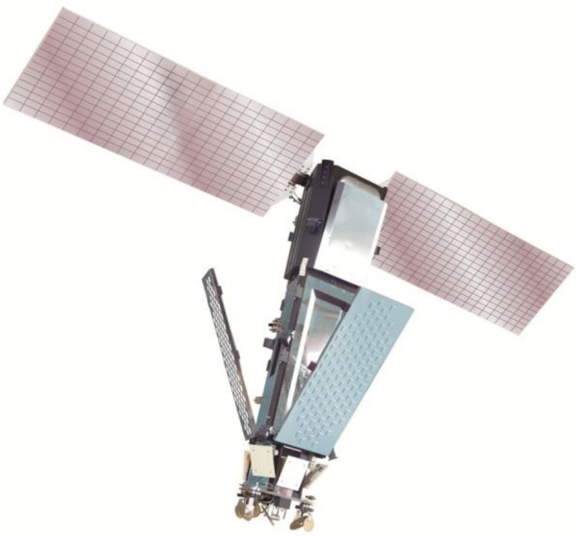


SPACECRAFT CONTROL SYSTEMS, HOMEWORK1

Dr. Demet Cilden-Guler

ABSTRACT

The main goal of this homework is to stabilize a satellite that was deployed earlier than expected from the orbital transfer vehicle.

Khady sarah Sall

92230129

In addition to the data provided in the statement and shared through the following link:
https://tinyurl.com/scchw1data24***, we have utilized external data from the in-class exercise session. These data will be explicitly explained at the concerned parties.***

Declined rate at the beginning.

We considered the initial part of the speed decline when it dropped from 330 to 200 degrees per second from June 12th to July 8th, 2023. We calculated the rate of decrease using MATLAB.

The decline rate is approximately 5 degrees per day. It may be due to the decrease in fuel diminishing ability to generate torque for rotation.

```
% Constants and Initial Conditions
omega_initial = 330;
omega_final = 200;
start_date = datenum('June 12, 2023');
end_date = datenum('July 8, 2023');
duration = end_date - start_date;      % Duration of the decline in days

% Calculation
decline_rate = (omega_initial - omega_final) / duration;  % Degrees per day

disp(['The decline rate is approximately ', num2str(decline_rate), ' degrees per day.']);
```

Detumbling Phase and three axis stabilization to the origin.

Issues encountered and how I handled them.

The issue I encountered in the detumbling phase and the 3-axis stabilization phase to the origin is that I failed to separately accomplish them.
I couldn't achieve this part initially, i.e., reducing speed from 200 to 50 degrees within the next 10 hours using the satellite's torque rods, and then applying the Quaternion Feedback Controller with a Designed Reaction Wheels Configuration to fully stabilize the satellite to the origin within one hour.

For my way of thinking or may be my weak background on spacecraft control, I lacked sufficient information on altitude and the mechanical motion equations governing the satellite. Since I couldn't obtain this data, I opted for direct stabilization, i.e., reducing speed from 200 to 0.1 degrees per second and stabilizing around 0.1 degrees per second across all three axes.
I used the four controls provided during the in-class session and the equation relating quaternion derivative to angular velocity.

For controllers' comparison, I plotted curves of Q, W, and L, i.e., quaternions, angular velocity, and torques, simulating them for all four controllers. I noticed that Controller 3 worked the most for all three parameters, although the controllers only worked when c equalled 50, contrary to the class examples starting at 100. So yes, I modified c and make it equal to 50 instead of 100.

The peak error was determined using only controller number tree which provide better stabilization with no oscillations.

It said in the homework that: Magnetic field vector needs to be calculated for the specific scenario!

So, regarding the magnetic field, I determined latitude and longitude from the satellite's coordinates in the ECI frame since they were given. Assuming the satellite was geostationary, I estimated the altitude at 36,000 km. I used MATLAB's IGRF to determine the magnetic field coordinates in the ECI frame at each satellite point, then transformed these coordinates into the satellite's body frame. This enabled me to plot the magnetic field variation history in both the ECI and body frame references. I plotted magnetic fields for each controller type but for this report we only consider the chosen one controller 3.
These are the issues I encountered and how I handled them.

