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SPACE ROBOTICS LAB – SATELLITE TEAM
TOHOKU UNIVERSITY – COLABS PROGRAM

Computer Modeling and Simulation of ALEe Micro Satellite's Orbit Decay

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Final Presentation

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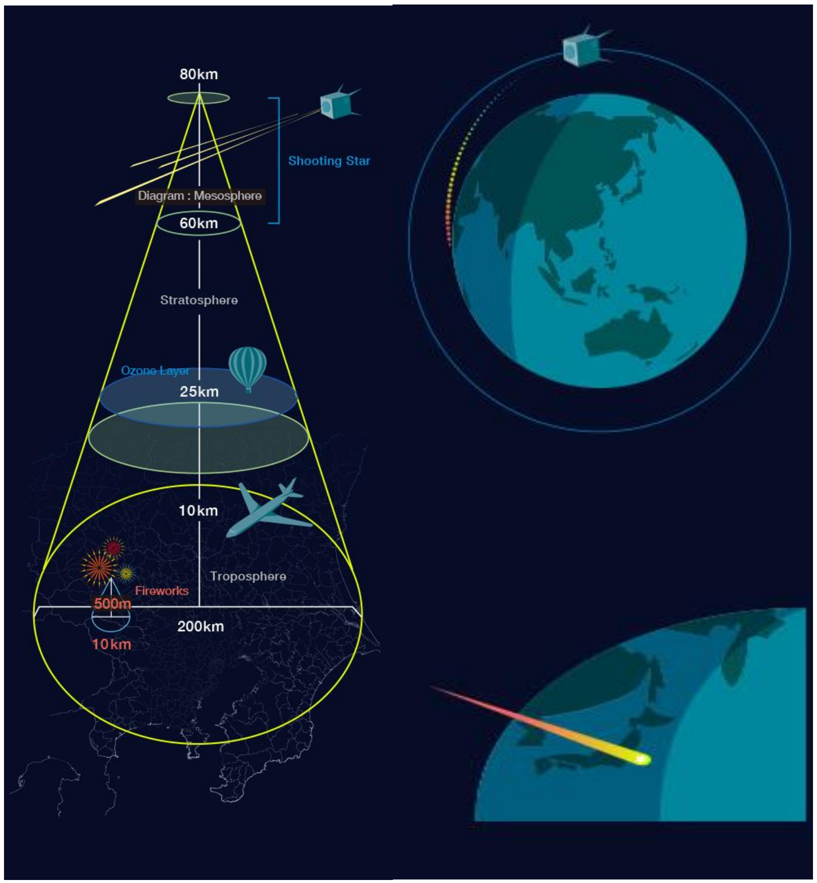
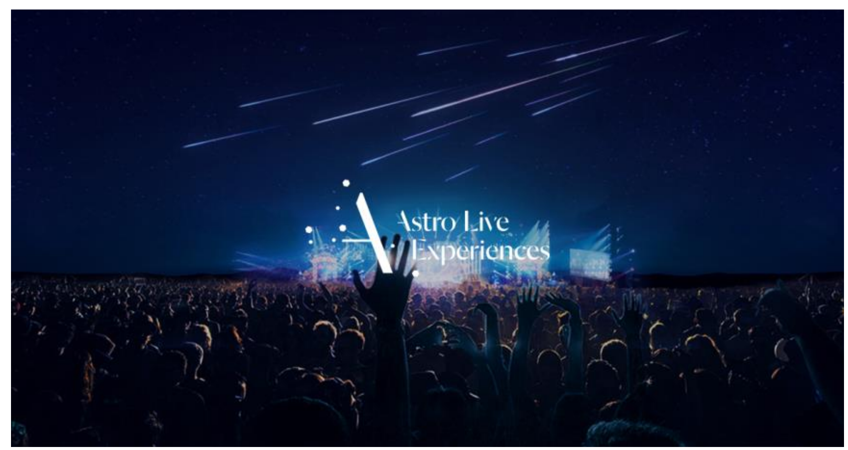
ALE Company and its Goal



Create Artificial Shooting Stars

- CubeSats loaded with tiny metal pellets
- Pellets shot from orbit down on Earth
- Pellets Burning while entering atmosphere
  → Visual effect of a shooting star
  → For entertainment purposes



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I - Context and Objectives

ALE Company and its Research Partners

Tohoku University
- Mechanical and Electronic Design
- Manufacturing
- Communications
- Orbital Calculation

