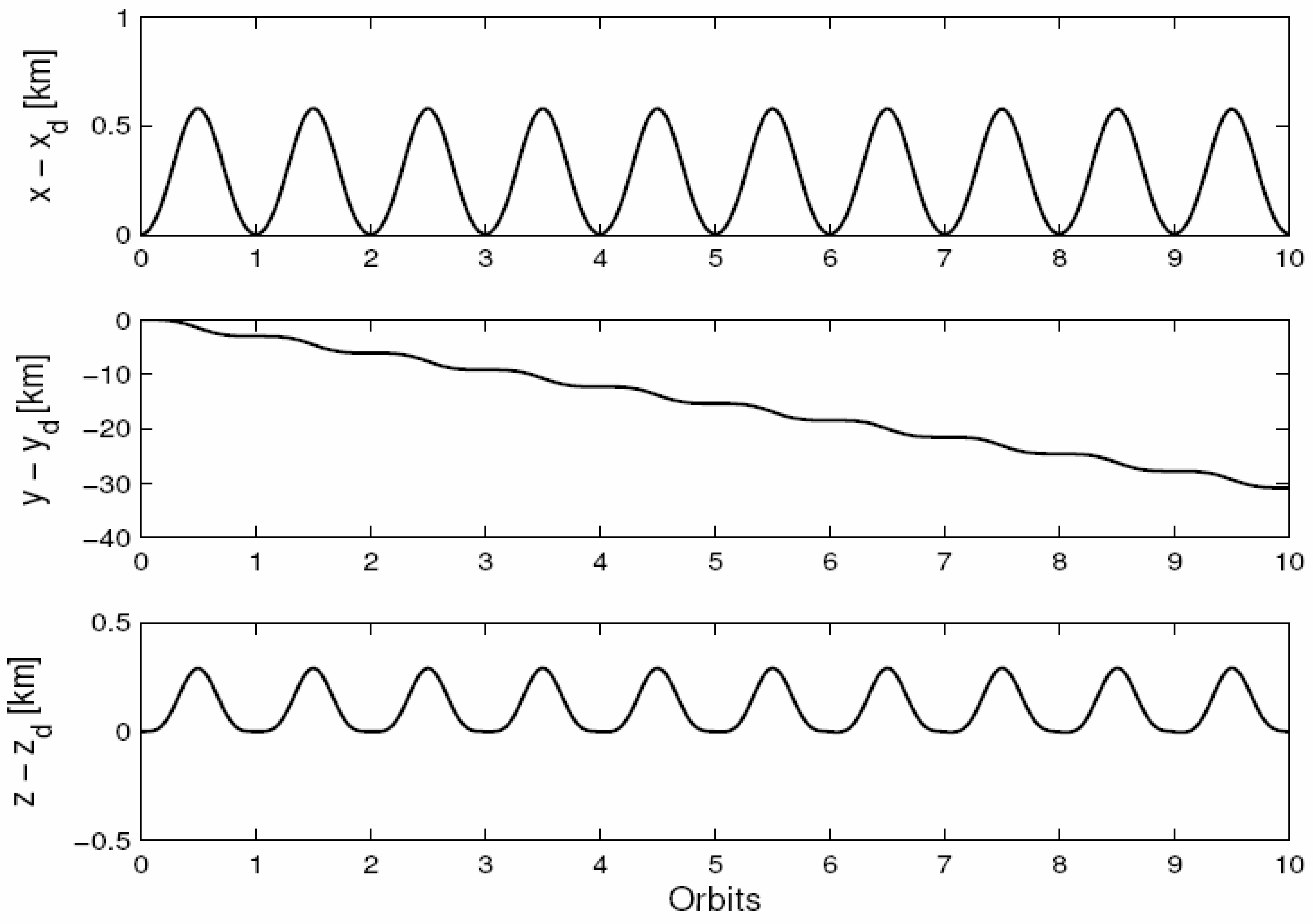
$$\vec{F}_s = 2\rho_s pA\left|\vec{s}\ .\ \vec{n}\right|\left(\vec{s}\ .\ \vec{n}\right)\vec{n}$$

- Resultant force components in the along track and radial direction

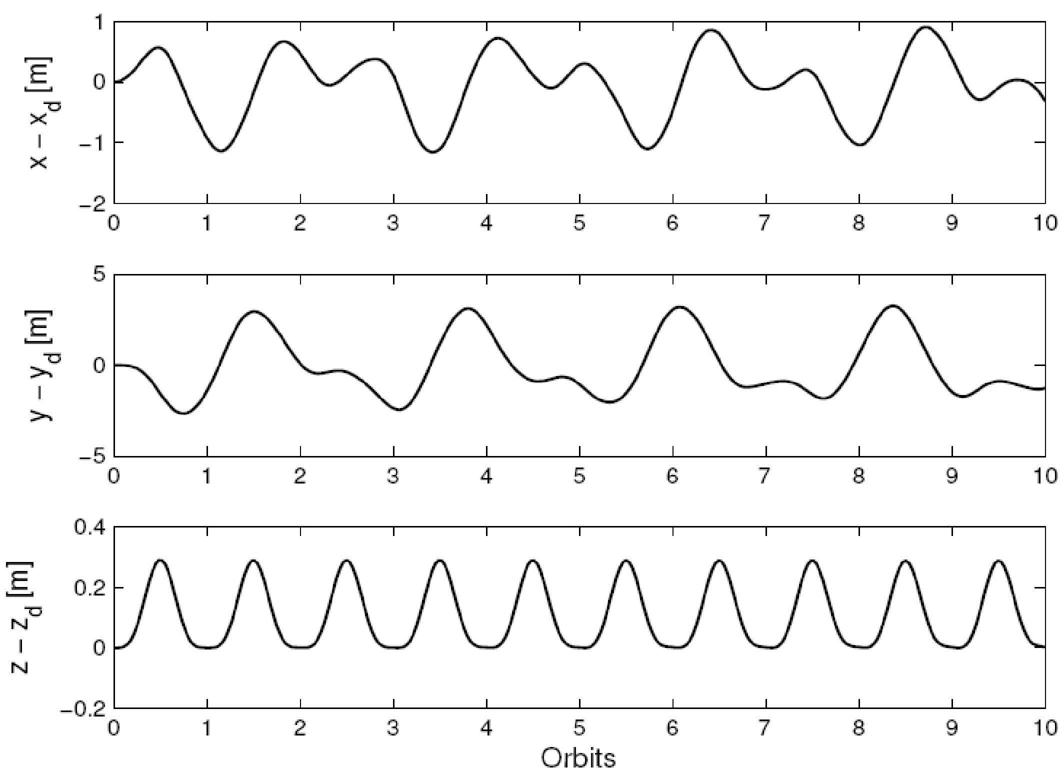
$$f_x = -C\left|\left(\cos\left(-\theta+\psi+\alpha_f\right)\right)\right|\cos\left(-\theta+\psi+\alpha_f\right)\cos\alpha_f - \left(-C\left|\left(\cos\left(-\theta+\psi+\alpha_l\right)\right)\right|\cos\left(-\theta+\psi+\alpha_l\right)\cos\alpha_l\right)$$