- *External data.*

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & \omega_3 & -\omega_2 & \omega_1 \\ -\omega_3 & 0 & \omega_1 & \omega_2 \\ \omega_2 & -\omega_1 & 0 & \omega_3 \\ -\omega_1 & -\omega_2 & -\omega_3 & 0 \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix}$$

Without loss of generality, consider the control logic of the form $\mathbf{u} = -\mathbf{K}\mathbf{q} - \mathbf{C}\boldsymbol{\omega}$. The origin, either $(0,0,0,+1)$ or $(0,0,0,-1)$, of the closed-loop nonlinear systems of a rigid spacecraft with such control logic is globally asymptotically stable for the following gain selections.

Controller 1:

$$\mathbf{K} = k\mathbf{I},\ \mathbf{C} = \operatorname{diag}(c_1, c_2, c_3)$$

Controller 2:

$$\mathbf{K} = k\operatorname{sgn}(q_4)\mathbf{I},\ \mathbf{C} = \operatorname{diag}(c_1, c_2, c_3)$$

Controller 3:

$$\mathbf{K} = k\operatorname{sgn}(q_4)\mathbf{I},\ \mathbf{C} = \operatorname{diag}(c_1, c_2, c_3)(1 + \mathbf{q}^{\mathrm{T}}\mathbf{q})$$

Controller 4:

$$\mathbf{K} = k\operatorname{sgn}(q_4)\mathbf{I},\ \mathbf{C} = \operatorname{diag}(c_1, c_2, c_3)(1 - \mathbf{q}^{\mathrm{T}}\mathbf{q})$$

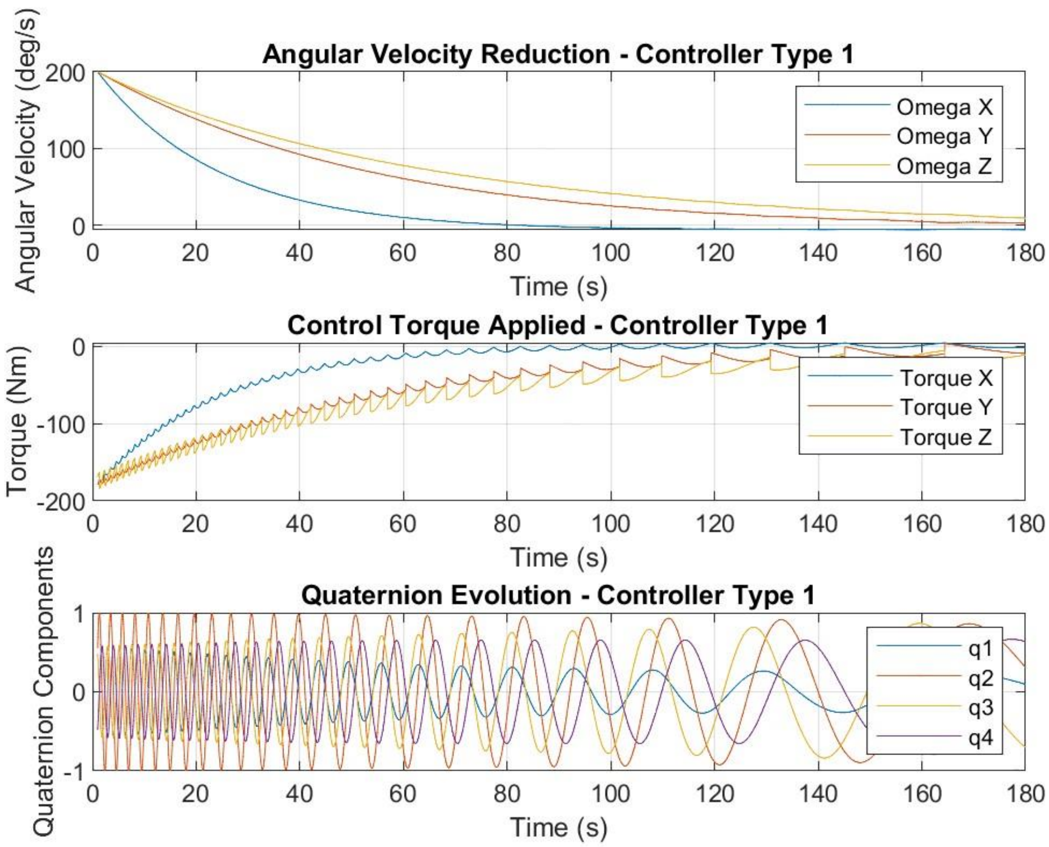
where k and c_i are positive scalar constants, $\mathbf{I}$ is a 3×3 identity matrix, $\operatorname{sgn}(\cdot)$ denotes the signum function, and α and β are nonnegative scalars.

