Jonathan Lephuoc
AERO 424
14 December 2021

Project Assignment #3: Report

Problem Statement: Given 1) a set of ADCS requirements and 2) a baseline design for the new Hubble Double mission below, verify that it is possible to meet all requirements with the baseline design. Provide evidence showing that it is possible to meet them. To do so, develop an attitude simulator building upon the work done in previous assignments. Use a combination of analysis and simulation results as well as plots to provide the evidence that the requirements can be met.

ADCS Requirements:

1. Maneuver 1: Slew 30 deg cross-track.
    a. Perform maneuver in less than 30 minutes (settling time)
    b. Steady state error less than 0.1 deg
2. Hold attitude constant (body frame aligned with inertial frame)
    a. Pointing accuracy better than 0.15 deg
3. Detumbling: From an initial state where omega = [0.1;0.1;0.1], bring the spacecraft to omega_{bi} = [0;0;0]and attitude = 0,0,0 (body frame = inertial frame)
    a. Perform maneuver in less than 12 hours
    b. Steady state error less than 0.1 deg
4. Momentum dumping: Fire thrusters for long enough time to bring saturated reaction wheel to omega = 0
    a. At most one maneuver per wheel per day
    b. Less than a minute

Parameters:

1. D = 20 for all axes
2. Atmospheric density: 3e-13 kg/m^3
3. CD = 2.5
4. J_c = diag([77217, 77217, 25000])
5. J_w = 0.84
6. Plate_areas = [23,18,18]
7. Plate_normals = {[1;0;0], [cos(30*pi/180);sin(30*pi/180);0],[cos(30*pi/180);sin(30*pi/180);0]}
8. Plate_positions = {[1;0;0],[0;0.6;0],[0;-0.6;0]}
9. Plate_absorpt = [0.1;0.2;0.2];
10. Plate_spec = [0.8;0.75;0.75];
11. Plate_diffus = [0.1;0.05;0.05]

Questions:

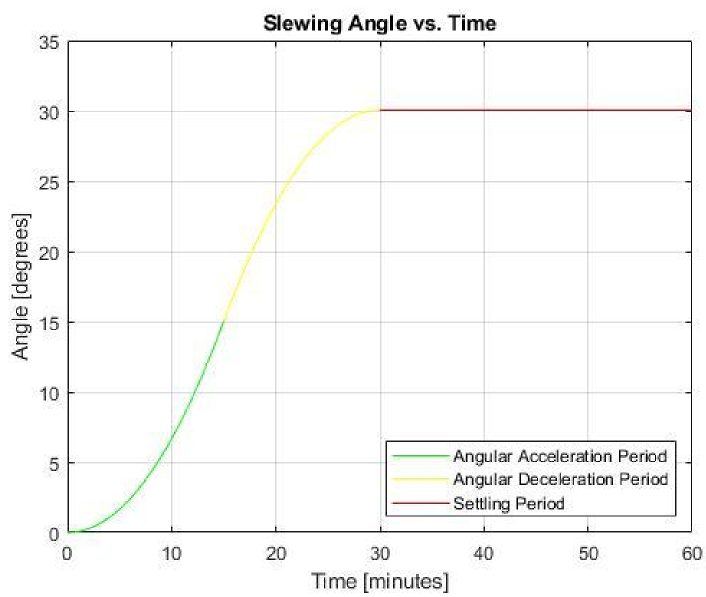
1. Verify that you can slew 30 degrees cross-track in less than 30 minutes open-loop (no controller). You may consider only one axis. What is the level of torque required?
2. Verify that you can meet the requirement that the steady state error for the 30-deg slewing maneuver is less than 0.1 deg.

Jonathan Lephuoc
AERO 424
14 December 2021

3. Implement a PID controller for each wheel and adjust the gains so that the closed-loop system is stable and you can meet your time specification requirements and steady state requirements.
4. Verify that you can keep a fixed attitude (body frame aligned with inertial frame) in the presence of the disturbance torques to within 0.05 arcsec (1.39e-5 deg) (use closed-loop control)
5. Verify that starting from [0;0;0;1] and 0 angular rates in the body frame, the attitude quaternion (body to orbital) after 10 orbits looks like Fig. 1, and starting from [0.5;0.5;0.5;0.5] yields Fig. 2 considering only disturbance torques (no controller)

Question 1. Verify that you can slew 30 degrees cross-track in less than 30 minutes open-loop (no controller). You may consider only one axis. What is the level of torque required?