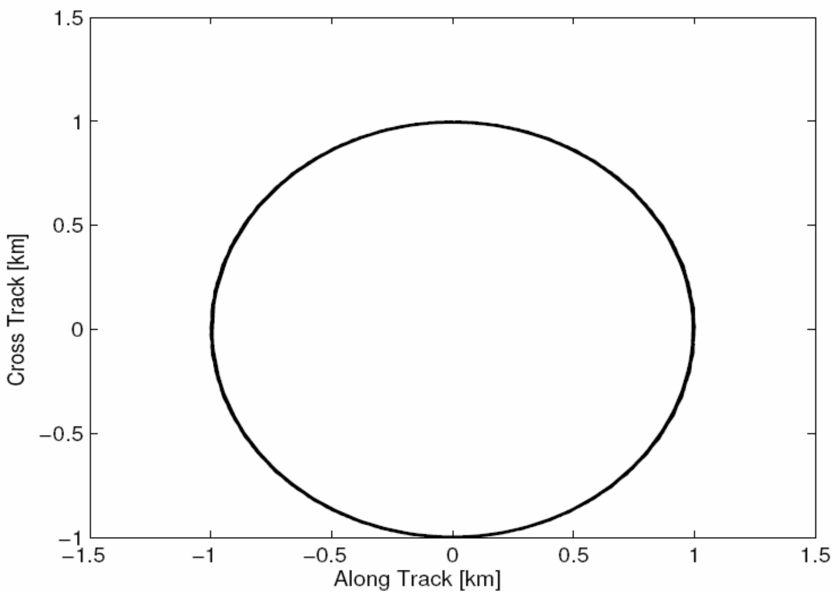
$$f_y = C\left|\left(\cos\left(-\theta+\psi+\alpha_f\right)\right)\right|\cos\left(-\theta+\psi+\alpha_f\right)\sin\alpha_f - C\left|\left(\cos\left(-\theta+\psi+\alpha_l\right)\right)\right|\cos\left(-\theta+\psi+\alpha_l\right)\sin\alpha_l$$

Uncontrolled system response

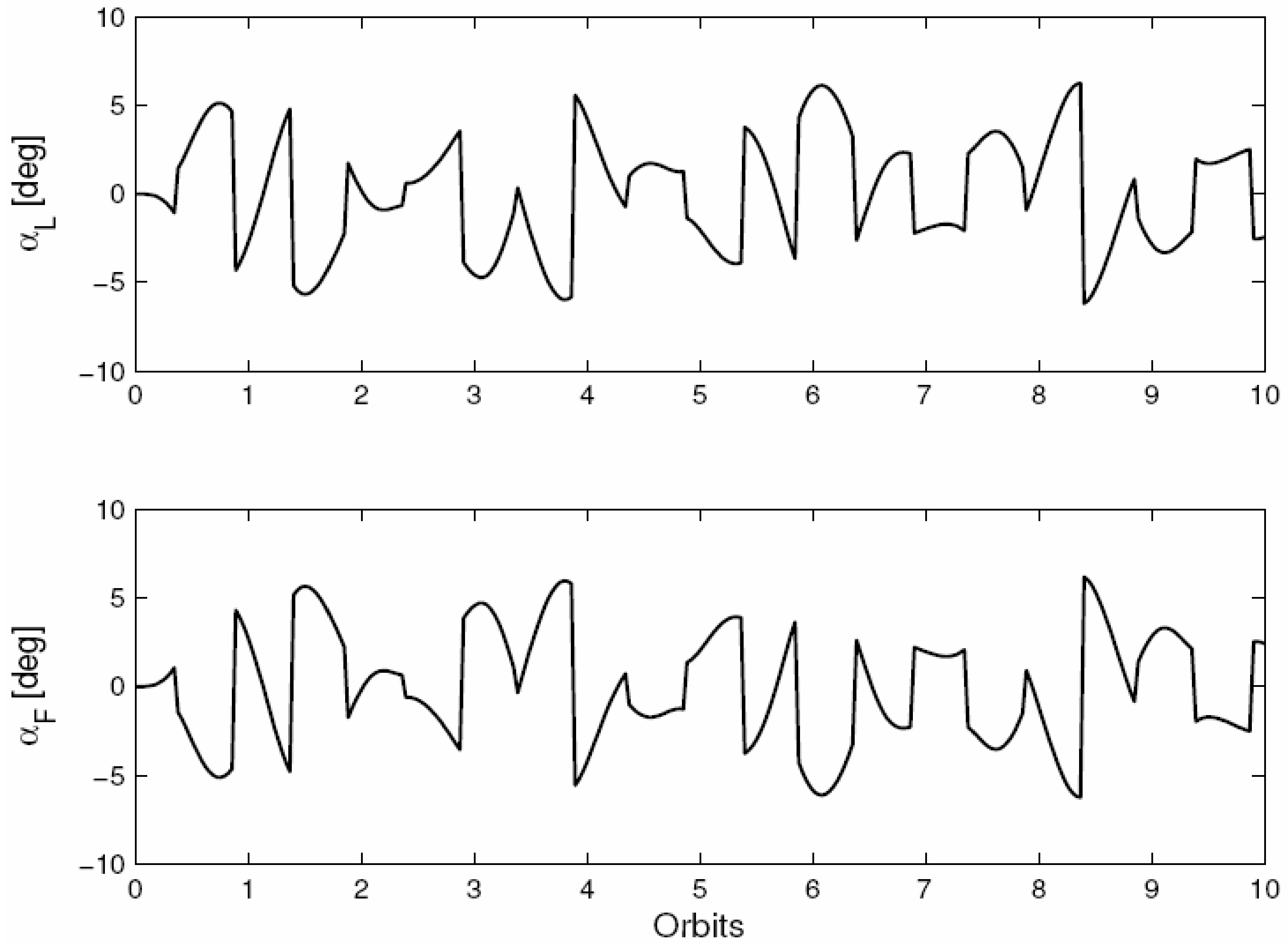


Projected circular formation with SRP force





Deflection of SRP wings on leader and follower satellites



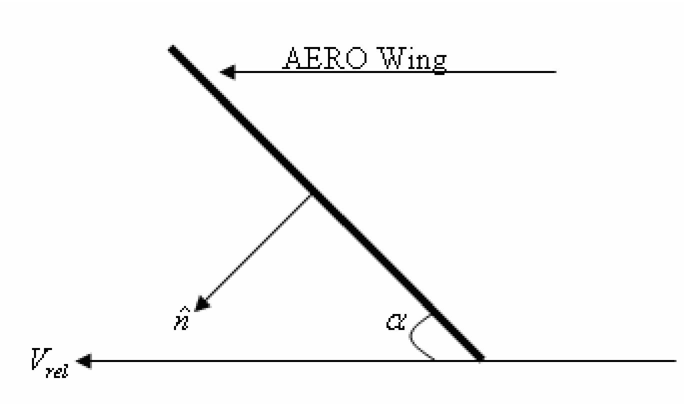
Aerodynamic force model

- Force experienced by the surface of the satellite is given by

$$\vec{F}_D = -\frac{1}{2}\rho C_D A V_{rel}^2 \hat{V}_{rel}$$

- Considering exponential density model:

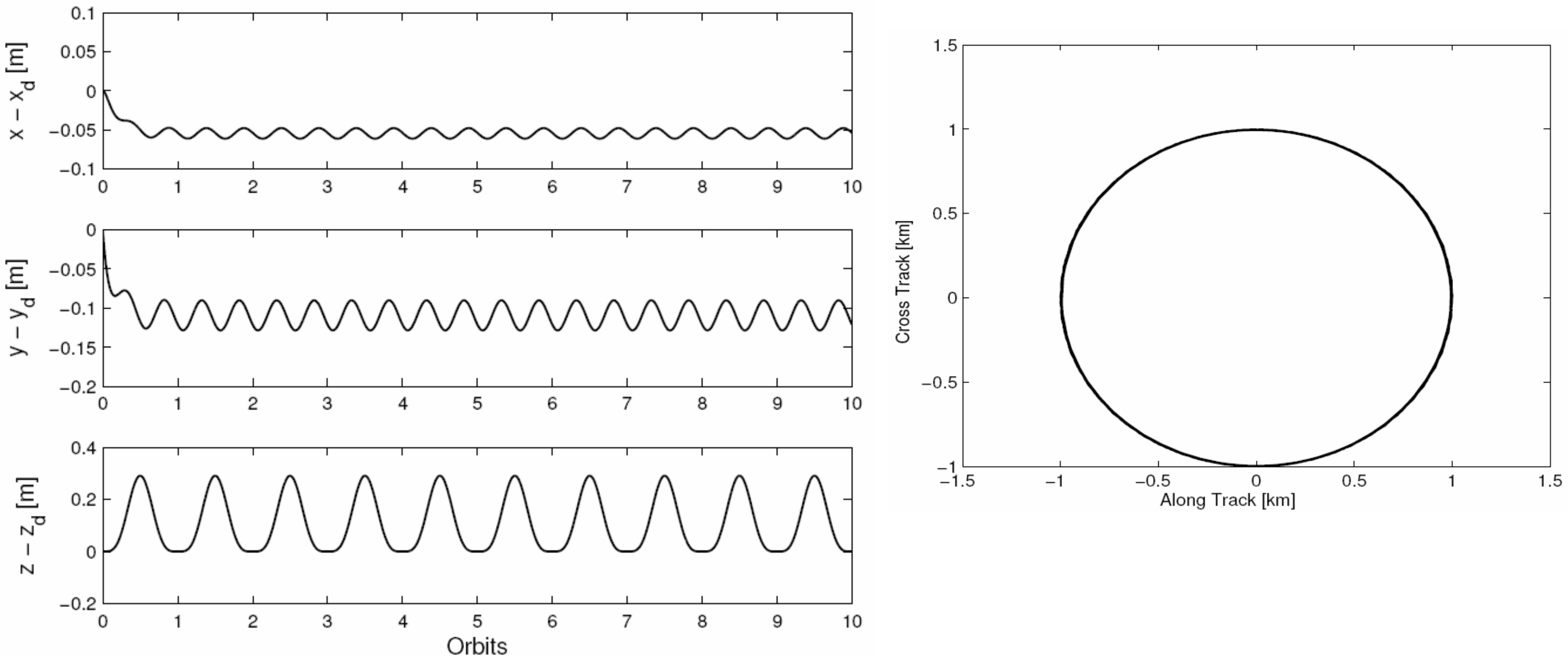
$$\rho = \rho_0 \exp\left[-\frac{h_{ellip} - h_0}{H}\right]$$



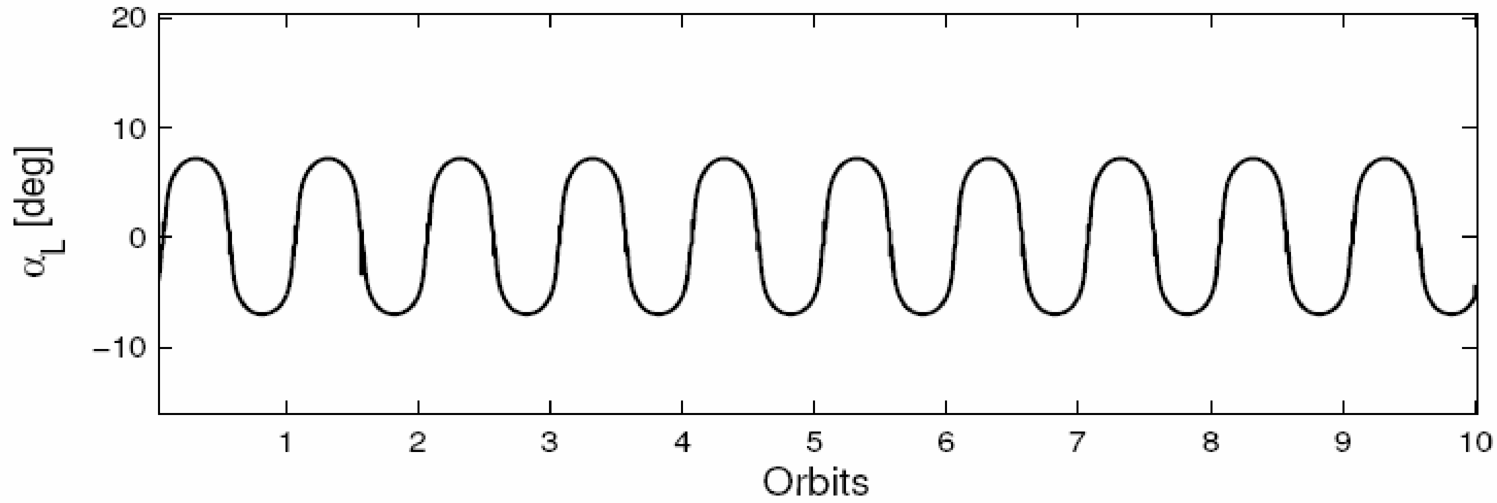
Resultant force acting in the along track direction