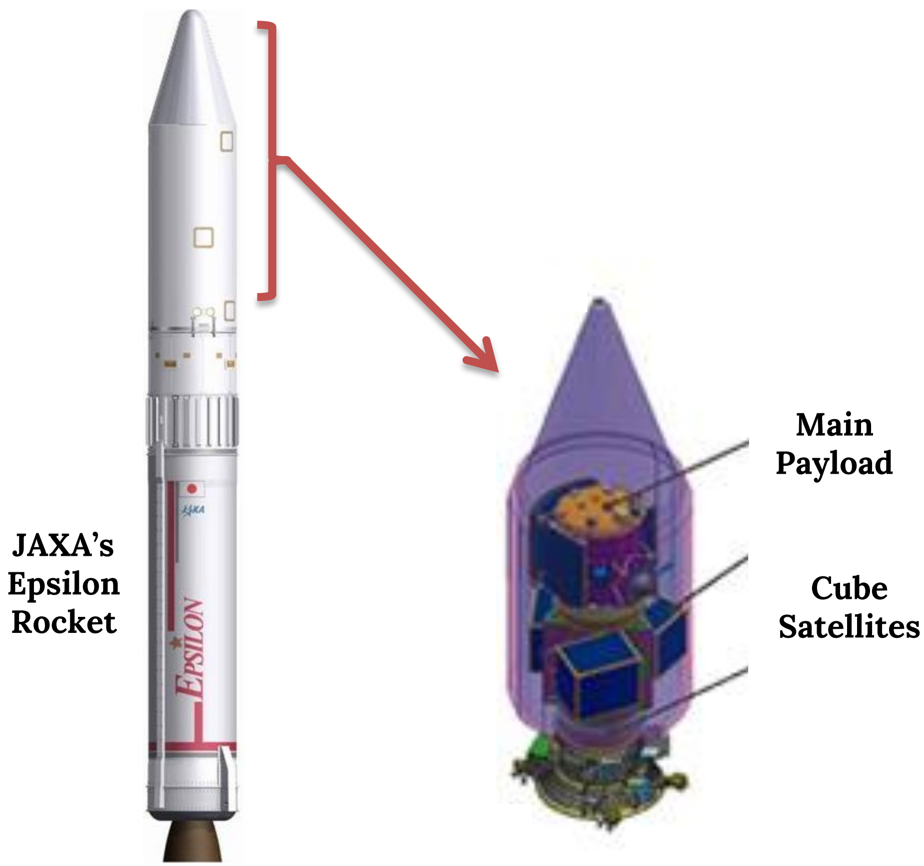
Tokyo Metropolitan University
- Thermal Analysis
- Orbital Simulation

Kanagawa Institute of Technology
- Material Analysis
- Structural Analysis

Nihon University
- Luminescence Observation
- Material Development

I - Context and Objectives

ALEe Mission



Outline

- ALEe CubeSat annexed to main payload
  → reduce launching costs (piggyback launch / ride)

- Deployment altitude fixed by main payload : 500 km
  → Above the ISS !

- Cruising altitude : 400 km
  → need for orbit decay

- Use of a Separable De-Orbiting Module (SDOM)

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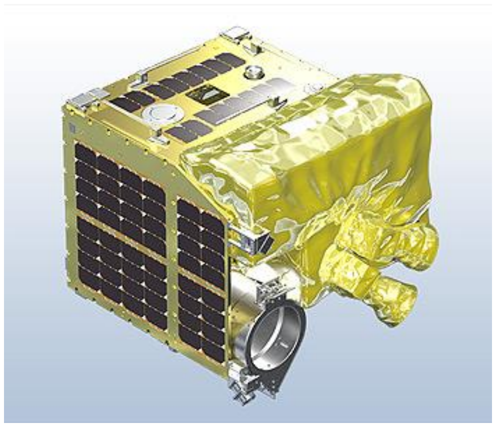
I - Context and Objectives

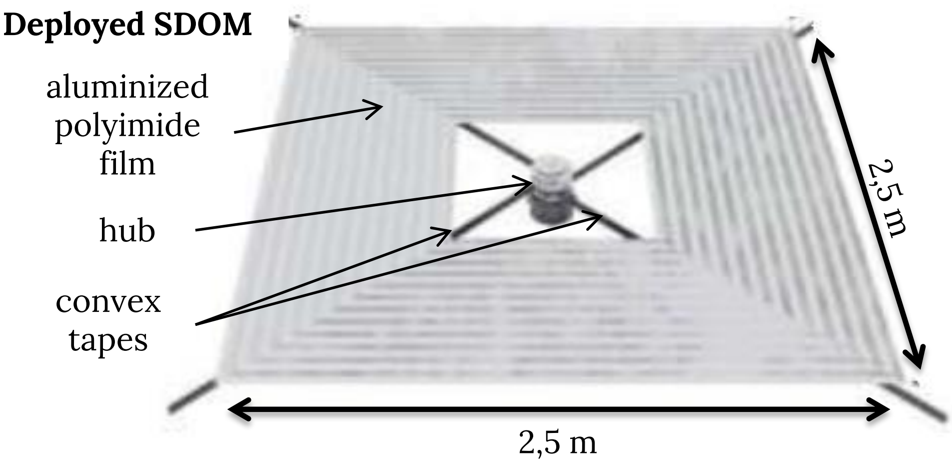
ALEe Separable De-Orbiting Module



ALEe Micro Satellite

→ Tethered to film by mast made by convex tape

Deployed SDOM



<u>Orbit Plan</u>

- 500 km :
  → Deployment of ALEe from rocket
  → Deployment of SDOM (film)

- From 500 km down to 400 km :
  → Orbit Decay thanks to atmospheric drag on the film

- 400 km
  → separation of the DOM

- From 400 km
  → Orbiting until fall on Earth

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I - Context and Objectives

Research Topic

- Build a **numerical model** of the {CubeSat + Deployed SDOM} system
- Compute the **orbit** and **attitude** of the system

Objectives

- Estimate the **behavior** of the system
- Estimate necessary **time span for orbit decay**
- **Decide** on some **dimensions** of SDOM

II – Forces for Orbit and Attitude Calculation

II.1 – Gravity

II.2 – Atmospheric Drag

II.3 – Solar Radiation Pressure

II.4 – Magnetic Field

II – Forces for Orbit and Attitude Calculation

Frame of Study

Earth-Centered Inertial (ECI)

→ $\mathcal{R}_0(\overrightarrow{e_{x0}}, \overrightarrow{\mathrm{e_{y0}}}, \overrightarrow{\mathrm{e_{z0}}})$

