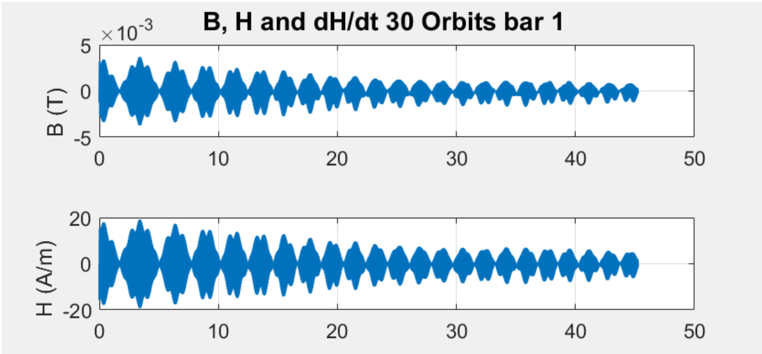
Homework PAE 8

Exercise 1.

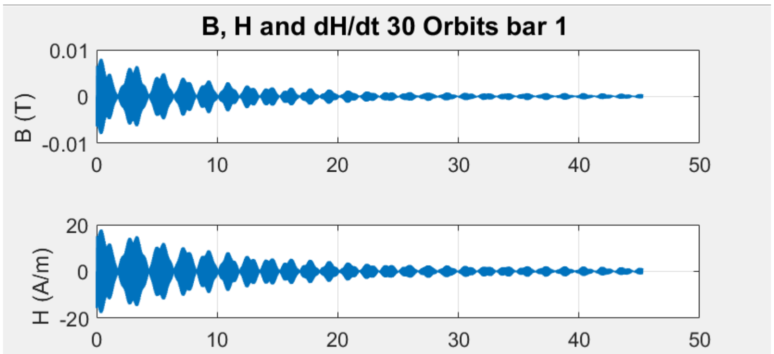
1.1. The parameter that changes between the 3 simulations is the “coercive force”.

The coercive force is a measure of how long an external magnetic field has to be applied to a material in order for it to lose its magnetic properties. Thus, it is only logical that, the lower the value (in descending order: 12, 6 and 3 A/m respectively), the graphs which show the magnetic flux density (B) and the magnetic field intensity (H) will have values which tend to 0 faster, as shown below.

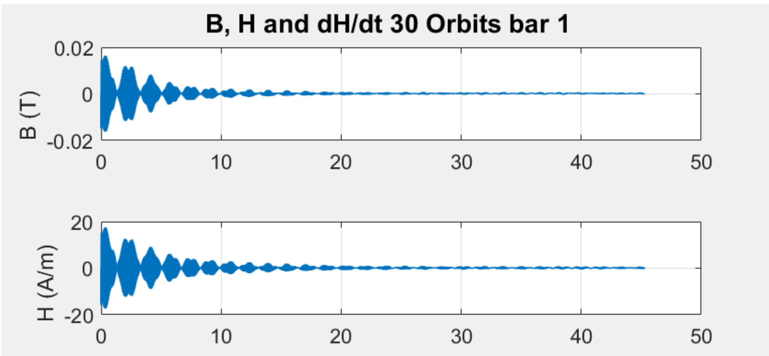
Fc = 12 A/m:



Fc = 6 A/m:



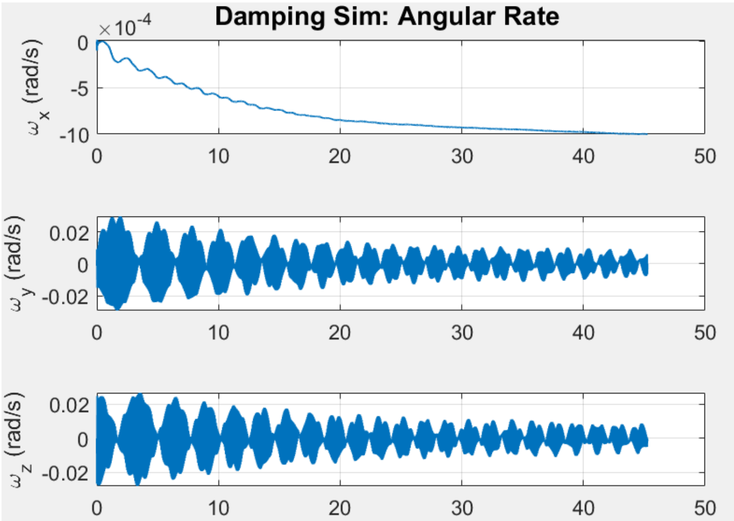
Fc = 3 A/m:



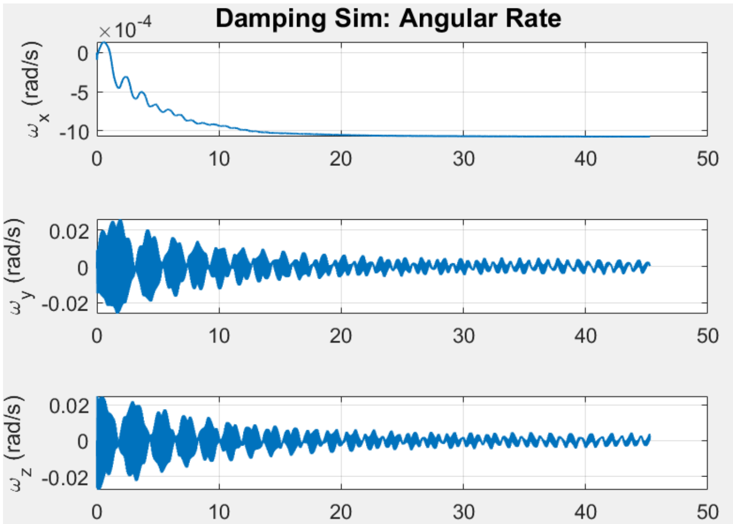
a) Let's now take a look at the graphs for the angular rate, the dipole torques and the angle with respect to Earth's magnetic field:

<u>Angular Rates:</u>

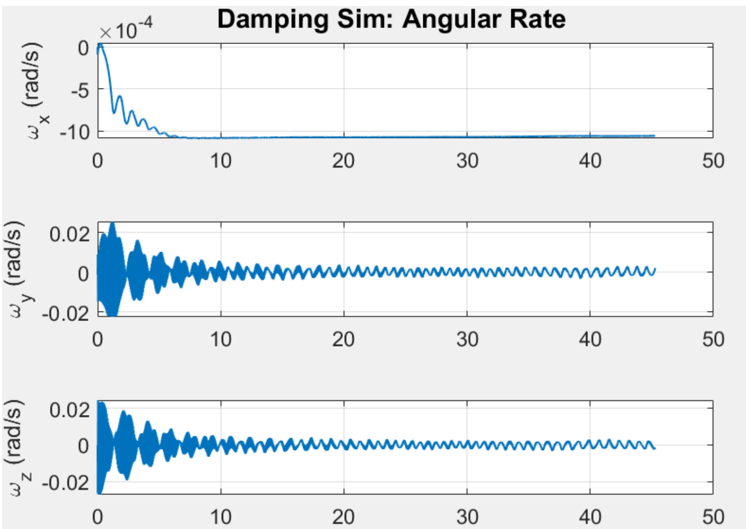
Fc = 12 A/m:



Fc = 6 A/m:

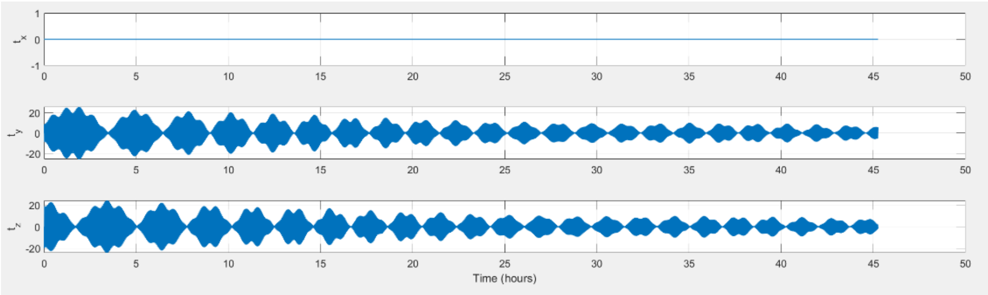


Fc = 3 A/m:

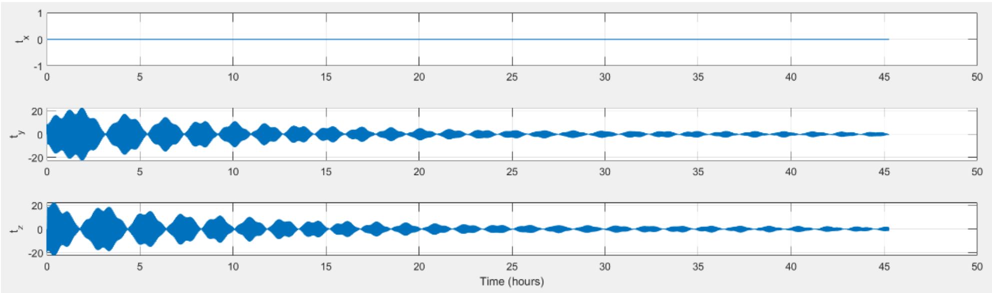


Dipole Torques:

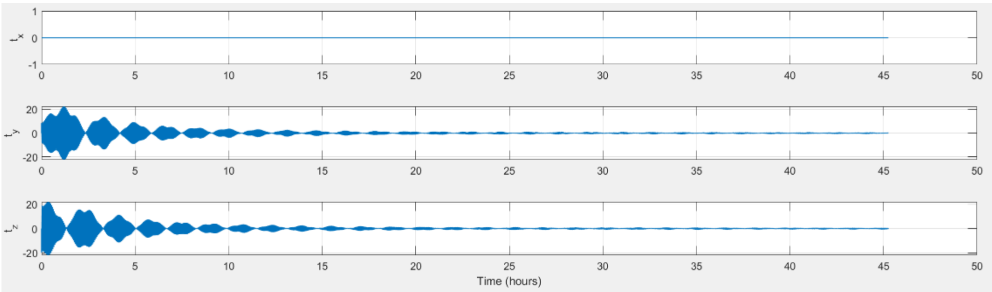
Fc = 12 A/m:



Fc = 6 A/m:

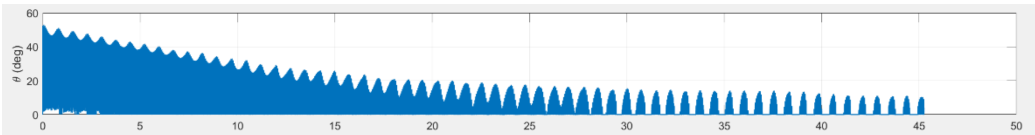


Fc = 3 A/m:

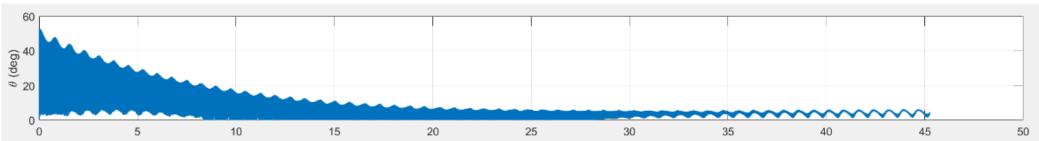


Angle to Field:

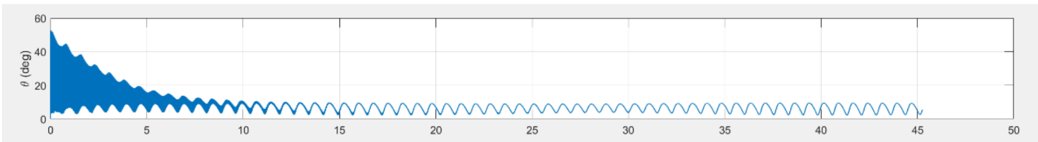
Fc = 12 A/m:



Fc = 6 A/m:



Fc = 3 A/m



We can clearly see from the graphs that, the lower the coercive force, the faster the stabilization of each of these variables. I think the main reason for this is because of the fact that a lower coercive force can be directly linked with an easier manipulation of the magnetorquers by the ADCS.
All these variables show how well a satellite is stabilized at any given moment and the coercive force is basically the "enemy" of the ADCS, opposing faster control of the magnetorquers and, in terms, slowing down the detumbling of the satellite.

b) As we can see from the graphs above, in all cases all values tend to some value asymptotically. For the angular rate, that value for the x axis is -10 rad/s, and for the y and z axes it is 0 rad/s, while for the dipole torques it is 0 (as expected) and for the angle to field that value is around 3°.

c) As we can see from the 3 graphs for the Angle to Field, the envelope for these value starts to tend to 3° and be approximately constant after some time, time which depends on the coercive force.

- For Fc = 12 A/m it is about 40 h when the envelope actually starts to look more horizontal;

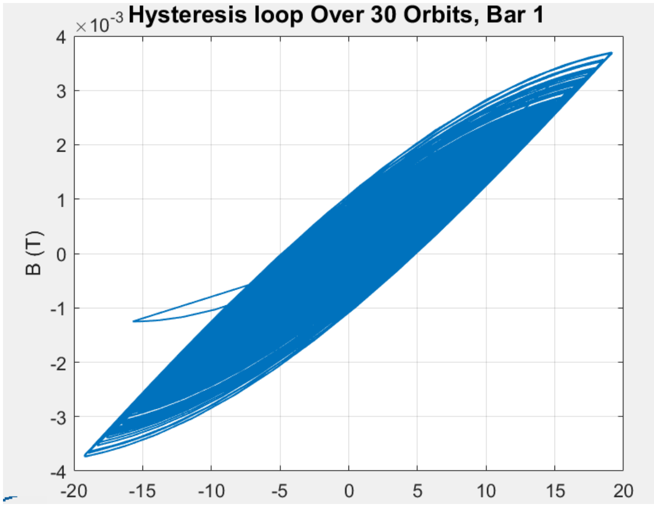
- For Fc = 6 A/m it is about 30 h when the envelope to actually look like y = 3;
- For Fc = 3 A/m it is about 15 h when the envelope actually mimics a constant.

d) As I've also said before, the asymptotic value for the angular rate on the X-axis is around -10 rad/s. There could be a lot of reasons for this, starting from intentional design to external factors.