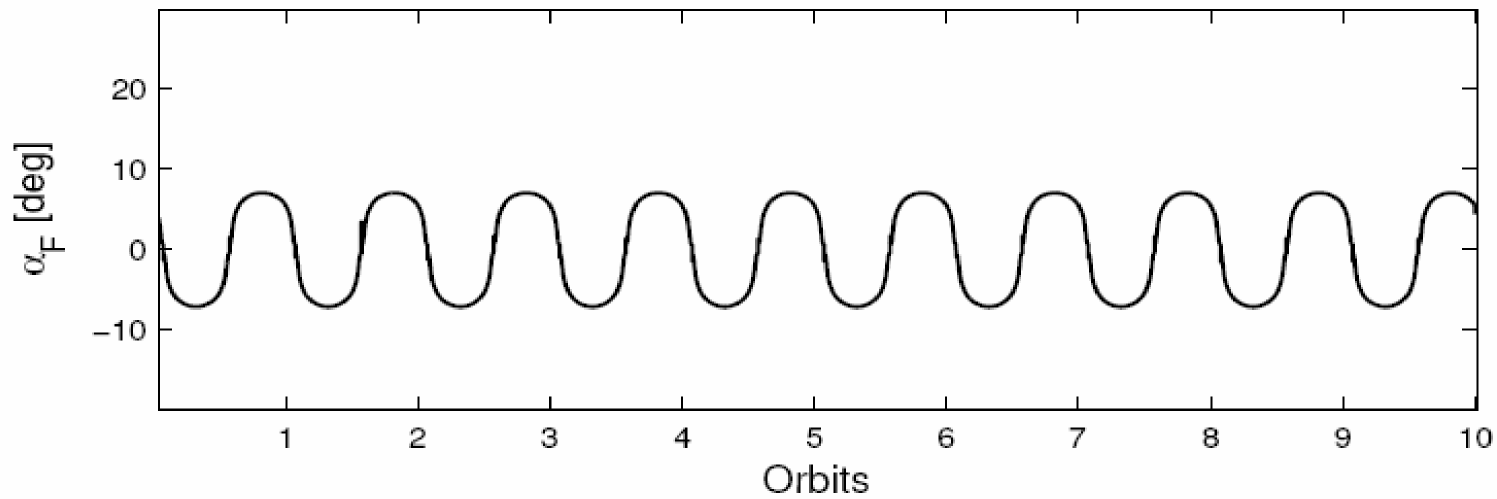
$$f_y = \left(-\frac{1}{2}\rho_f C_d V_{frel}^2 A_f \sin\alpha_f - \left(-\frac{1}{2}\rho_f C_d V_{frel}^2 A_f \sin\alpha_l\right)\right)$$

