Perturbations and Momentum dumping

Trade Study Number – A0005

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Purpose of Trade Study (Foresee)

The purpose of this trade study is to determine the sources of perturbations and their significance which would affect the control torques required from the active ACS. Further, it will assume a need for momentum dumping to desaturate the reaction wheels and determine the torque needed to carry this out. Lastly, we shall look at different strategies for momentum dumping.

Investigation

Perturbation

Thee major sources of perturbations shall be considered:

1. Aerodynamic forces at 500 km orbital altitude[1]
2. Solar radiation torque[2]
3. Magnetic field[2]

Gravity gradient torques shall not be considered for perturbation study as previous trade studies resulted determined gravity gradient as a means of stabilization.

Aerodynamic Forces

Aerodynamic forces have been shown to have a significant impact on the attitude of satellites within a 650 km orbital altitude. (ref) these forces lead to drag and reduction in altitude of the CubeSats. This force is calculated as follows:

$$f_{atm}^{s} = C_a^s \begin{bmatrix} 0 \\ \frac{1}{2}\rho v^2 C_d A \\ 0 \end{bmatrix} \tag{1}$$

Where, ρ is the atmospheric density, v is the CubeSats tangential velocity, C_d is the coefficient of drag and A is the total surface area of the spacecraft in motion.

Further, C_a^s is the orbit frame rotation matrix and is calculated as,

$$C_a^s = \begin{bmatrix} \frac{p}{r} & \mathrm{esin(v)} & 0 \\ -esin(v) & \frac{p}{r} & 0 \\ 0 & 0 & \frac{pv}{h} \end{bmatrix}$$

(2)

Where h is the angular momentum, p is the latus rectum, v is the true anomaly, and e is the eccentricity of the orbit.

Solar Radiation Torque

This is the torque on the CubeSat due to solar radiation and particles hitting the faces of the satellite. It is calculated as follows,

$$\tau_s = F(c_p - c_g) \tag{3}$$

$$F = \frac{F_s}{c} A_s(1+q)\cos(\beta) \tag{4}$$

Where, F_s = 1367 W/m^2 is the solar constant, c is the speed of light, A_s is the surface area of exposed face, c_p is the center of pressure, c_g is center of gravity, q is the reflectance factor, and β is the angle of incidence of sun.

Magnetic Field

Residual magnetic dipole due to electronic components inside the CubeSat may result in interactions with the Earth's magnetic field. The torque produced due to this interaction is calculated as follows:

$$\tau_s = DB \tag{5}$$

Where D is the residual dipole of the CubeSat and B is the Earth's magnetic field.

Momentum Dumping

Perturbations cause parasitic torques on the satellites. To counteract these torques, the reaction wheels need to spin and produce a counter torque to nullify it. Over time, reaction wheels get saturated due to the acceleration and are no longer to perform their attitude maneuvering capabilities. To desaturate the wheels, a momentum dumping strategy needs to be put into place for the wheel to function again.

For the firelock CubeSats, 3 magnetic torquers shall be used for performing momentum dumping. These torquers will be aligned with the axis of the momentum wheels for a simple and efficient design.

In order for magnetic torquers to perform momentum dumping, they must produce a higher torque than the sum of torques due to the perturbing forces. Magnetic torquers use the Earth's magnetic field to function. The field strength decreases as a function of height shown below:

$$B = \frac{m_d}{r^3} \tag{6}$$

Where r is the radial distance from center of the Earth and m_d = 7.96 x 10^{15} Wbm is the magnetic dipole strength of the Earth.

To calculate the total torque produced by specific magnetometers can be calculated as follows:

$$\tau_a^b = m \, x \, B \tag{7}$$

Where m is the magnetic moment produced by the magnetic torquers and can be calculated as $m = i_c NA$, where i_c is current supplied, N is no. of turns in the coil and A is coil area.

To analyze if a torquer can be used, we sum up the perturbation torques and compare its value to the torque value that our choice of magnetic torquer can produce, or find a torquer that can produce the stipulated value of torque.

Record

Using the mathematical models shown and metrics for constant derived parameters (ρ, q etc) from previous mission[3], we calculated the maximum perturbation torques that the CubeSats could experience:

SOURCE	APPROXIMATE MAXIMUM TORQUE (Nm)
Aerodynamic Drag	1.557×10^{-7}
Solar Radiation Torque	0.2305×10^{-7}
Magnetic field	10×10^{-7}
TOTAL	**~1.1787×10^{-6}**

Next, research was done to make a list of state of the art COTS magnetic torquers and their torque production capabilities were recorded for final decision making:

MAGNETIC TORQUER	AVERAGE TORQUE CAPABILITY (Nm)	MASS (kg)	POWER (mW)	LINK
MT01- compact magnetorquer	4.6624×10^{-6}	0.0075	250-750	https://www.cubesatshop.com/product/mt01-compact-magnetorquer/
NCTR-M002 Magnetorquer rod	4.9078×10^{-6}	0.03	200 at 5V	https://www.cubesatshop.com/product/nctr-m002-magnetorquer-rod/
NCTR-M012 Magnetorquer rod	2.9201×10^{-5}	0.05	<800	https://www.cubesatshop.com/product/nctr-m012-magnetorquer-rod/

According to the research, all the above mentioned magnetic torquers provide the torque capability required for desaturation of reaction wheels caused by perturbation forces. However, while MT01 weighs less that NCTR-M002, it consumes more power. Since our power budget is more restricted than our mass budget, we shall choose to incorporate 3 NCTR-M002 magnetorquer rods for momentum dumping.

Execute

Signatures:

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Subteam Liason(s): ____

Team Lead: ____

References

[1] https://www.jossonline.com/wp-content/uploads/2014/12/0201-Aerodynamic-Stability-for-CubeSats-at-ISS-Orbit.pdf
[2] https://www.researchgate.net/publication/251889729_Reaction_wheel_design_for_CubeSats
[3] https://pdfs.semanticscholar.org/5341/6df42ae8a000dafcc121b5463e5c6e44df56.pdf