Note that controller 1 is a special case of controller 4 with $\alpha = 0$, and that β can also be simply selected as zero when $\alpha \neq 0$. Controllers 2 and 3 approach the origin, either $(0,0,0,+1)$ or $(0,0,0,-1)$, by taking a shorter angular path.

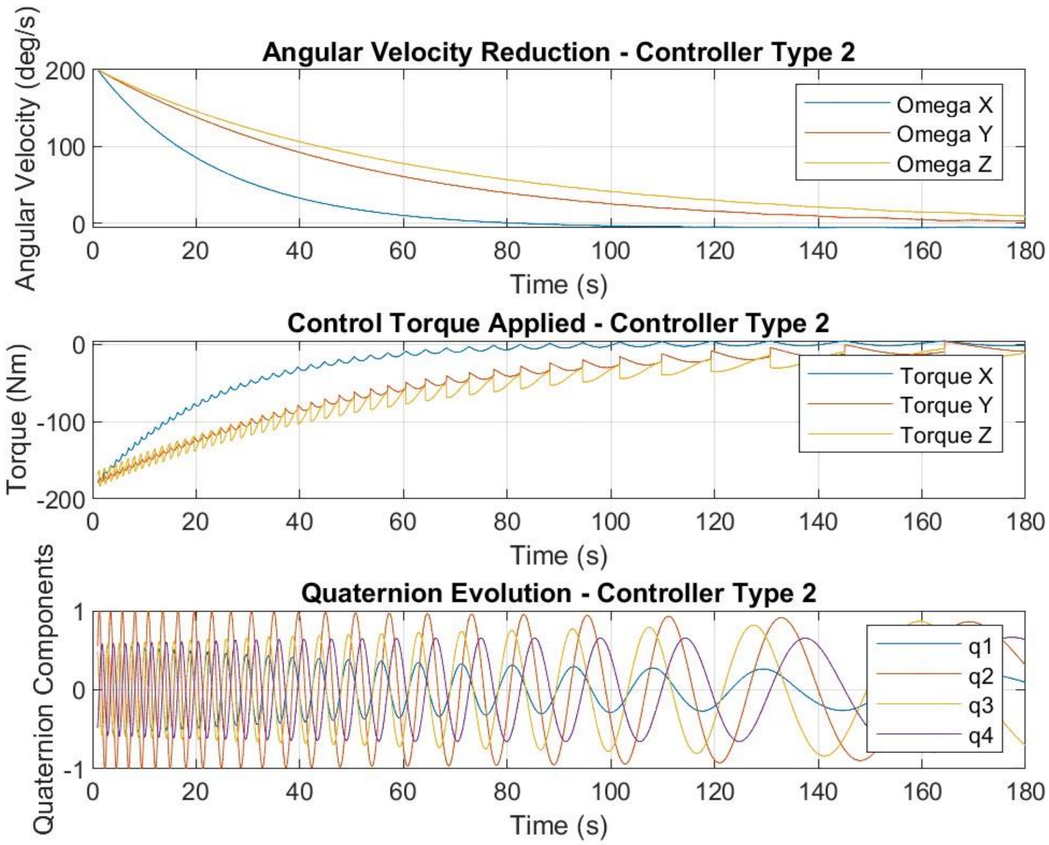
Initial conditions regarding quaternions that I assumed.