Projected Circular formation with AERO force

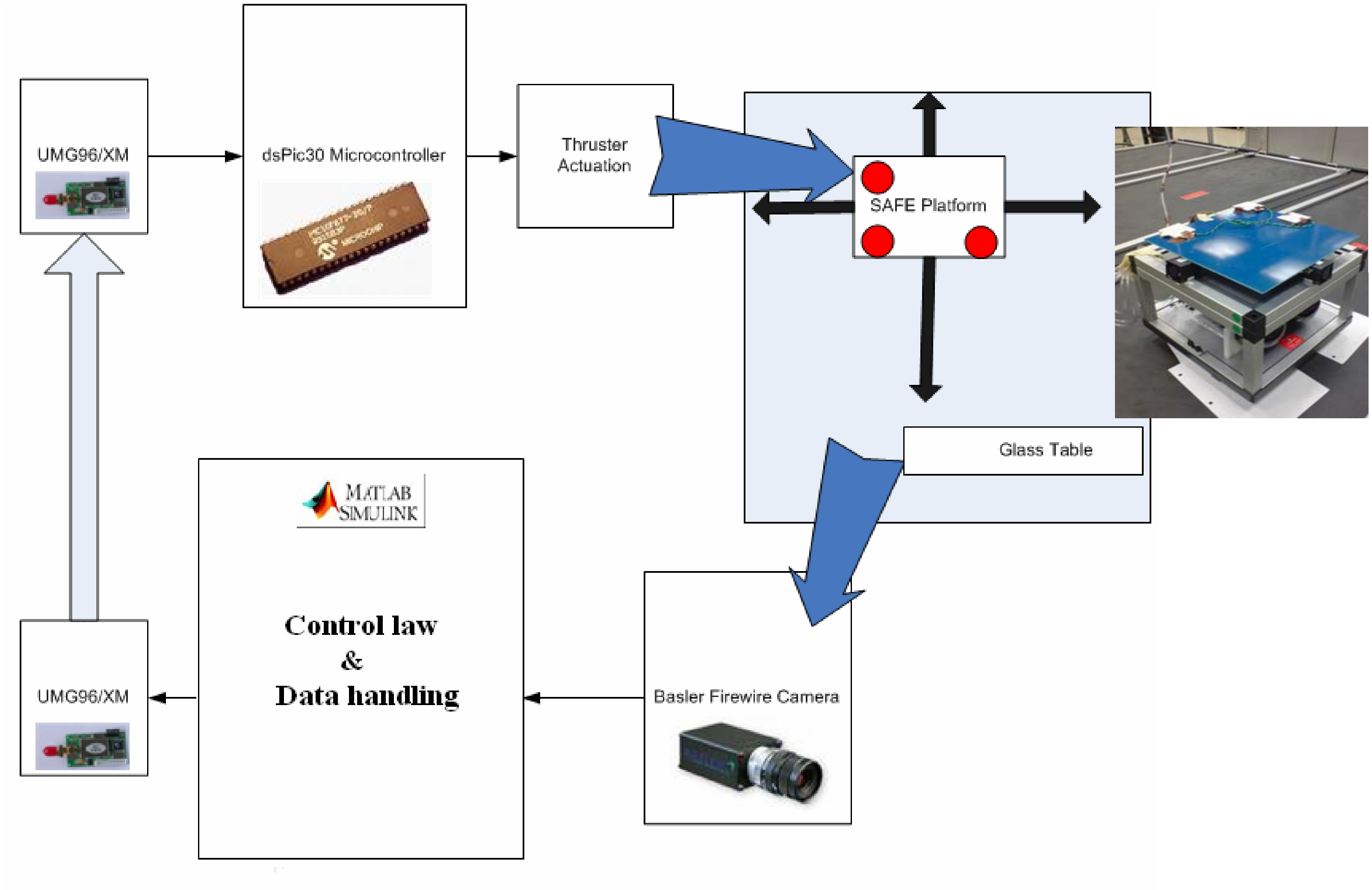


Deflection of AERO wings on leader and follower satellites using SMC

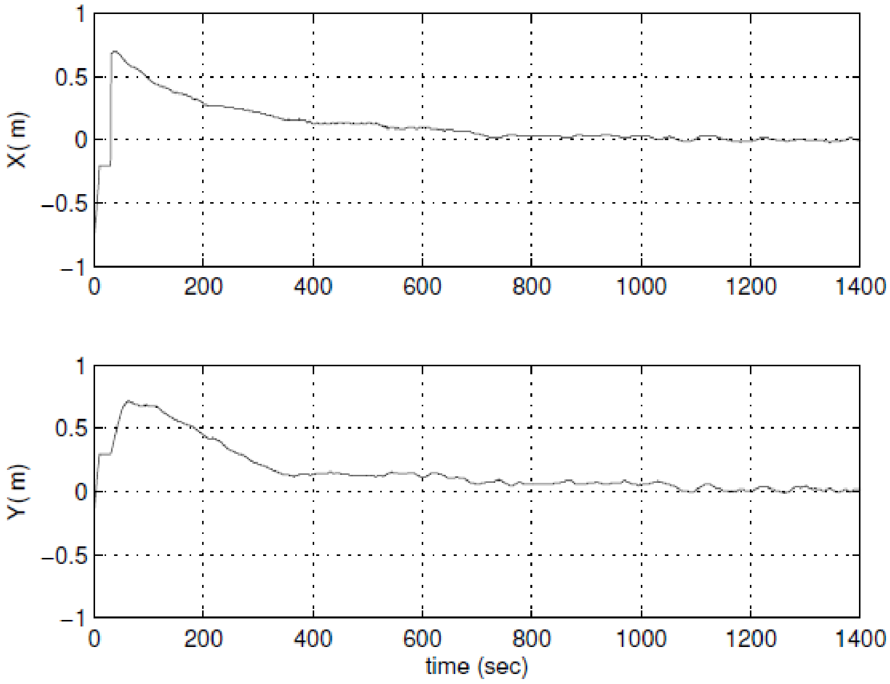




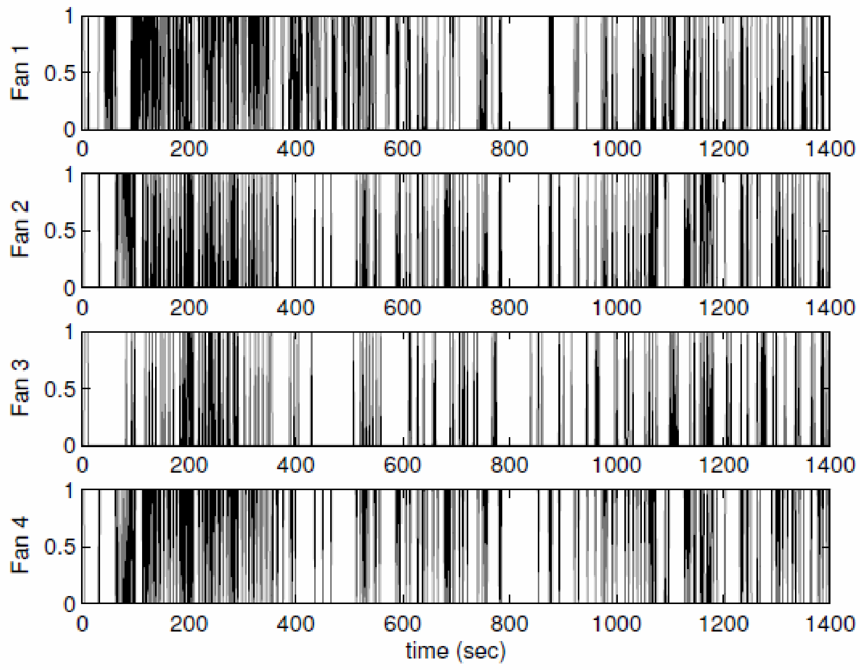
Formation Experiment



Along Track Formation Maintenance (Fully actuated Configuration)

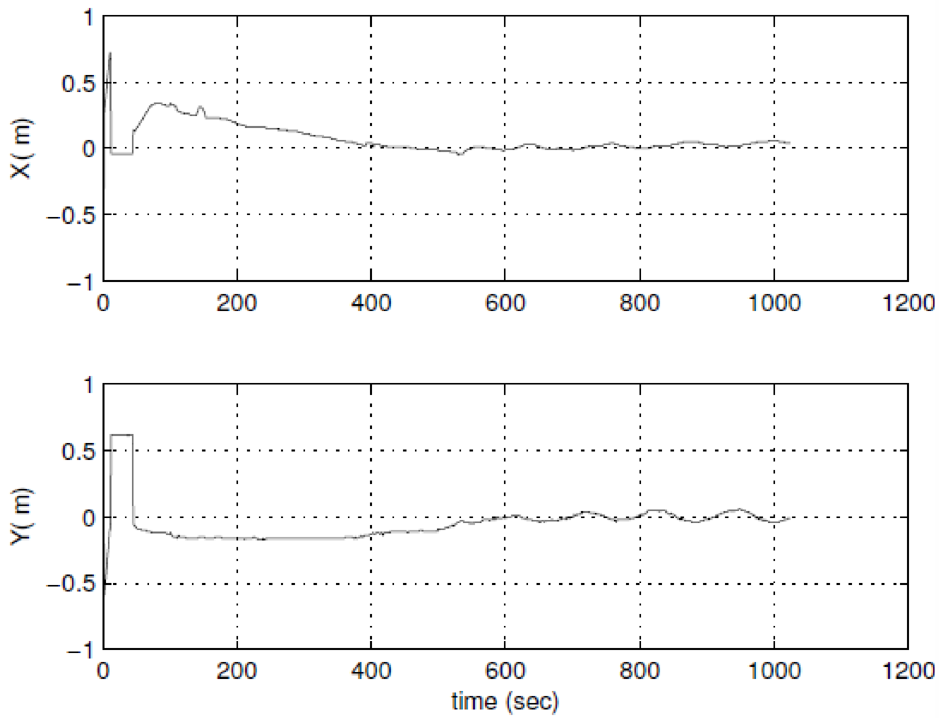


Relative Errors

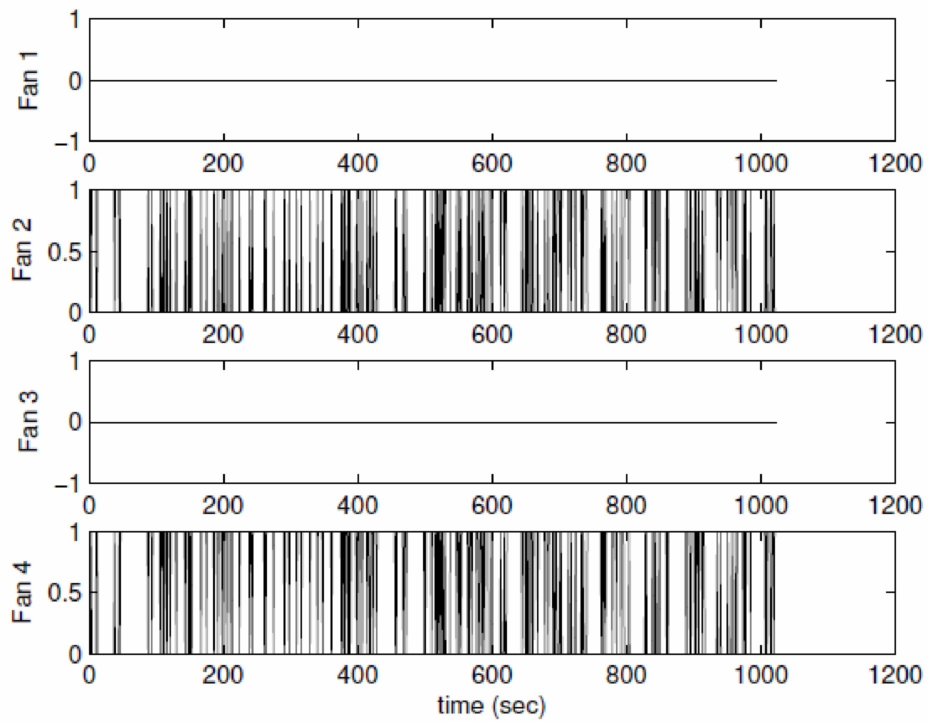


Control Profile

Along Track Formation Maintenance (Underactuated Configuration)