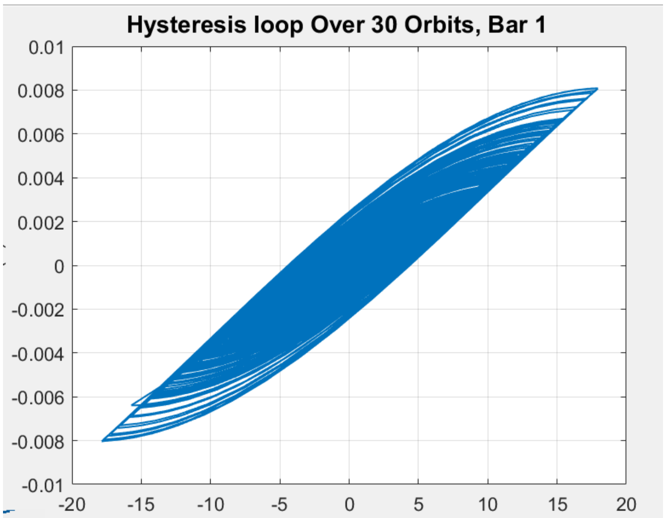
I think the most likely explanation is the existence of the VGA Camera payload, which can, because of this constant rotation, take pictures of way more of the Earth from any point, than if it was "stationary". 10 rad/s means the satellite does a full rotation in 36 seconds, which is pretty slow and means that the pictures will not be blurry but it is fast enough to capture a lot in a pretty short amount of time.

e) Let's take a look, for example, at the first Hysteresis graph for all 3 cases, since they are all similar:

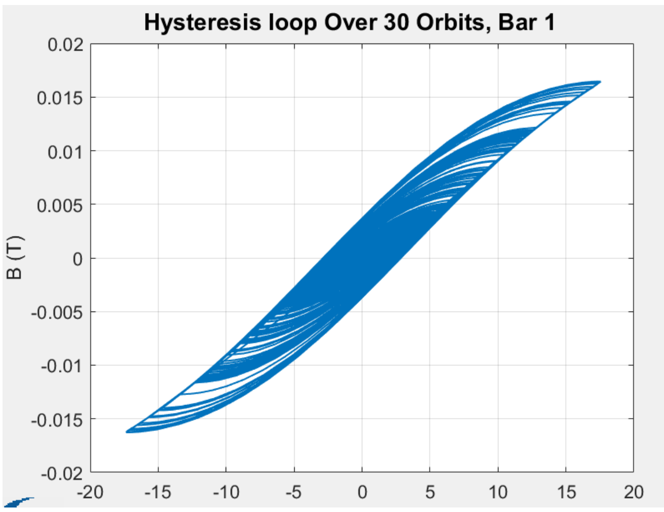
Fc = 12 A/m:



Fc = 6 A/m:



Fc = 3 A/m:



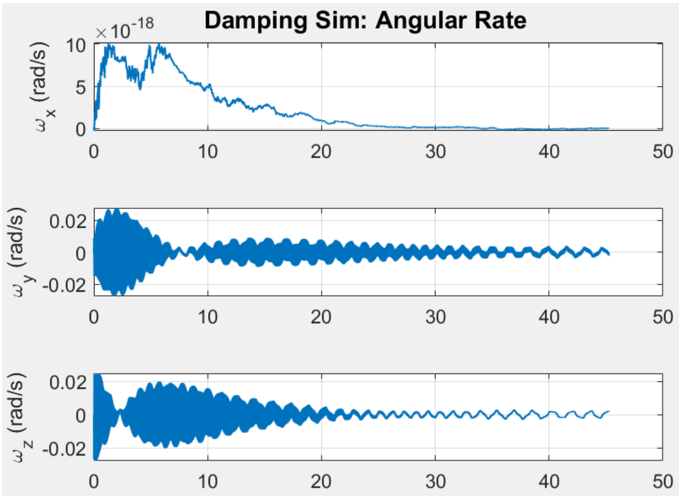
As we can see, several observations can be made about these hysteresis rods, starting with:

- Their width: Wider loops are for materials with more accentuated magnetic properties, which obviously coincides with a higher coercivity (as it can be seen);
- Their area: Smaller area corresponds with less lost energy, so the ones with lower coercivity are also the ones with less energy loss;
- Their "density": The higher the coercive force, the higher the number of individual traces. This can mean that the materials with a higher coercivity are less stable and the magnetic properties are subject to gradual changes;
- Their values: The higher the coercive force, the lower the values. This can also be proven by the fact that the value of B(H = 0) is a direct indicator of the coercive force.

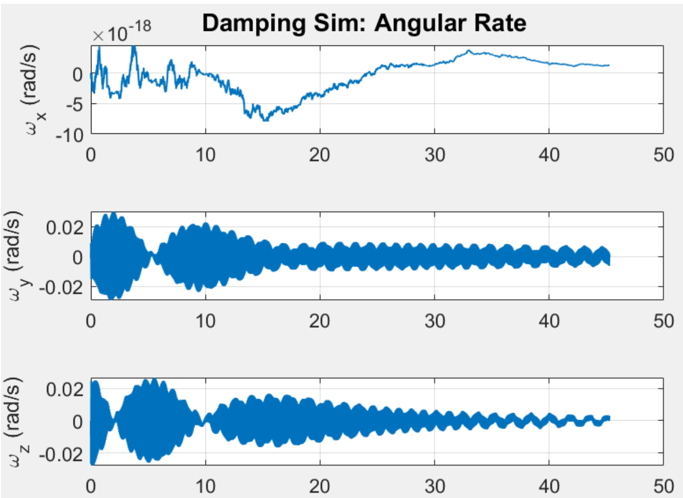
1.2. For this one, I will not show all the graphs again, just both cases of dampingData for Fc = 3 A/m, since there are a lot of them.