It is assumed that $(q_1, q_2, q_3, q_4) = (0.5, 0.5, 0.5, -0.5)$

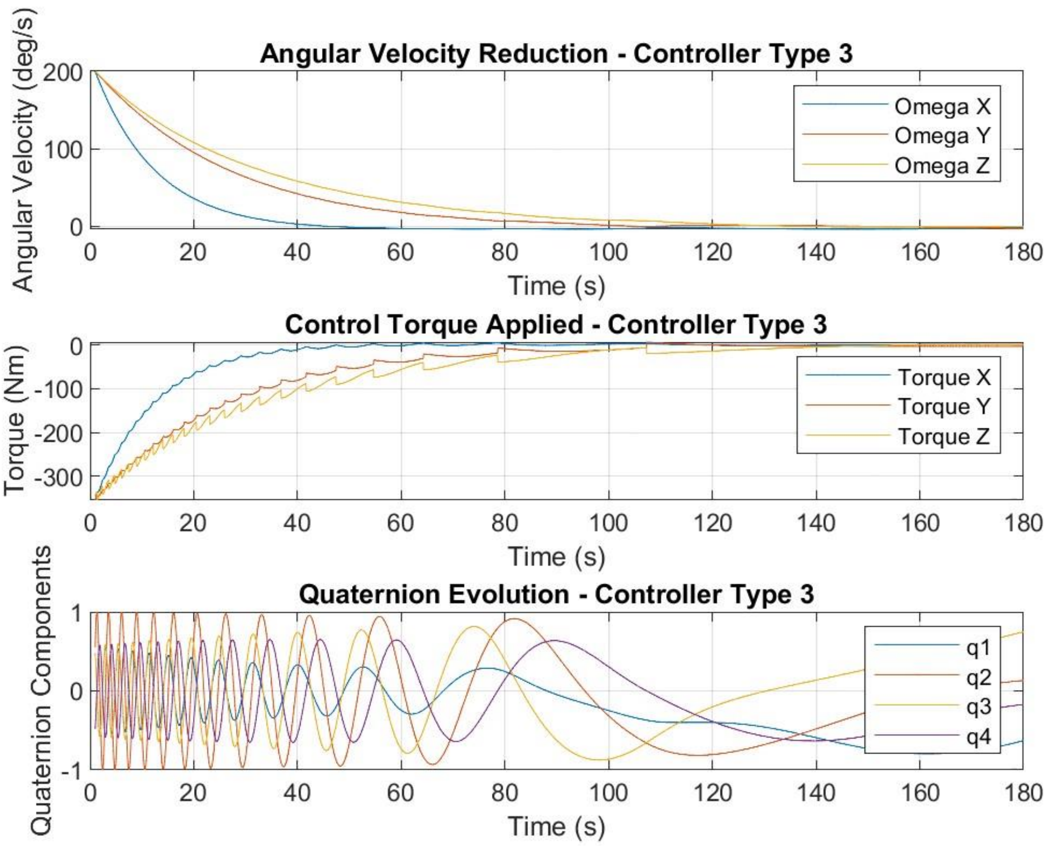
- the time history of $\mathbf{q}$, $\boldsymbol{\omega}$ and $\mathbf{L}$ controller 1