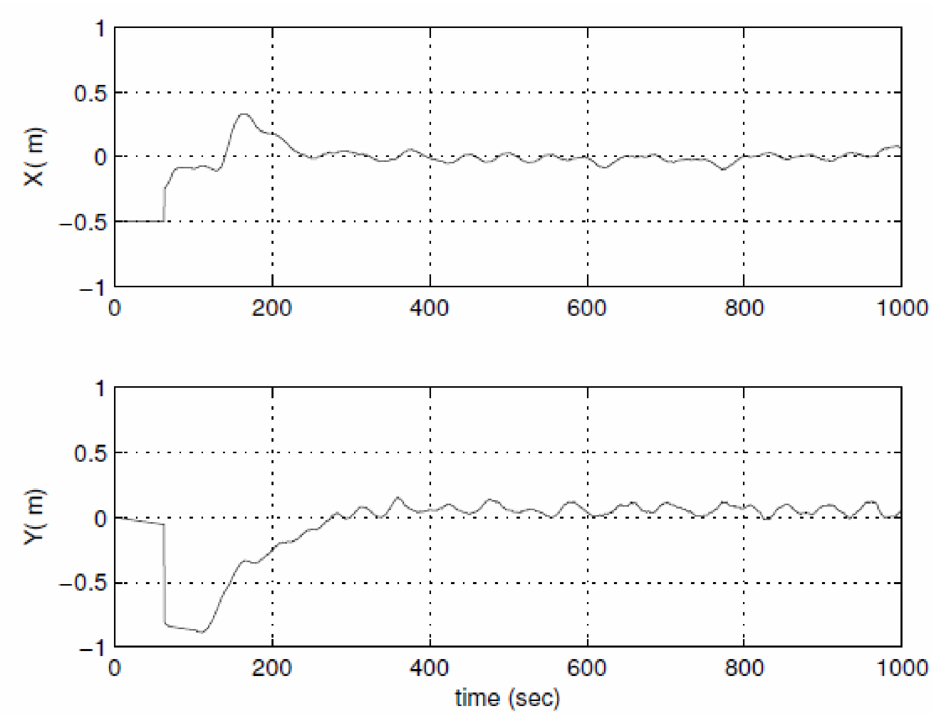


Relative Errors

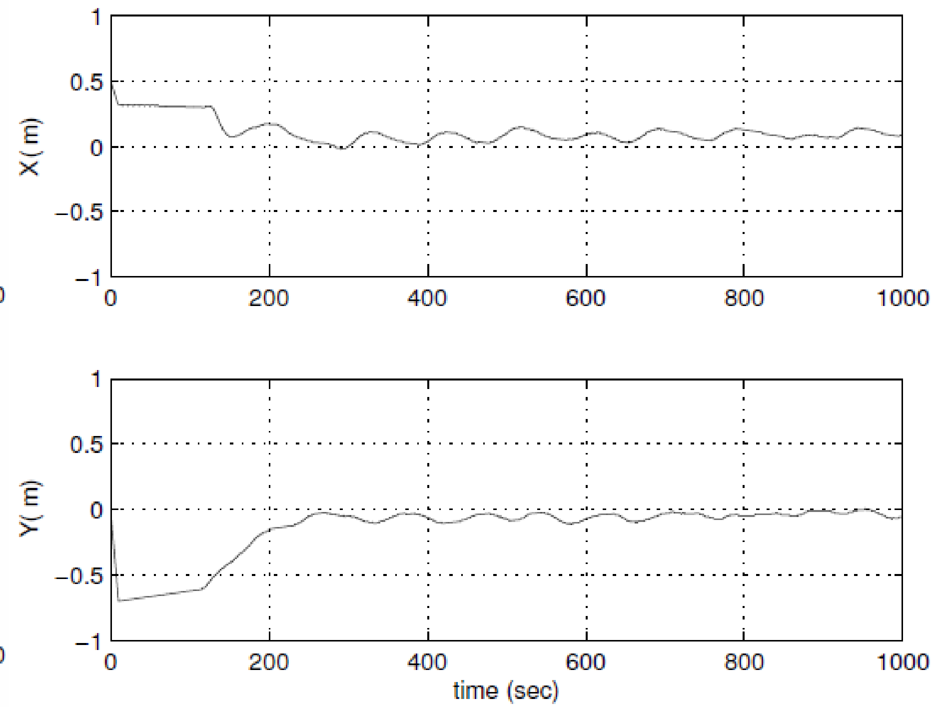


Control Profile

Circular Formation Maintenance



Relative Errors for Satellite -1, $\phi = 0^o$

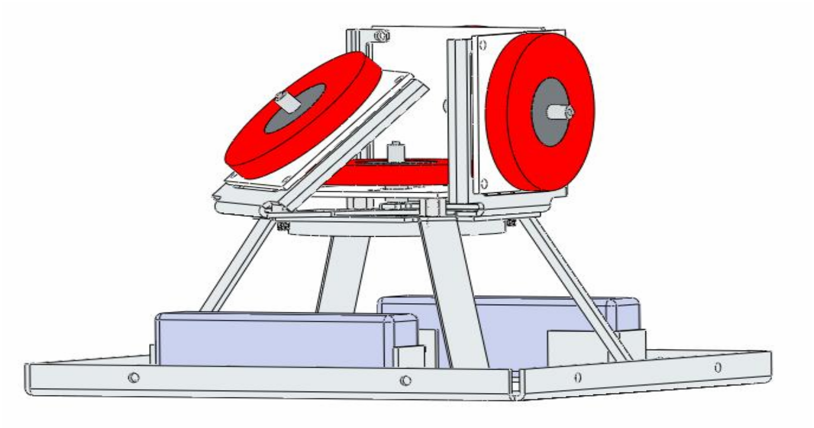


Relative Errors for Satellite -1, $\phi = 180^o$

Fault Tolerant Control of Satellite Attitude In the Case of Reaction Wheels' Failures