Orbit

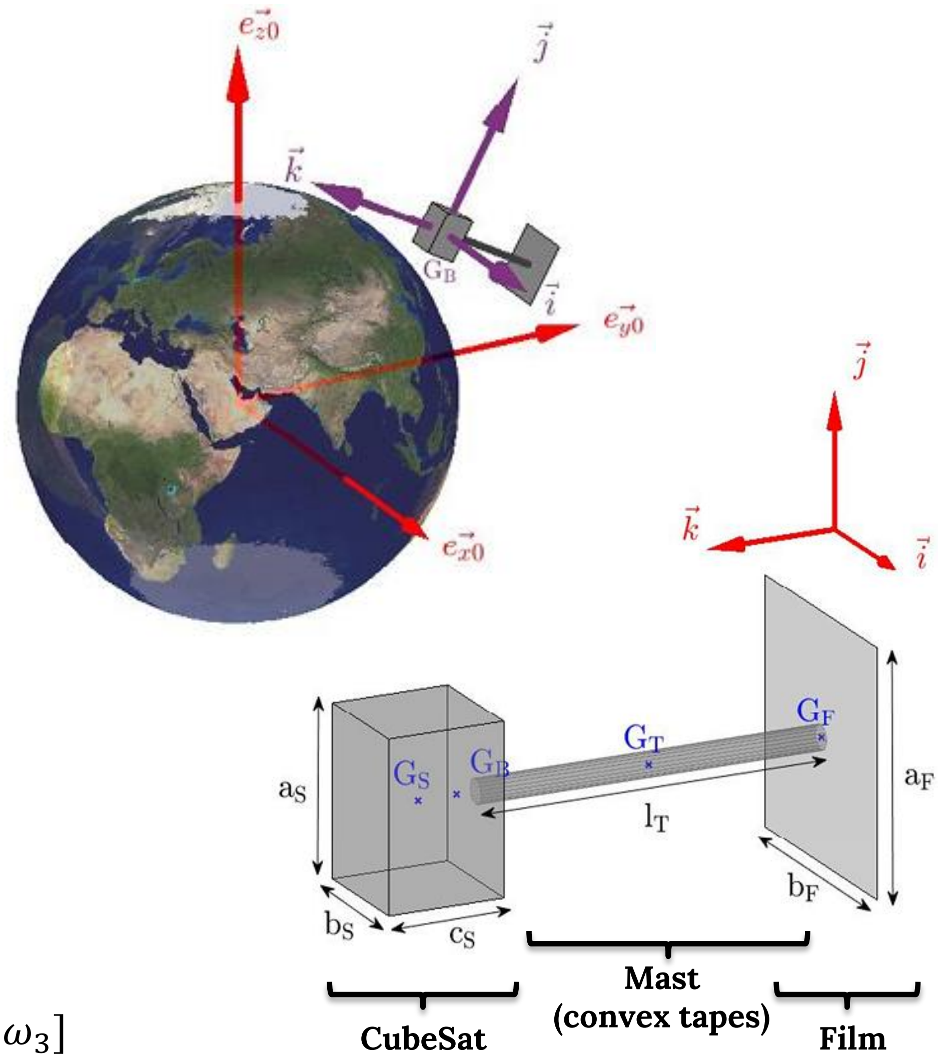
→ position : $\mathrm{R_B} = [x_B, y_B, z_B]$

→ velocity : $\mathrm{V_B} = [vx_B, vy_B, vz_B]$

Attitude

→ rotation : $\mathrm{q} = [e_0, e_1, e_2, e_3]$

→ angular velocity : $\omega = [\omega_1, \omega_2, \omega_3]$



II – Forces for Orbit and Attitude Calculation

II.1 - Gravity

For each attractor i of mass M_i whose center of mass is located at P_i, the system is subject to a force $\overrightarrow{F_{grav,i}}$ given by :

- Force : $\overrightarrow{F_{grav,i}} = \dfrac{-GM_i m_B}{\|\overrightarrow{P_iG_B}\|^3}\,\overrightarrow{P_iG_B}$
- Torque : $\overrightarrow{M_{grav,i}} = \dfrac{3GM_i}{\|\overrightarrow{P_iG_B}\|^5}\begin{pmatrix} YZ(I_3 - I_2) \\ XZ(I_1 - I_3) \\ XY(I_2 - I_1) \end{pmatrix}_{(\vec{i},\vec{j},\vec{k})}$

where

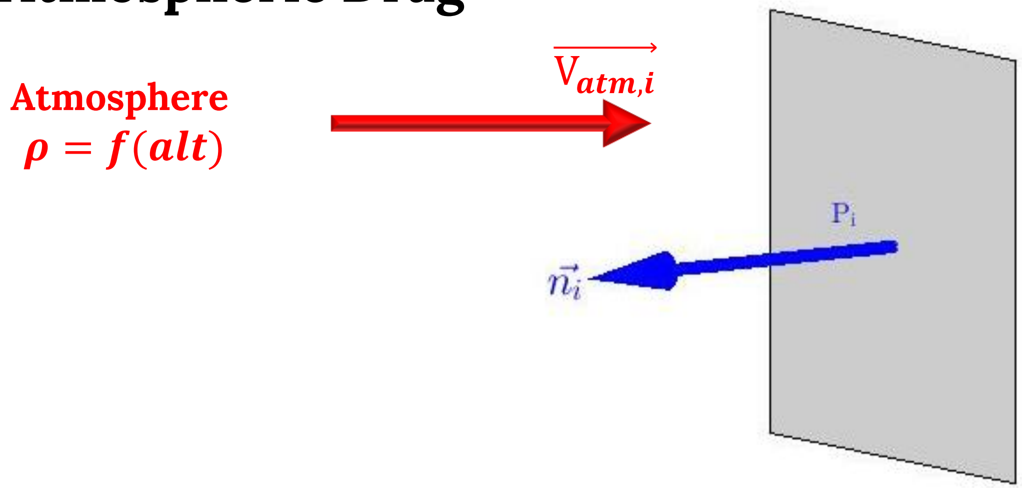
- $I_{G_B} = I(G_B)_{(\vec{i},\vec{j},\vec{k})} = \begin{pmatrix} I_1 & 0 & 0 \\ 0 & I_2 & 0 \\ 0 & 0 & I_3 \end{pmatrix}$
- $\overrightarrow{P_iG_B} = [X \quad Y \quad Z]_{(\vec{i},\vec{j},\vec{k})}$