Fig.1



- From the linearized, decoupled pitch equation of motion, it was determined that the level of torque required to change the cross-track angle (in this case, θ) by 30 degrees was 0.05 Nm. There was no controller applied to the torque and it is evident from Fig.1 that it is possible to slew 30-deg cross-track within 30 minutes. Thus, we have verified that we can slew 30 degrees cross-track in less than 30 minutes open-loop.

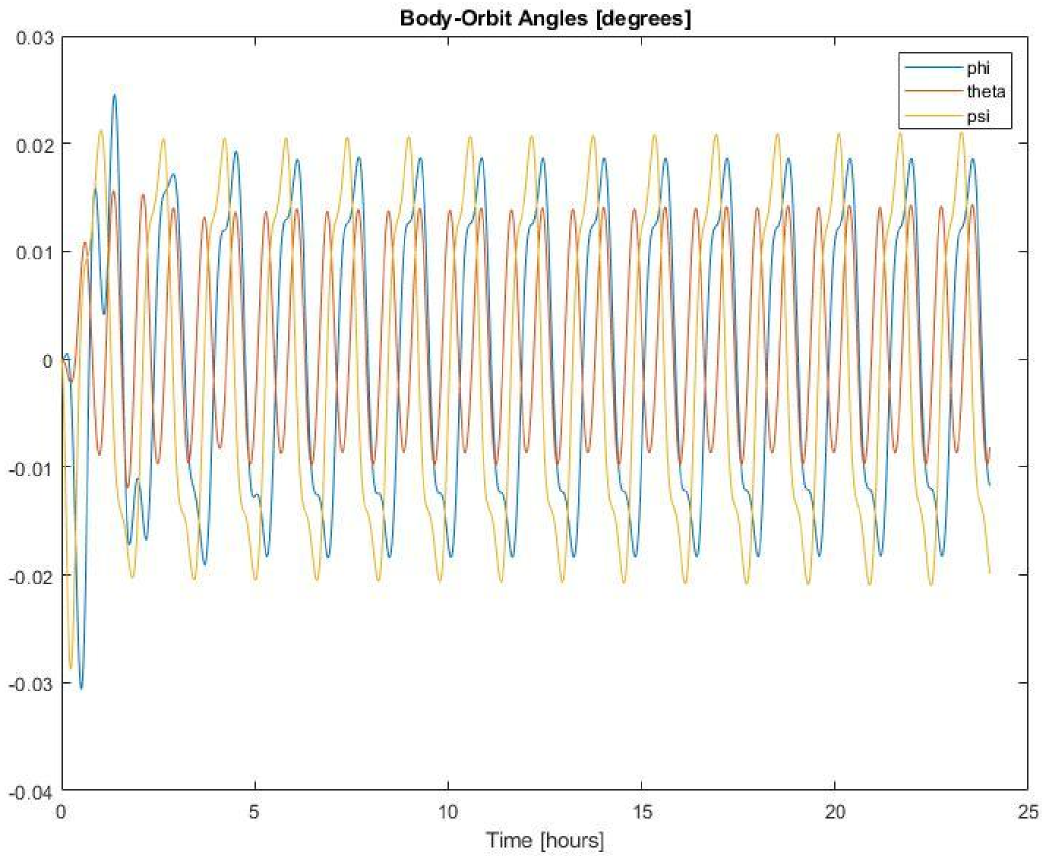
Question 2. Verify that you can meet the requirement that the steady state error for the 30-deg slewing maneuver is less than 0.1 deg.

- After about 10 minutes, the cross-track angle has reached a steady state value of 30.0514. As such, the error for the maneuver is given by 0.0514, which is less than 0.1 deg. Thus, we have verified that the requirement that the steady state error for the 30-deg slewing maneuver is less than 0.1 deg is able to be met.

Jonathan Lephuoc
AERO 424
14 December 2021

Question 3. Implement a PID controller for each wheel and adjust the gains so that the closed-loop system is stable and you can meet your time specification requirements and steady state requirements.