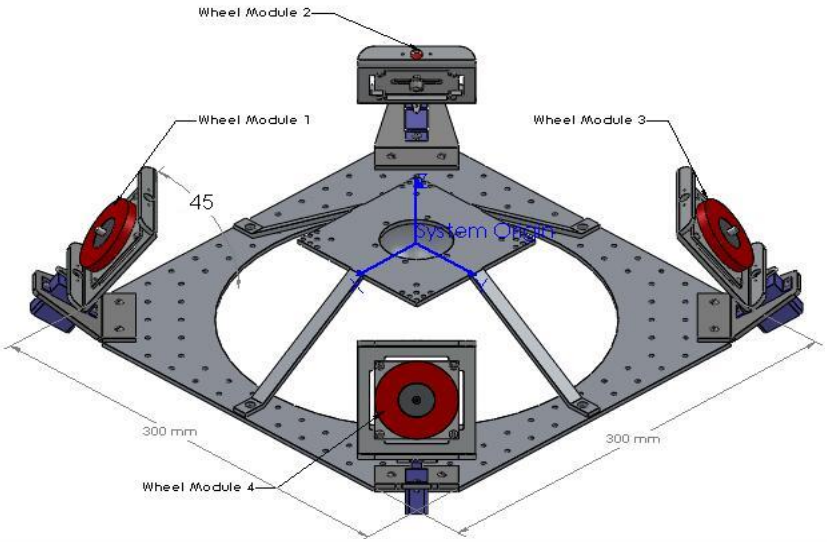
Reaction Wheel Assemblies

3 orthogonal + 1 oblique



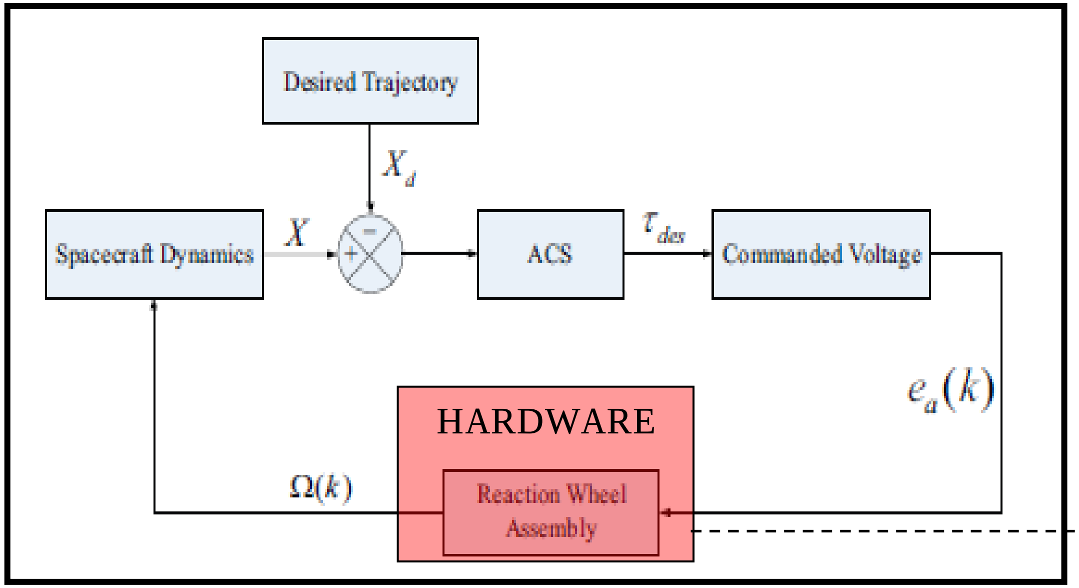
$$\begin{bmatrix} \tau_x \\ \tau_y \\ \tau_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & -\cos(\phi_2)\cos(\phi_1) \\ 0 & 1 & 0 & -\cos(\phi_2)\sin(\phi_1) \\ 0 & 0 & 1 & \sin(\phi_2) \end{bmatrix} \begin{bmatrix} \tau_{w1} \\ \tau_{w2} \\ \tau_{w3} \\ \tau_{w4} \end{bmatrix}$$

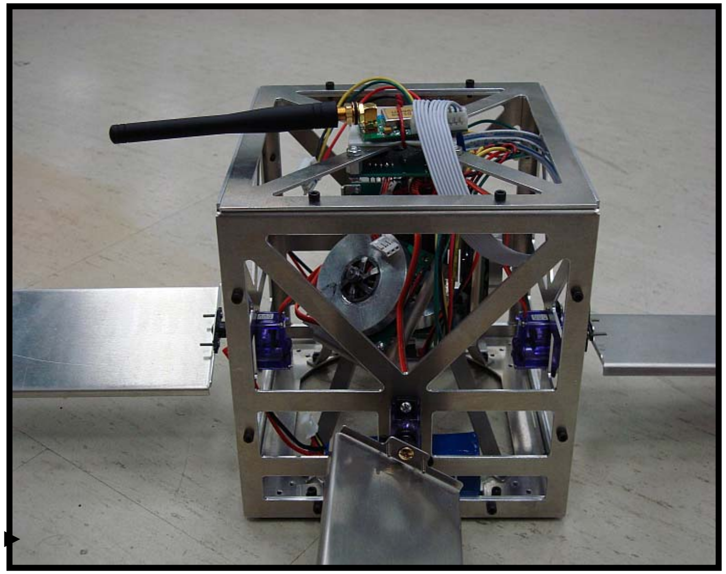
4 wheels - Pyramid



$$\begin{bmatrix} \tau_x \\ \tau_y \\ \tau_z \end{bmatrix} = \begin{bmatrix} c\phi_1 s\phi_2 & -c\phi_1 s\phi_2 & -c\phi_1 s\phi_2 & c\phi_1 s\phi_2 \\ -c\phi_1 c\phi_2 & -c\phi_1 c\phi_2 & c\phi_1 c\phi_2 & c\phi_1 c\phi_2 \\ s\phi_1 & s\phi_1 & s\phi_1 & s\phi_1 \end{bmatrix} \begin{bmatrix} \tau_{w1} \\ \tau_{w2} \\ \tau_{w3} \\ \tau_{w4} \end{bmatrix}$$