To get the position of each attractor $i \in [|1, N|]$, we also need to solve the N-body problem :

$$\forall\ i \in\ [|1,N|],\quad \overrightarrow{a_i}\ =\sum_{j\,\in\,[|1,N|]\setminus\{i\}}\overrightarrow{q_{j\longrightarrow i}}$$

II – Forces for Orbit and Attitude Calculation

II.2 – Atmospheric Drag



- Force : $$\overrightarrow{F_{drag,i}} = \begin{cases} -\frac{1}{2} c_{D_i} \rho A_i \left\| \overrightarrow{V_{atm,i}} \right\|^2 \cos(\alpha_i) \, \overrightarrow{v_{atm,i}} & if \ \cos(\alpha_i) < 0 \\ \vec{0} & otherwise \end{cases}$$

- Torque : $$\overrightarrow{M_{drag,i}} = \overrightarrow{G_B P_i} \wedge \overrightarrow{F_{drag,i}}$$

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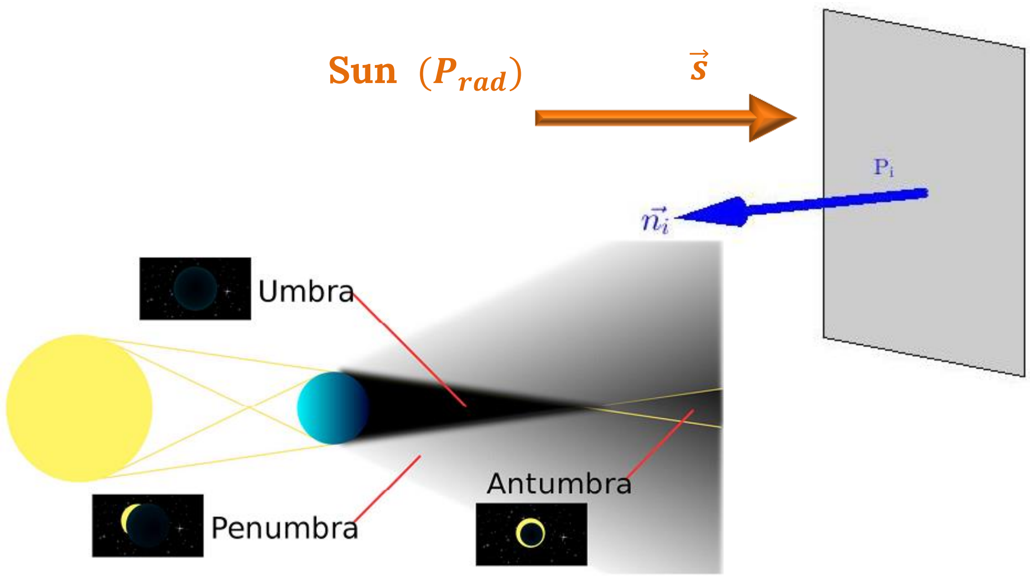
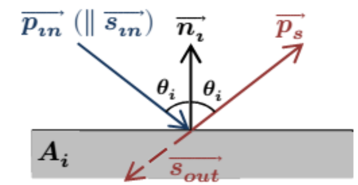
II – Forces for Orbit and Attitude Calculation