Angular Rates:

dampingData = 1e-6:

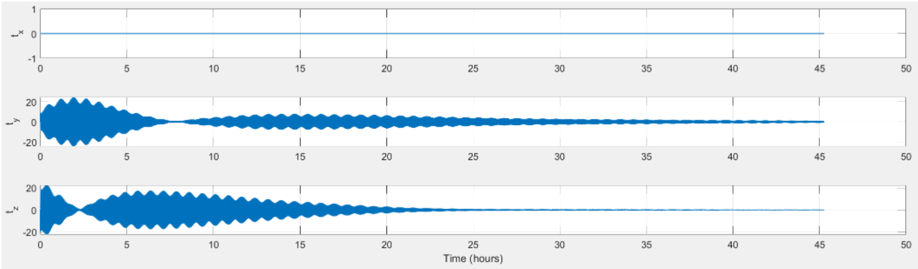


dampingData = 0.5e-6:

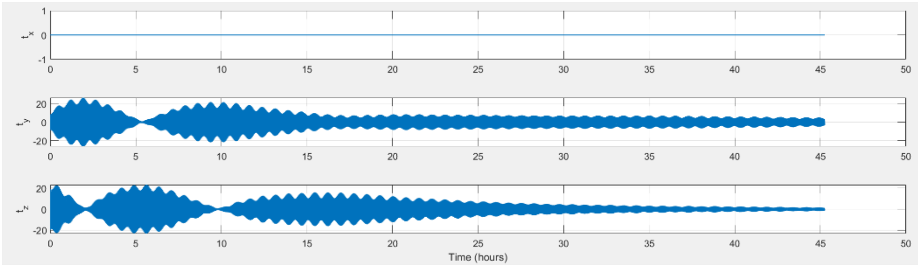


Dipole Torques:

dampingData = 1e-6:

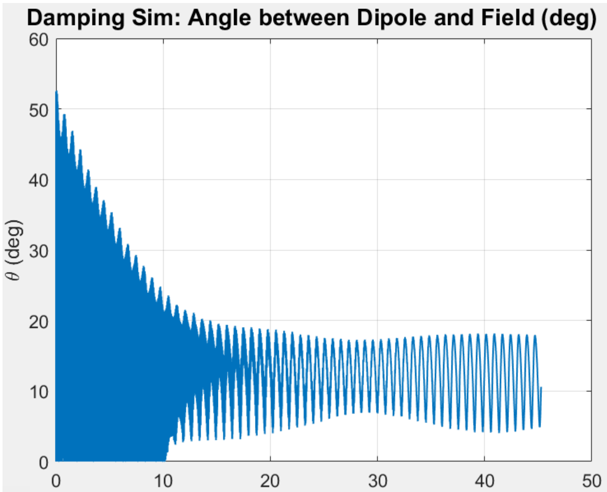


dampingData = 0.5e-6:

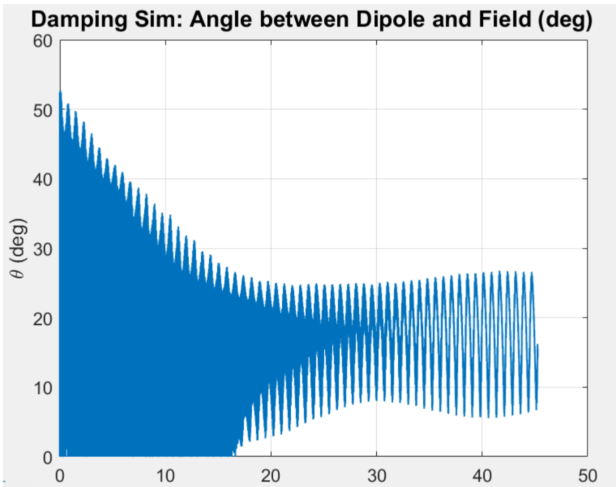


Angle to Field:

dampingData = 1e-6:



dampingData = 0.5e-6:



a), b) and c) Firstly, we need to understand what the dampingData constant stands for.

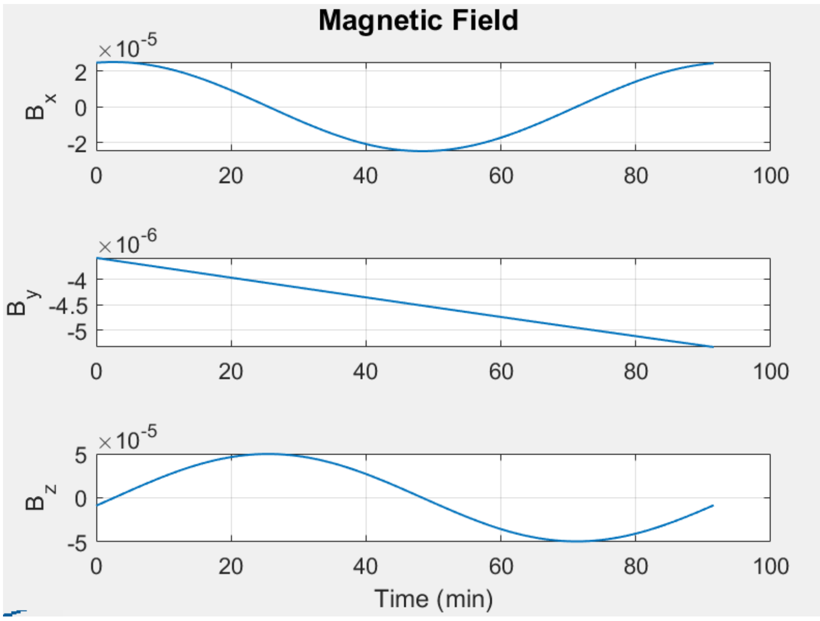
In short, the dampingData constant represents the damping constant, which is a measure of how much the oscillatory motion of the satellite is reduced by external forces. So, of course, the lower the constant the more chaotic and not asymptotic the graphs will be.

It is pretty apparent that the angular rates and the dipole torques are still asymptotically tending to values for dampingData = 1e-6, yet for the other value they are not, fact given by what the dampingData constant means.

The angle to the field, on the other hand, is not asymptotic for any value, yet it oscillates around a constant for both cases (12° for the first one and 17° for the second one). So, the envelope does not stabilize at all.

Exercise 2.

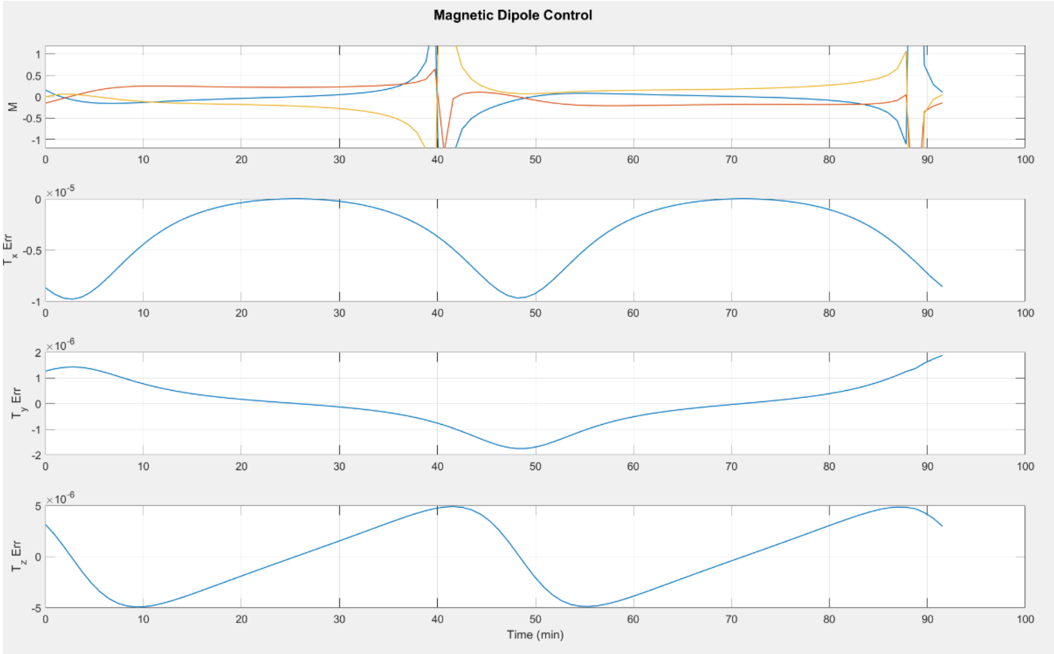
2.1. a)