Hardware-in-the-Loop (HIL) Simulation





Control Law

$$u_r = -\alpha A^T \sigma - (\rho + 1)\eta A^T \text{sgn}(\sigma)$$

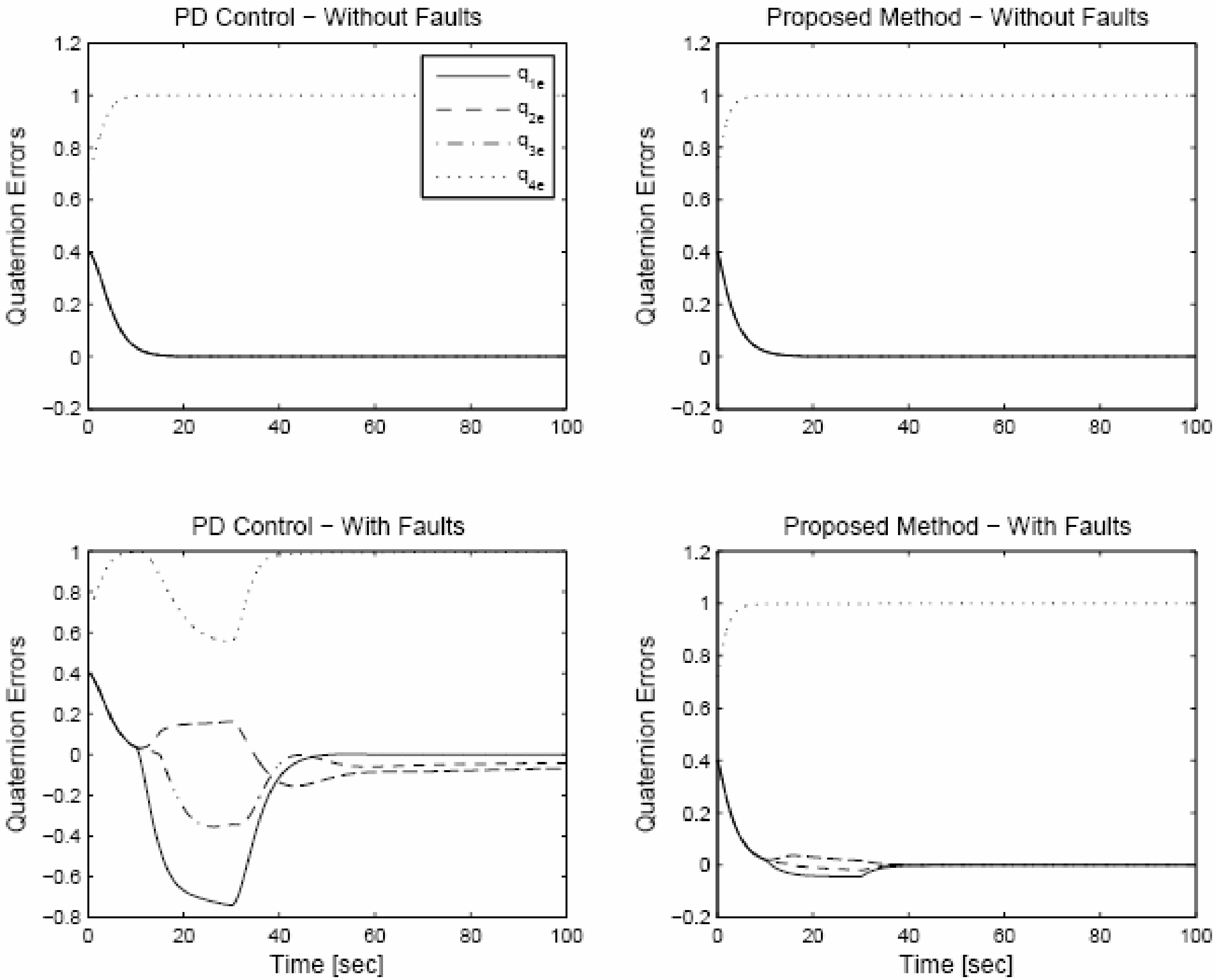
Adaptive Law

$$\dot{\rho} = -b_1 \rho + b_2 \eta \| \sigma \|$$

Input voltage required

$$e_a = K_b \Omega - R_a K_t^{-1} (u_r - \tau_f)$$

3 wheels orthogonal + 1 wheel skewed



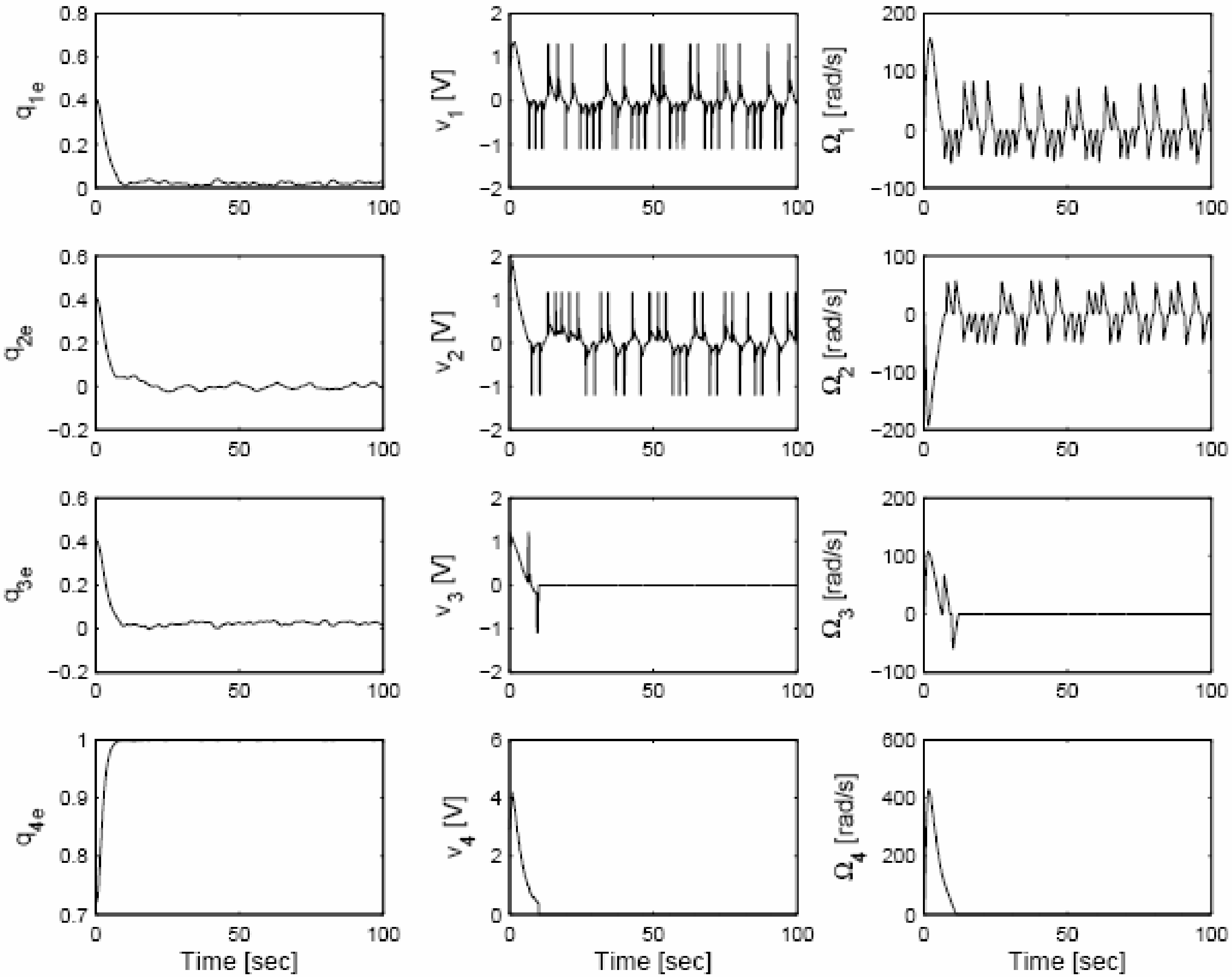
Fault Scenario

$$v_1 = 0.1 + v_1, \quad \text{for } 10 \leq t \leq 30\,\text{s}$$

$$v_3 = 0, \quad \text{for } t \geq 10\,\text{s}$$

$$\Omega_2 = 0.5\Omega_2, \quad \text{for } t \geq 10\,\text{s}$$

4 Wheels in Pyramid Cluster



Fault Scenario

$v_2 = 0.1 + v_2$, for $10 \leq t \leq 20\,\text{s}$

$v_1 = 0$, for $t \geq 5\,\text{s}$

$v_3 = 0$, for $t \geq 5\,\text{s}$

Conclusions

- It is possible to achieve desired formation and attitude control using solar radiation pressure and aerodynamic drag by rotating the respective panels based on numerical and experimental results;

- We can have demonstration missions to verify these concepts; JC2Sat plans to use aerodynamic drag for formation maintenance by rotating the complete satellite.

- Fault Tolerant Control of Satellite Attitude in the case of Reaction wheels' failures is feasible; We can have a demonstration mission to test the control algorithms.

Thank You for Your Attention

Questions ?