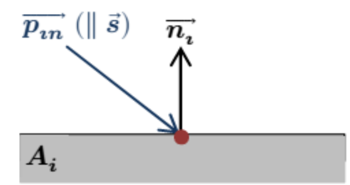
II.3 – Solar Radiation Pressure



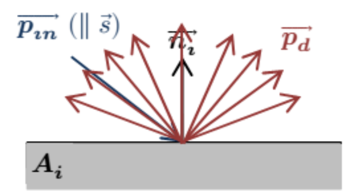
Reflection



Absorption



Diffusion

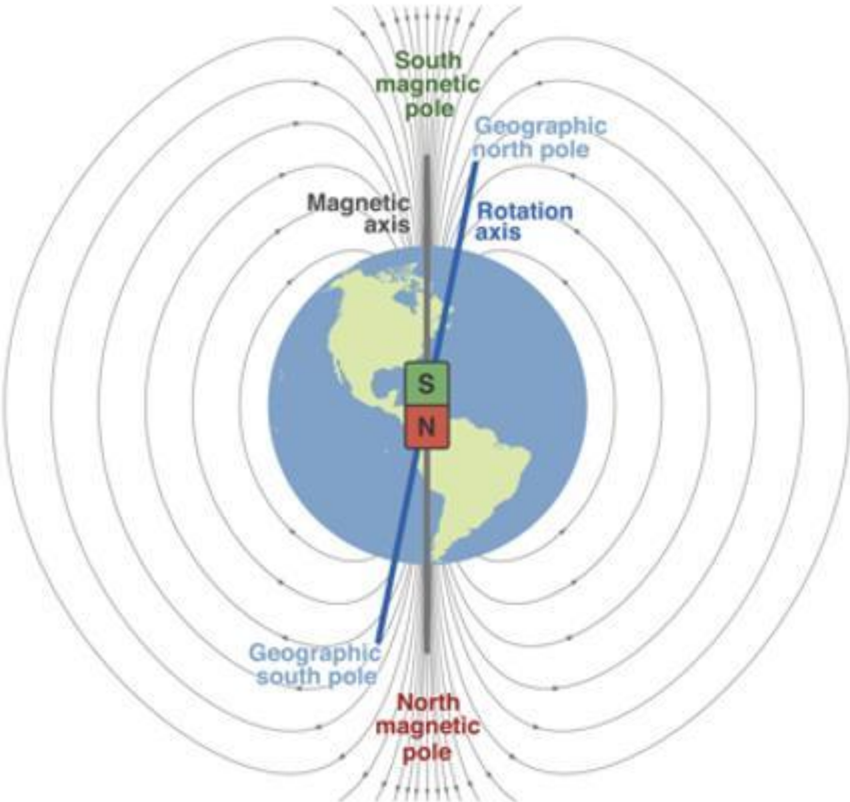


- Force : $\overrightarrow{F_{SRP,i}} = \overrightarrow{F_{a,i}} + \overrightarrow{F_{d,i}} + \overrightarrow{F_{s,i}} = \nu p_{rad} A_i \cos(\theta_i)\left[\, (1-\rho_s)\vec{s} \;-\; \left(2\rho_s \cos(\theta_i) + \frac{2}{3}\rho_d\right)\overrightarrow{n_i} \,\right]$

- Torque : $\overrightarrow{M_{SRP,i}} = \overrightarrow{G_B P_i} \wedge \overrightarrow{F_{SRP,i}}$

II – Forces for Orbit and Attitude Calculation

II.4 – Magnetic Field



Characteristics

- For LEO orbits
  → dipole approximation (11,5°)

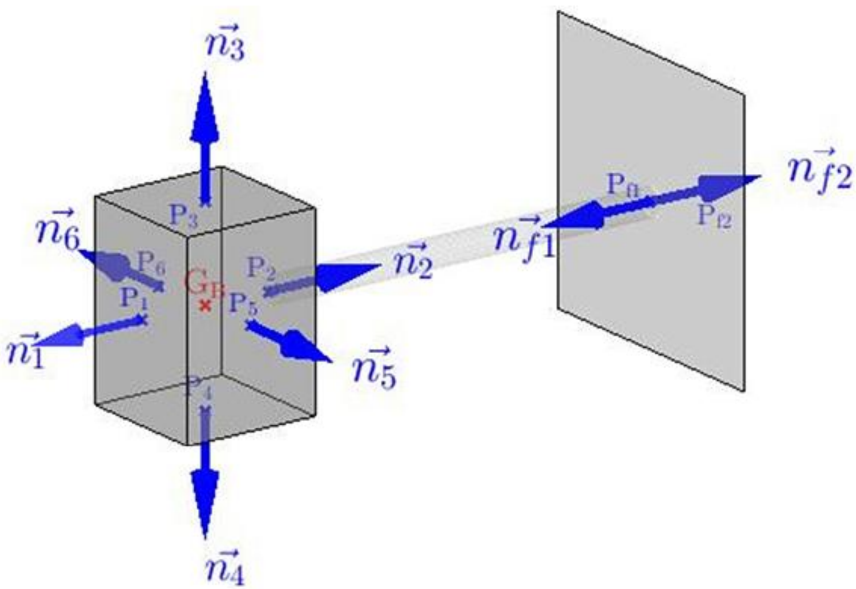
- Force on CubeSat
  → negligible

- Torque on CubeSat
  → mostly used for control

$$\vec{T}_{\text{mag}} = \vec{m} \times \vec{B}$$

III – Modeling of the satellite

III.1 – All rigid Model



- Set of Faces : $S_F = \{1, 2, 3, 4, 5, 6, f_1, f_2\}$
- Drag Force : $\overrightarrow{F_{drag}} = \sum_{i \in S_F} \overrightarrow{F_{drag,i}}$
- SRP Force : $\overrightarrow{F_{SRP}} = \sum_{i \in S_F} \overrightarrow{F_{SRP,i}}$

Description

- Mass Properties
  - → mass : m_B
  - → barycenter : G_B
  - → principal axes of inertia : $BRF(\vec{\imath}, \vec{\jmath}, \vec{k})$
  - → inertia tensor : I_{G_B}
- Dimensions
  - → CubeSat : a_S, b_S, c_S
  - → Mast : l_T
  - → Film : a_F, b_F
- Orbit
  - → $\overrightarrow{a(G_B)} = \overrightarrow{F_{tot}}$
- Attitude
  - → $I_{G_B}\dot{\omega} + \omega \wedge (I_{G_B}\omega) = \overrightarrow{M_{tot}}$
  - → $\dot{q} = \frac{1}{2} \mathrm{q} \bigtriangleup \omega$
- Integration :
  - → ***Runge-Kutta 4***