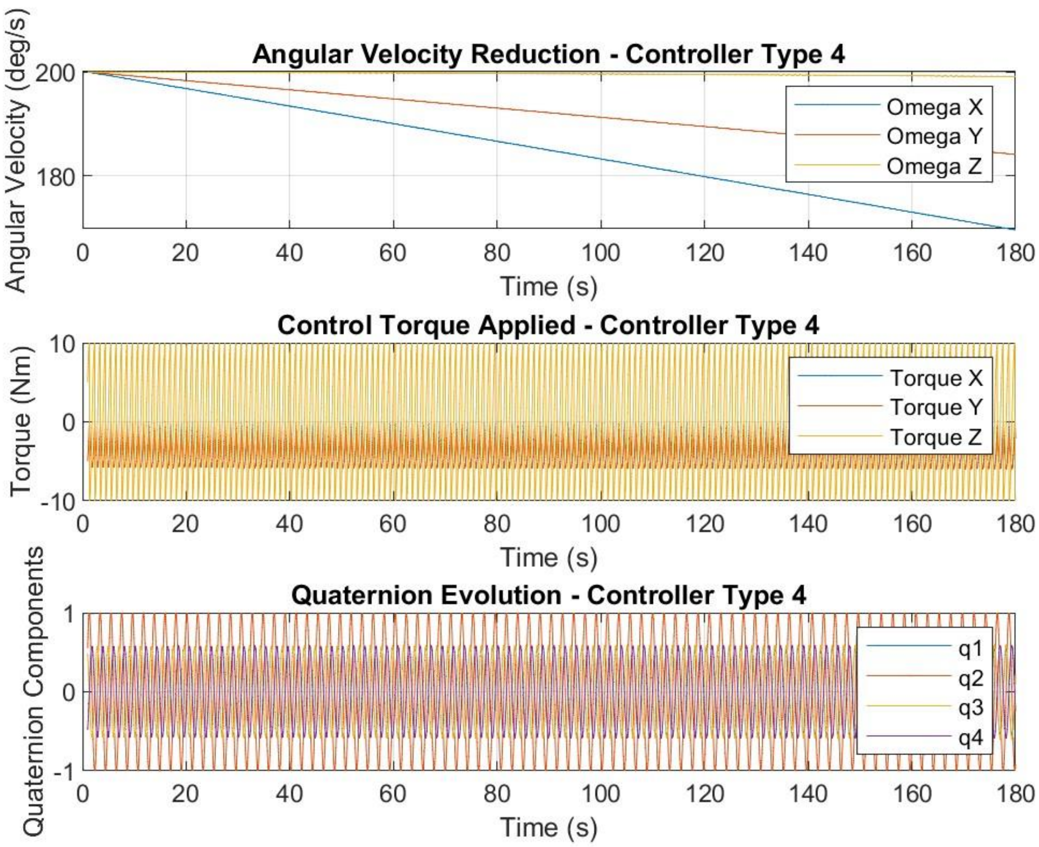
❖ the time history of $\mathbf{q}$, $\boldsymbol{\omega}$ and $\mathbf{L}$ controller 2



❖ the time history of $\mathbf{q}$, $\boldsymbol{\omega}$ and $\mathbf{L}$ controller 3



❖ the time history of $\mathbf{q}$, $\boldsymbol{\omega}$ and $\mathbf{L}$ controller 4



1. Stable Speed: With Controller 3, I observed that the speed of the satellite was perfectly stabilized where we wanted it under 0.1 degree/sec. This indicates that Controller 3 effectively regulates the rotation speed, meeting the stabilization requirements.