The magnetic field on this satellite appears to keep its periodicity for a longer period of time on the X and Z axis, while on the Y axis it is in decline and also with a negative polarity. Having a periodic magnetic field with little to no degradation is beneficial for a satellite with magnetic control in an inclined orbit for the following key reasons:

1. Predictable Control: A consistent magnetic field allows for predictable and reliable control of the satellite's orientation using its onboard magnetic torquers.
2. Efficient Torque Generation: The satellite can efficiently generate torque at specific points along its orbit, crucial for maintaining alignment with the Local Vertical Local Horizontal (LVLH) frame.
3. Reduced Energy Loss: Minimal field degradation ensures effective use of the satellite's energy resources for attitude control.

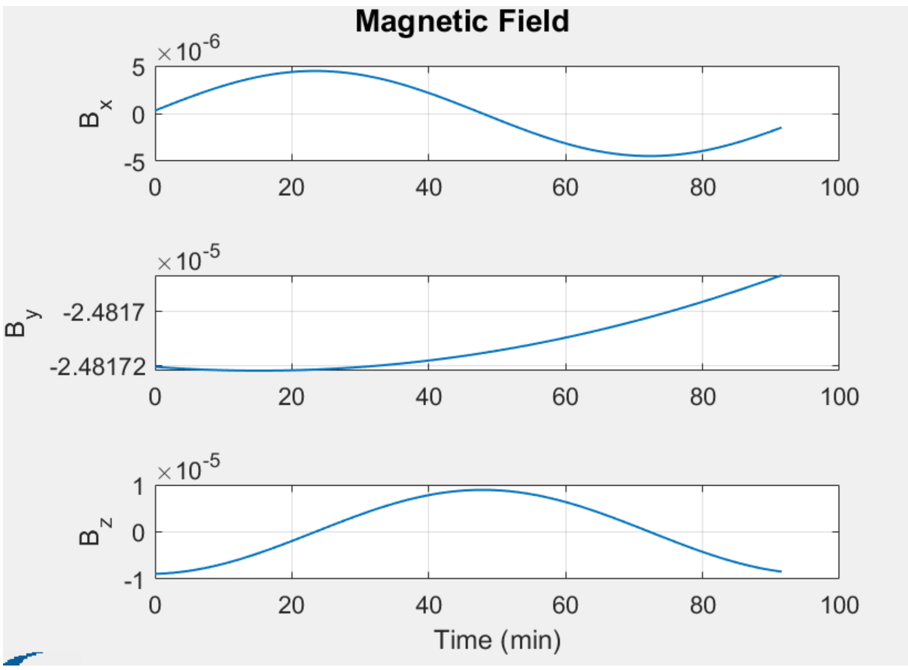
b)



As we have expected, the Magnetic Dipole control is relatively periodic, and has peak values that happen around once every 40-45 mins. The error is obviously periodic and its value is not concerningly high (around 0.5e-5 on all axis, which is good).

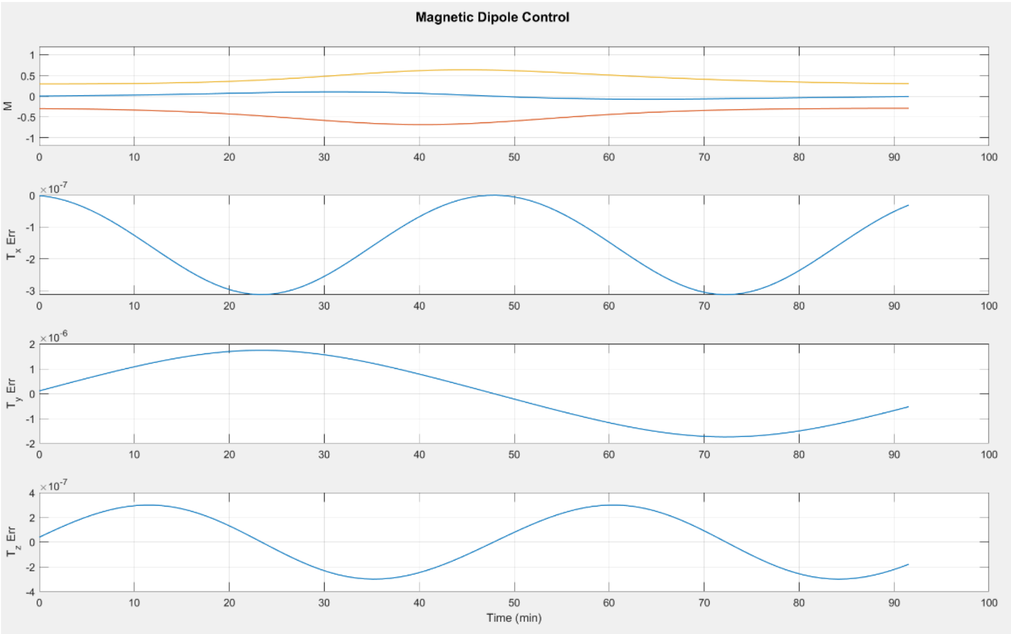
Error should always be taken into account when designing the ADCS because, with time, the errors stack up and your satellite will be completely disoriented if you don't consider them.

2.2. a)



More of the same, some good, predictable, periodic graphs. We can see how the change in orbit inclination has had opposite effects on the different axis, which makes sense. While Bx is now smaller, Bz has increased, and By is now not in decline anymore, growing infinitesimally in the period of time in which it is observed. All of this is expected behavior when you basically "rotate" the satellite relative to the Earth.

b)



Here, we can see a significant change in the shape of the graphs of the magnetic dipole control. The first graph now does not present any peaks like before, and the values of the magnetic moment (M) are more stable across the time period in which they are observed. Also, I have to mention the fact that the errors have decreased on all axis, even by 2 orders of magnitude, meaning that for magnetic dipole control this setup is more beneficial.

Exercise 3.

a) The "altitude flip" in polar regions for satellites refers to a phenomenon that occurs when satellites with magnetic attitude control systems pass over the Earth's polar regions. This effect is a result of the unique characteristics of the Earth's magnetic field near the poles. Near the poles, the Earth's magnetic field lines are nearly vertical. This differs significantly from equatorial regions, where the field lines are more horizontal.