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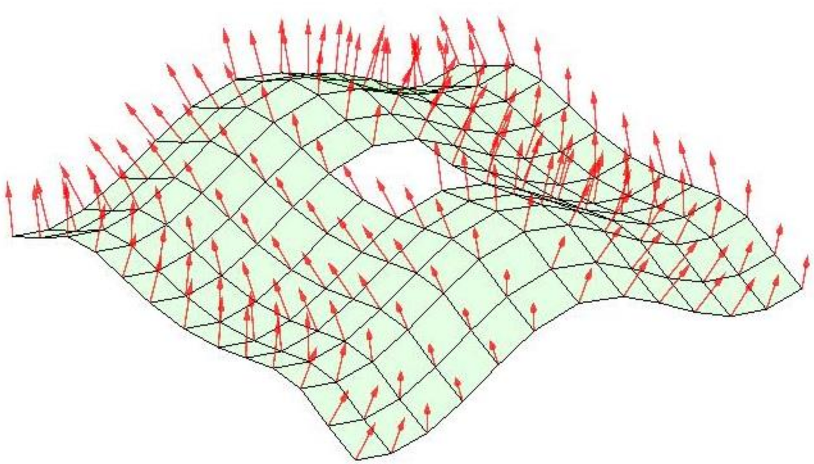
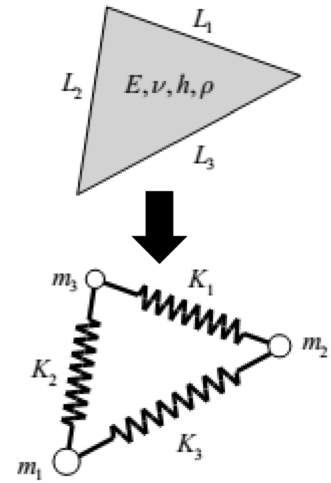
III – Modeling of the satellite

III.2 – Flexible Film Model



- Set of Faces : $S_F = \{1, 2, 3, 4, 5, 6\} \cup \{f_{i,j}^1, f_{i,j}^2\}$
- Drag Force : $\overrightarrow{F_{drag}} = \sum_{i \in S_F} \overrightarrow{F_{drag,i}}$
- SRP Force : $\overrightarrow{F_{SRP}} = \sum_{i \in S_F} \overrightarrow{F_{SRP,i}}$

Description



- Mass Properties
  → (IDEM)
- Dimensions
  → (IDEM)
- Flexible Film
  → meshing
  → mass-spring network
  → internal forces
- Orbit
  → $\boldsymbol{a}(\overrightarrow{\boldsymbol{G_B}}) = \overrightarrow{\boldsymbol{F_{tot}}}$
- Attitude
  → $\boldsymbol{I_{G_B}}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \wedge (\boldsymbol{I_{G_B}}\boldsymbol{\omega}) = \overrightarrow{\boldsymbol{M_{tot}}}$
  → $\dot{\boldsymbol{q}} = \frac{1}{2}\mathbf{q} \triangle \boldsymbol{\omega}$
- Integration :
  → ***Runge-Kutta 4***

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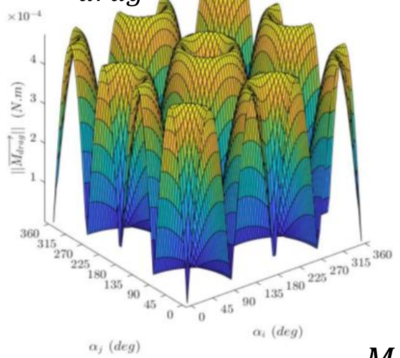
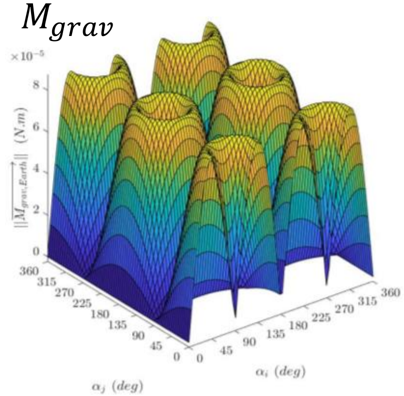
IV – Results and Discussions