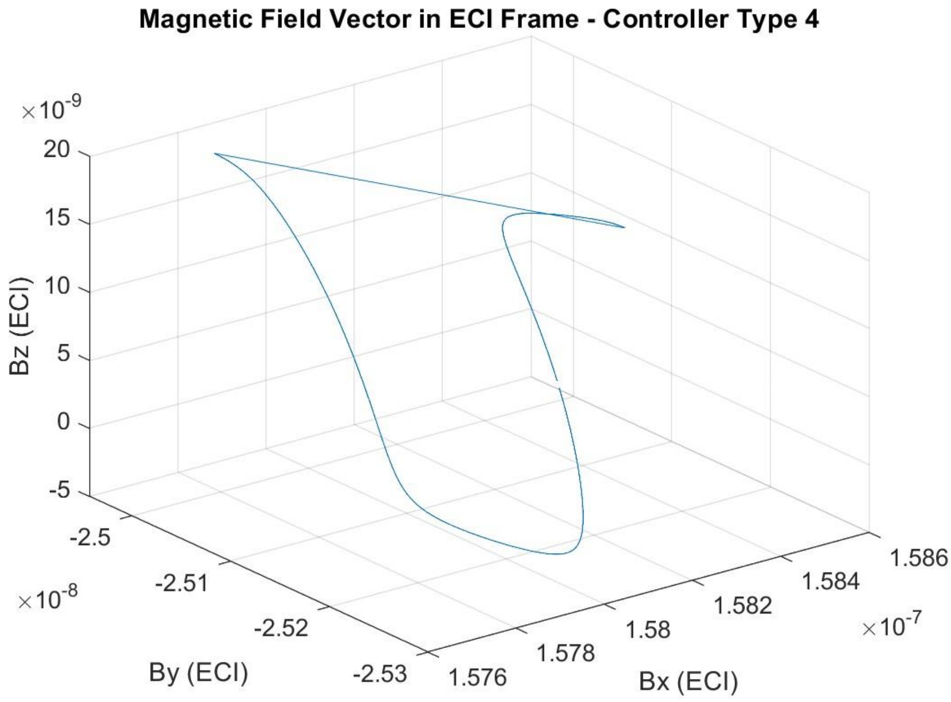
2. Decreasing Torques: I noticed that with Controller 3, the torques tended toward zero. This suggests that the controller can minimize external disturbances and maintain stability without excessive use of torque, which is desirable for efficient satellite operation.

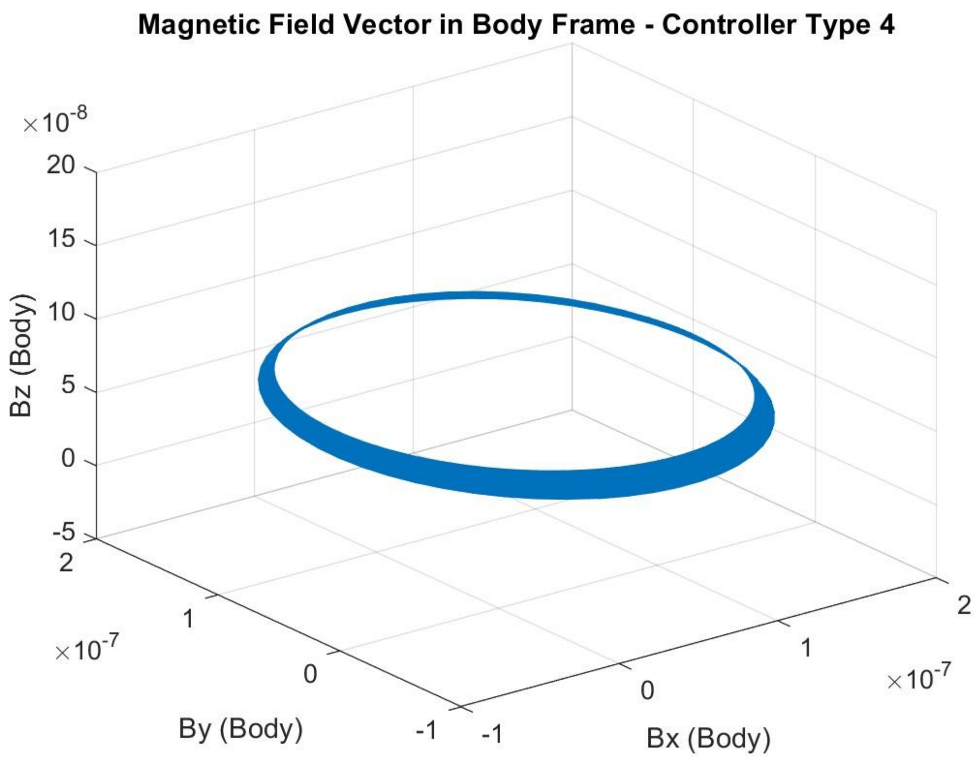
3. Stable Quaternions: I observed that the quaternions stopped oscillating and tended toward finite values, becoming more constant over time with Controller 3. Stable quaternions indicate that the orientation of the satellite is effectively maintained, which is crucial for accurate positioning and functionality.