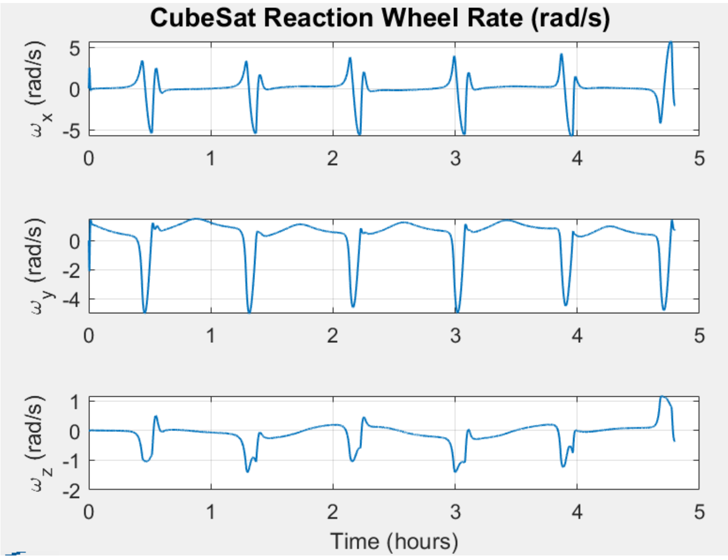
Satellites using magnetic torquers rely on the interaction between their own magnetic moment (M) and the Earth's magnetic field (B) to generate torque ($\tau = M \times B$). When a satellite crosses the polar regions, the orientation of the Earth's magnetic field changes dramatically compared to the satellite's usual operating environment.

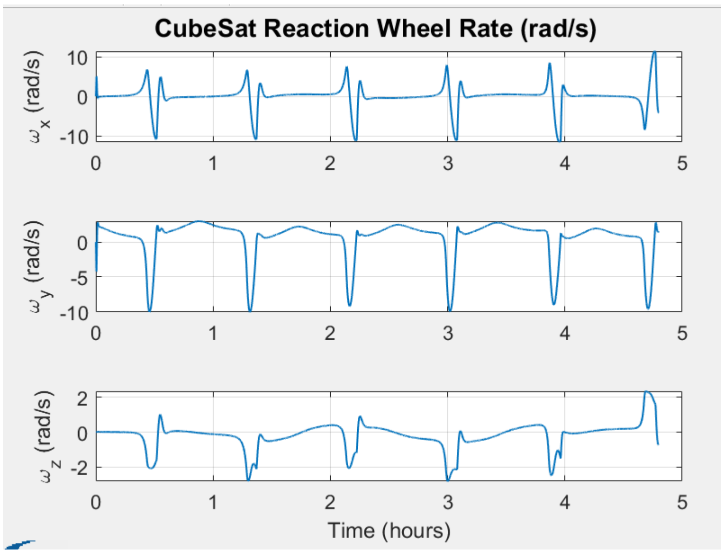
As the satellite passes over the poles, the effectiveness of the magnetic torquers in generating the desired torque can be significantly reduced due to the alignment of the satellite's magnetic moment with the Earth's nearly vertical magnetic field. The reduced effectiveness in control can lead to a situation where the satellite temporarily loses its desired orientation.

This is sometimes referred to as an "altitude flip" or "attitude flip" because the satellite might experience an unintended change in its attitude. This phenomenon poses a challenge for attitude control systems, particularly for satellites in polar or sun-synchronous orbits, which regularly pass over the polar regions.

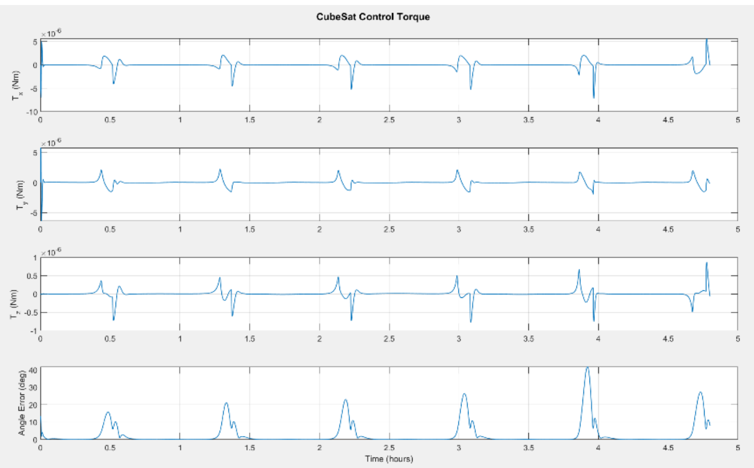
b) When changing the mass:

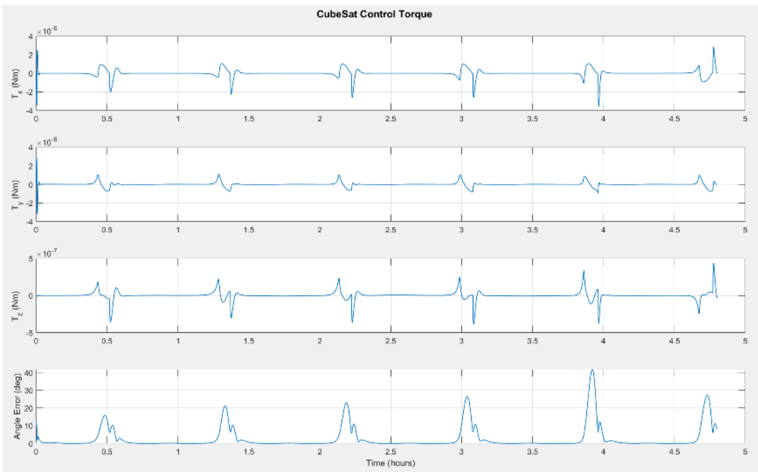
- The Reaction Wheel Rate doubles when the mass is halved:



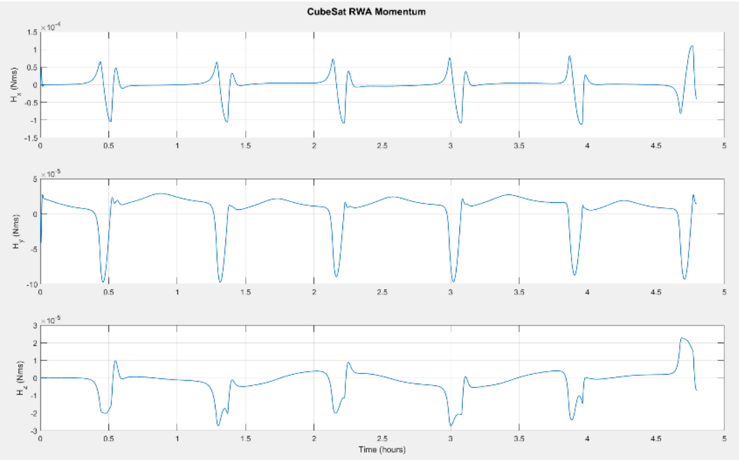


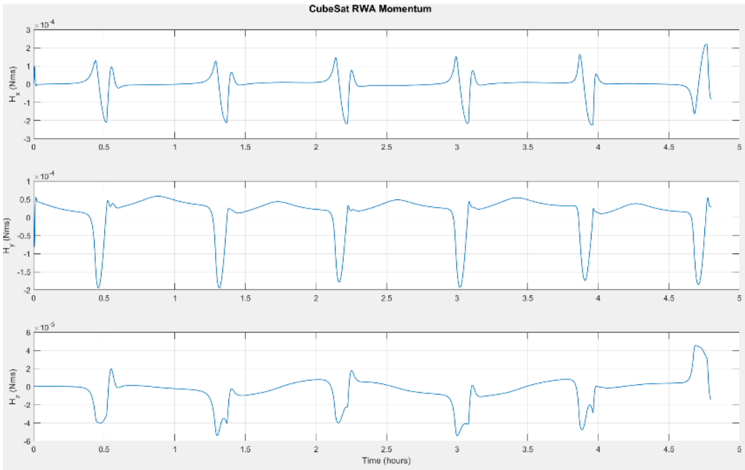
- The Control Torque doubles:





- The RWA Momentum also doubles:





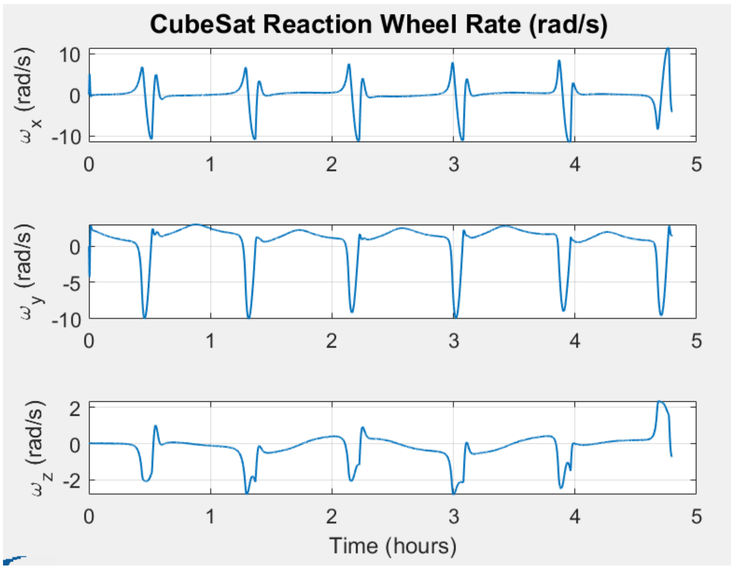
As we can seem all of these values double (as an absolute value) when the mass is halved. The really simple reason is because all of these values inversely depend on the mass.

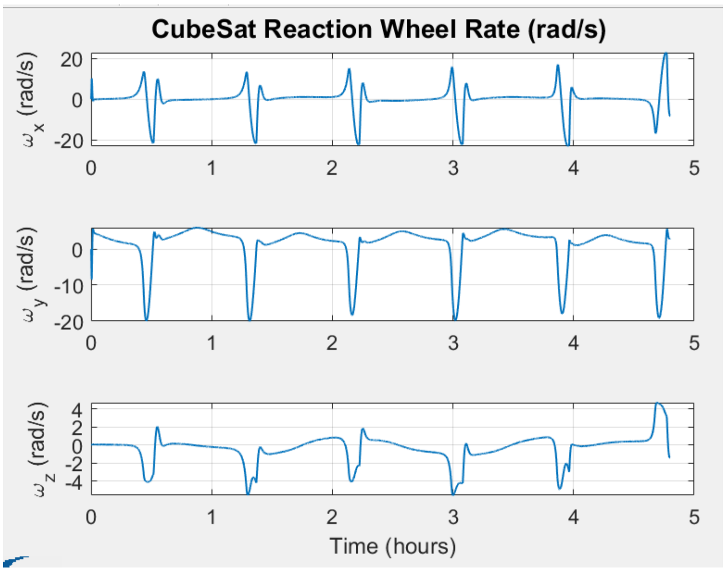
i.e.: Value = function (1 / mass).

These values depend on the mass because they are mostly mechanical units which are related to the workload that needs to be put in order for something to happen, and that always depends on the mass of the object.

When changing the thickness:

- Only the Reaction Wheel Rate doubles:

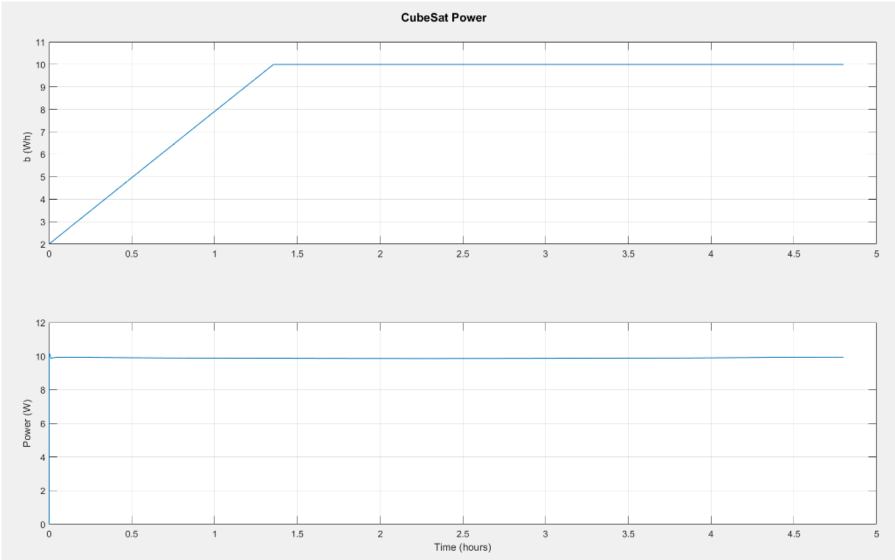




This happens because material thickness is directly linked with inertia (higher thickness, higher inertia) so, obviously, a wheel twice as thin has to spin twice as fast.

c) Changing a satellite's orbit from a polar to an equatorial orientation impacts various parameters due to differences in Earth's magnetic field, gravitational forces, and solar exposure. Taking them one by one:

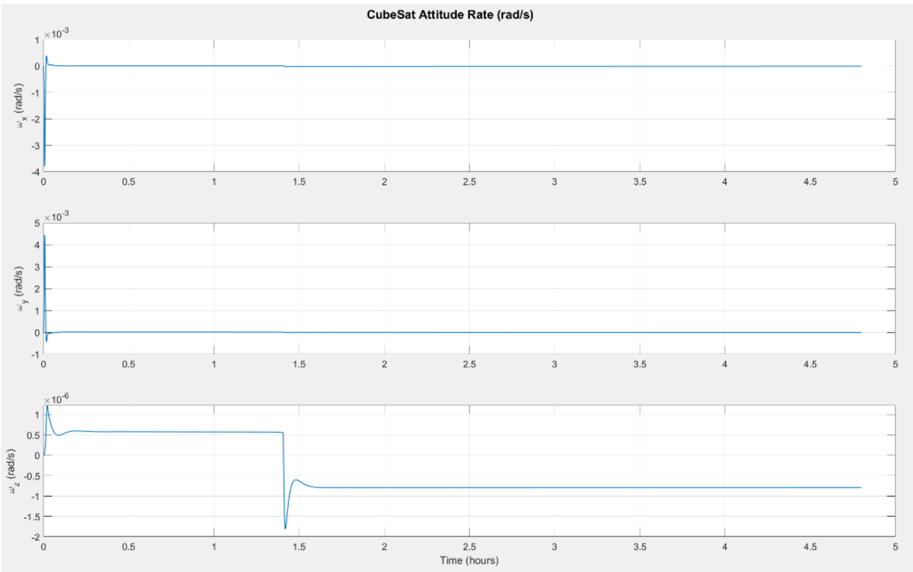
1. Power:



The power generation of a satellite, primarily through its solar panels, is influenced by its exposure to sunlight, which varies between polar and equatorial orbits.