Forces and Torques

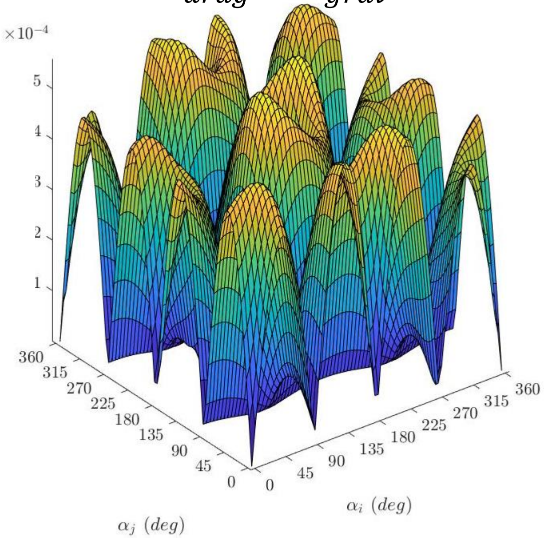
M_{drag}



M_{grav}



$M_{drag} + M_{grav}$



Results

- Dominant forces between 500km and 400km of altitude :
  → Gravity
  → Air Drag

- Drag and Gravity :
  → stabilizing attitude

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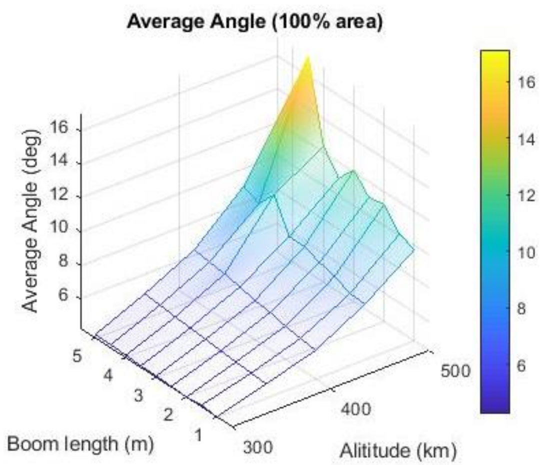
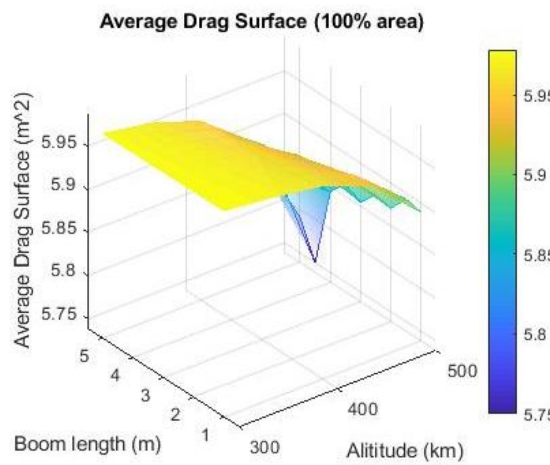
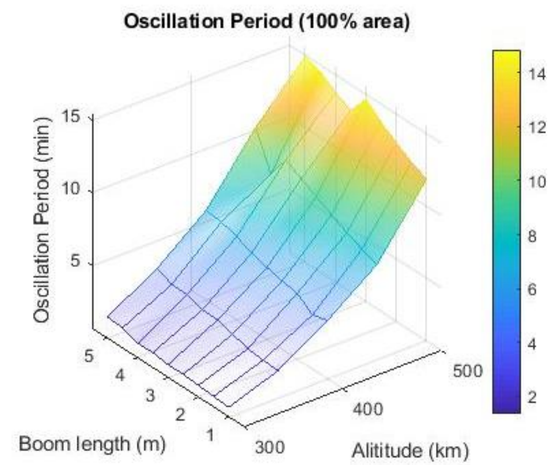
IV – Results and Discussions

Forces and Torques



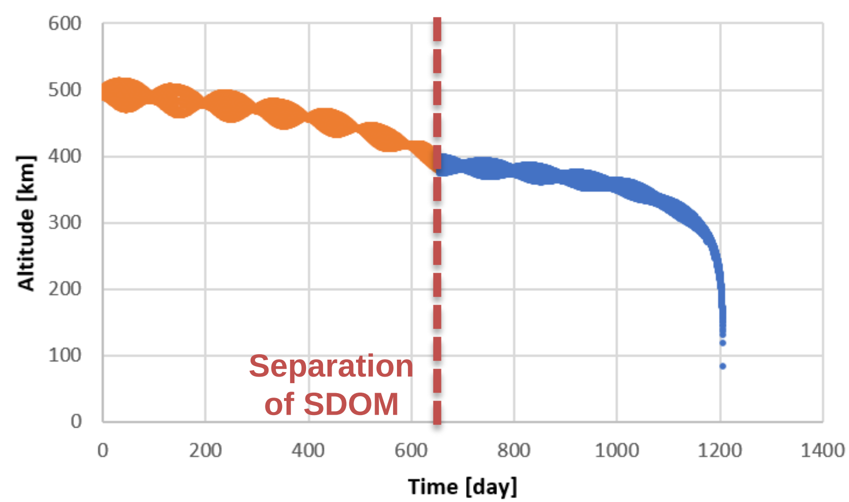




<u>**Length of the mast (convex tapes)**</u>

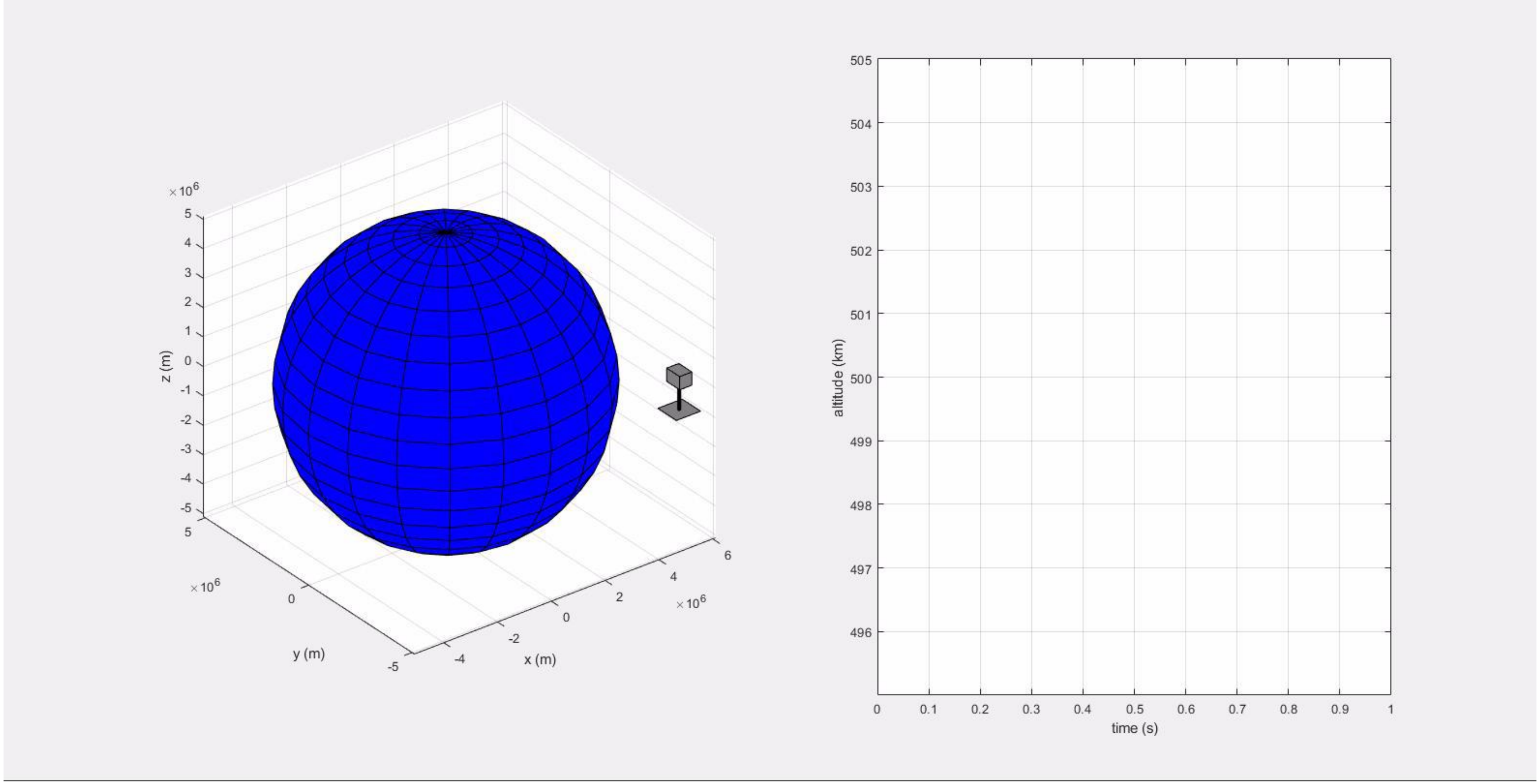
- Goal
  - → Minimize time span for orbit decay
  - → Maximize average effective drag surface