4. Comparison with Other Controllers: When comparing Controller 3 with Controllers 1, 2, and 4, i observed that Controller 4 didn't stabilize at all, Controllers 1 and 2 yielded oscillating results for quaternions per example, while Controller 3 provided stable speed, decreasing torques, and stable quaternions. This comparison highlights the superior performance of Controller 3 among the options tested.

Therefore, based on these observations, it's justified to choose Controller 3 for stabilizing the satellite due to its ability to effectively regulate speed, minimize torques, and maintain stable orientation, as demonstrated in the simulation results.

❖ Plot the time history of magnetic field vector in ECI and body frames for detumbling stage.



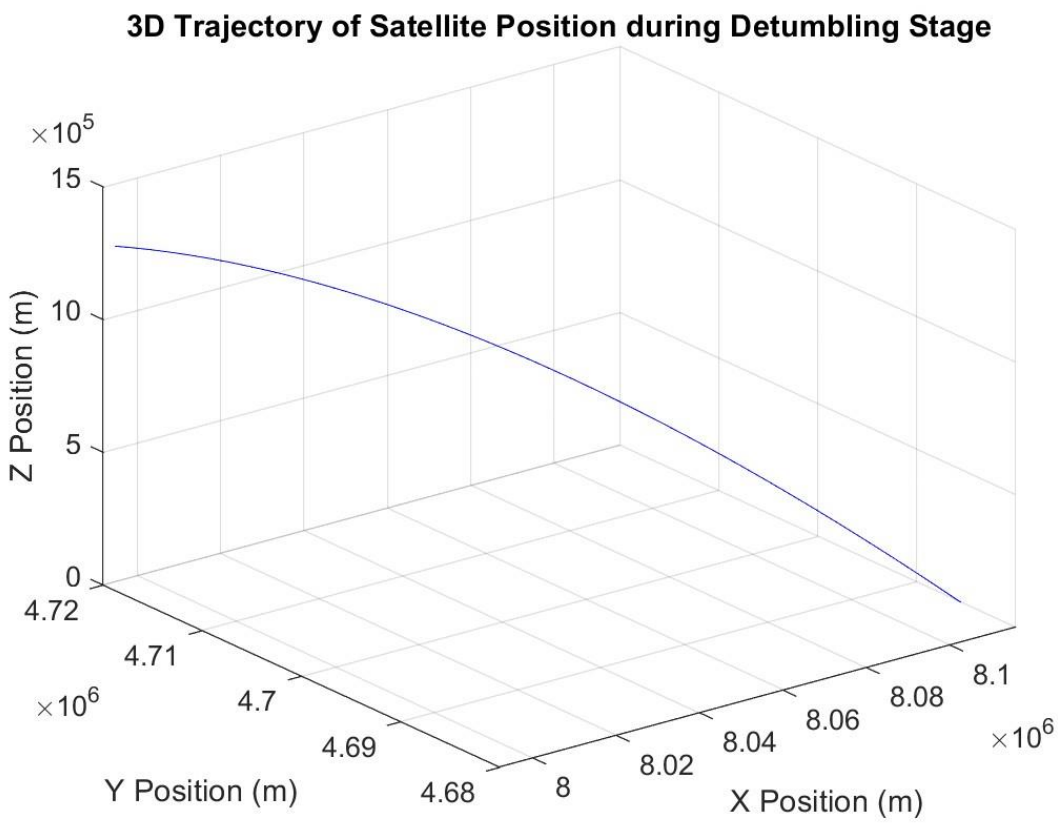


We obtained the magnetic field plots in the ECI and Body Frame reference frames and noticed differences between them. Before commenting on these plots, we'll explain the adjustments made. Given the satellite's positions per second in the ECI reference frame, totalling 9029 positions, and the requirement to determine the magnetic field in this specific case, we opted to use MATLAB's IGRF function with geocentric coordinates as the chosen coordinate unit. The drawback is that the function's database is limited to 2019. Since our problem occurred in 2023, we selected July 8, 2019, hoping the Earth's magnetic field components didn't vary significantly from 2019 to 2023. Apart from that, this function enables the calculation of magnetic field coordinates given latitude longitude altitude and coord unit. Thus, using the provided ECI positions, we calculated latitude and longitude per second, resulting in 9029 latitudes and 9029 longitudes. We used these values as parameters for the IGRF function. Assuming a stationary orbit, we considered a geostationary satellite, implying an altitude of 36,000 km. This provided us with the magnetic field coordinates in the ECI reference frame. Next, we used quaternion to transform these coordinates from the ECI reference frame to the Body Frame reference frame, resulting in the historical magnetic field data in both reference frames.

The elliptical shape of the magnetic field in the Body Frame reference may result from the interaction between Earth's magnetic field and the satellite's orbital motion. This shape reflects how the magnetic field gets compressed and distorted by the satellite's movement in orbit. The turning lines could indicate local variations in the magnetic field caused by factors like the satellite's orbit inclination relative to Earth's magnetic equator.

The fluctuating magnetic field figure in the ECI reference reflects natural variations in Earth's magnetic field at different orbital positions of the satellite. The figure's attempt to turn into an ellipse at times and then descending suggests cyclic or periodic variations in the magnetic field. This could stem from geophysical phenomena such as magnetic field variations induced by ocean currents or movements in Earth's core.