In equatorial orbits, especially geostationary, the satellite might have more consistent sunlight exposure, potentially leading to more stable power generation but also requiring careful thermal management due to continuous exposure.

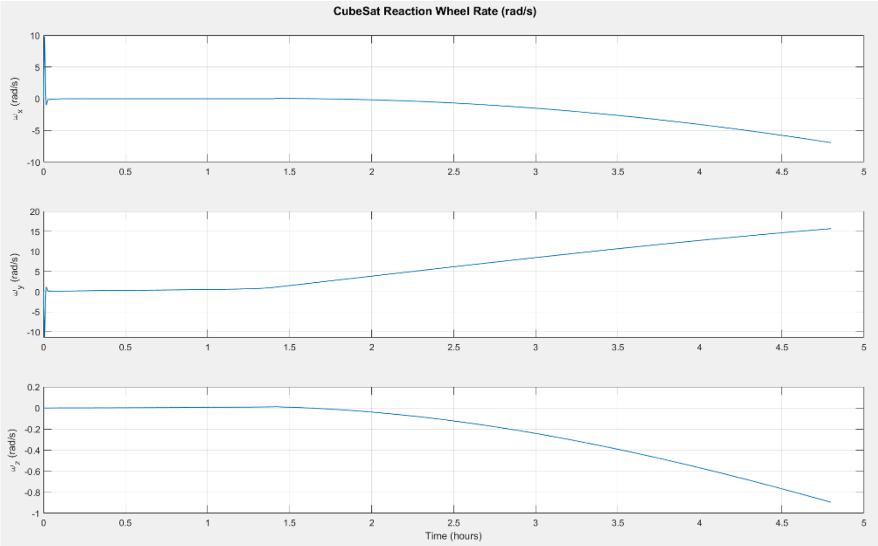
2. Attitude Rate:



In a polar orbit, a satellite often experiences a consistent sunlight pattern and Earth's rotation beneath it. In an equatorial orbit, however, the satellite's orientation relative to the Earth and Sun changes more significantly over each orbit, potentially requiring more frequent or different attitude adjustments.

The attitude rate adjustments might be more dynamic in an equatorial orbit to maintain proper orientation for communication, solar panel alignment, or sensor targeting.

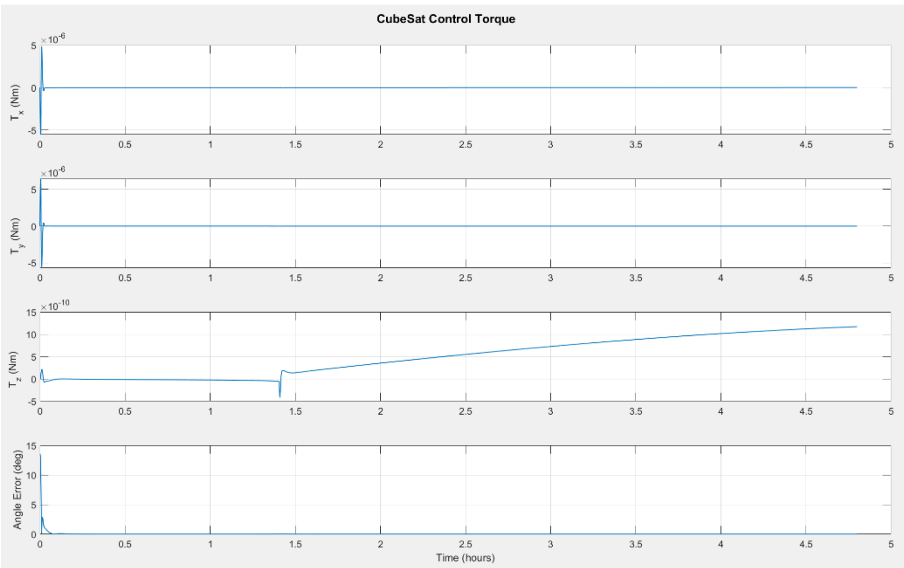
3. Reaction Wheel Rate:



Reaction wheels control the satellite's orientation by spinning at controlled rates. The rate change needed to maintain or alter attitude will differ between orbits due to varying gravitational forces and inertial properties.

The satellite in an equatorial orbit might require less frequent but more substantial adjustments to maintain a geostationary position relative to Earth, affecting how the reaction wheels are used.

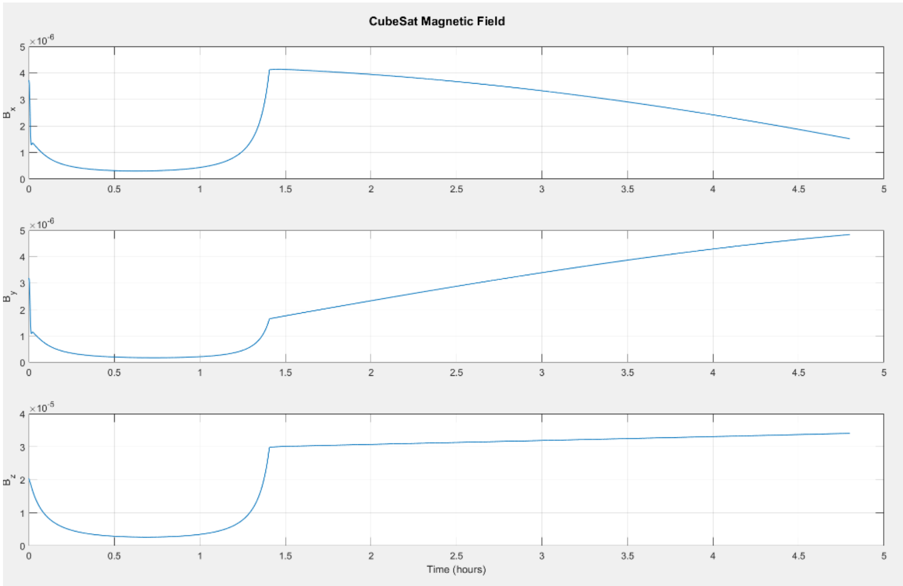
4. Control Torque:



The torque needed to adjust the satellite's attitude depends on gravitational gradient torques and any aerodynamic forces, which can differ between polar and equatorial orbits.

Equatorial orbits, especially if geostationary, may require different control torques to maintain a fixed position relative to Earth's surface, given the different dynamics of Earth's gravitational field at the equator.

5. Magnetic Field:



Earth's magnetic field varies in strength and orientation between the poles and the equator. Magnetic torquers (used for attitude control) rely on this field and will have different efficiencies and control capabilities in equatorial orbits.

The interaction between the satellite's magnetic control system and Earth's magnetic field will be different, possibly requiring adjustments in control algorithms.