- Choice
  - → Parameter Analysis (length, altitude)



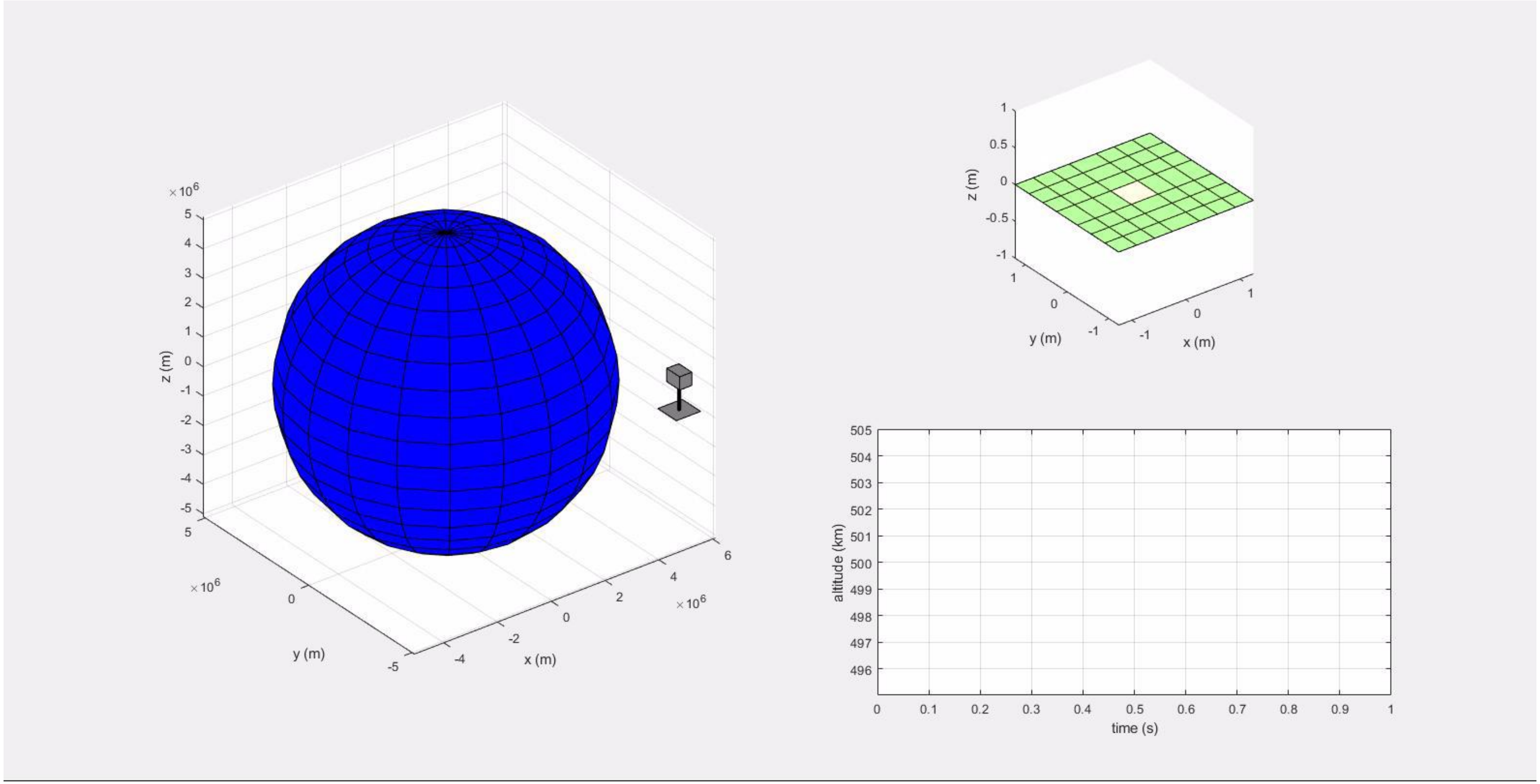
IV – Results and Discussions

Motion – Rigid Model



IV – Results and Discussions

Motion – Flexible Film Model



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Questions ?