- Plot the time history of position vector of the satellite for detumbling stage.



This trajectory is normal to assuming the case we are studying. Nothing anormal it's an orbit path.

- Computed transient times **(%2 of the peak error)** for each component of the state vector in each stage separately (Show how you have calculated the transient time).

```
……..
……..
% Update peak error for each component of state vector
    if controller_type == 3  % Only update peak errors for Controller Type 3
      for j = 1:3
        peak_errors(j) = max(peak_errors(j), abs(omega(j) - omega_final(j)));
      end
……
% Compute transient times for each component of state vector
transient_times = 0.02 * peak_errors;
```

transient times table = [0.0522383663663884;0.052307456518084;0.052312715364080]

The transient time is low and the same for each state vector This result show that the satellite has good ability to stabilize quickly after disturbance: 0.0522 seconds.

- Comment on the given “alternative way of B-Dot control law” and the selected controller for detumbling stage in light of the analysis.

The alternative B-Dot control approach, as described in in class session, uses magnets to generate a reaction torque in response to the Earth's magnetic field. Unlike quaternion-based controllers B-Dot control focuses solely on using the magnetic field to generate the reaction torque. This has distinct advantages and disadvantages:
Advantages:
B-Dot control does not require a complex representation of the satellite's orientation, thereby reducing reliance on magnetic field data. Although it is greatly defined with. Simplicity of design: This approach may be easier to implement as it does not require complex orientation data processing.

But B-Dot control relies on orbital characteristics such as orbit inclination and period, which can limit its robustness in scenarios where these parameters change. Because it heavily relies on the Earth's magnetic field, B-Dot control can be sensitive to unwanted magnetic disturbances or anomalies in the magnetic field. Also In certain situations, B-Dot control may not be as precise or responsive as quaternion-based methods, especially when the magnetic field is complex or changes rapidly.

Not Done

- Plot the time history of wheel angular momentum vector for the last stage.
- Comment on the momentum dumping for the last stage, where you use reaction wheels (Did you need it?)

During this exercise, I struggled to follow the recommended chronology, and there were parts I couldn't complete, likely due to that. However, it allowed me to learn more about the field of control and to assess my level of comprehension and knowledge in this area, there is still a lot of work to be done.