Fig.2

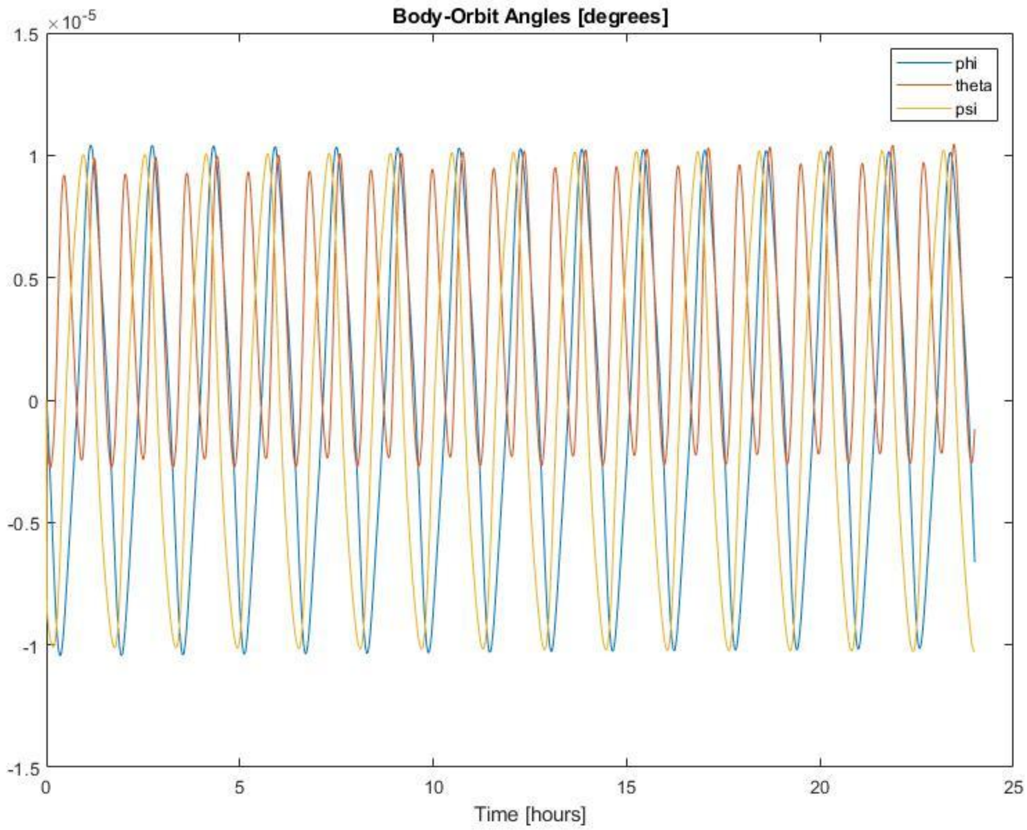


- For the designed PD controller, the gains for each wheel were as follows:
    - $K_x = K_y = K_z = 0.35$
    - $K_{xd} = K_{zd} = 32$, $K_{yd} = 35$
- In order to satisfy the detumble requirements, the gains were designed such that the time specification requirement of 12 hours and steady state error requirement of 0.1 deg while ensuring that the torques applied by each of the reaction wheels does not exceed 1 Nm, the approximate maximum output torque. The provided code verifies that the reaction wheel torque remains below 1Nm (the code will return the value of any reaction wheel torque that exceeds 1) and as can be seen from Fig. 2, the maneuver attains steady state well within 12 hours. Furthermore, in steady state, the maximum distance between the actual attitude and target attitude of 0 degrees is roughly 0.02 degrees; therefore, the steady state error requirement of 0.1 degree has also been verified.

Jonathan Lephuoc
AERO 424
14 December 2021

Question 4. Verify that you can keep a fixed attitude (body frame aligned with inertial frame) in the presence of the disturbance torques to within 0.05 arcsec (1.39e-5 deg) (use closed-loop control)

Fig. 3



- As can be seen from Fig. 4, in order to hold the attitude constant and keeping the spacecraft body frame aligned with the inertial frame, the gains were adjusted as follows:
    - K_x= 850, K_{xd} = 10000
    - K_y = 350, K_{yd} = 10000
    - K_z = 650, K_{zd} = 10000
- The gains had to be dramatically increased compared to that of the detumbling mode in order to attain the stringent pointing accuracy requirement of 0.05 arcseconds (1.39e-5 degrees). Nevertheless, as can be seen from Fig. 3, the Euler angles remain within about 1e-5 degrees of the target of 0 degrees. Therefore, the minimum pointing accuracy requirement of 0.15 degrees as well as the requirement to keep attitude constant in the presence of disturbance torques to within 0.05 arcseconds have been verified.

Question 5. Verify that starting from [0;0;0;1] and 0 angular rates in the body frame, the attitude quaternion (body to orbital) after 10 orbits looks like Fig. 1, and starting from [0.5;0.5;0.5;0.5] yields Fig. 2 considering only disturbance torques (no controller)

Jonathan Lephuoc
AERO 424
14 December 2021

Fig.4: Starting from [0;0;0;1]

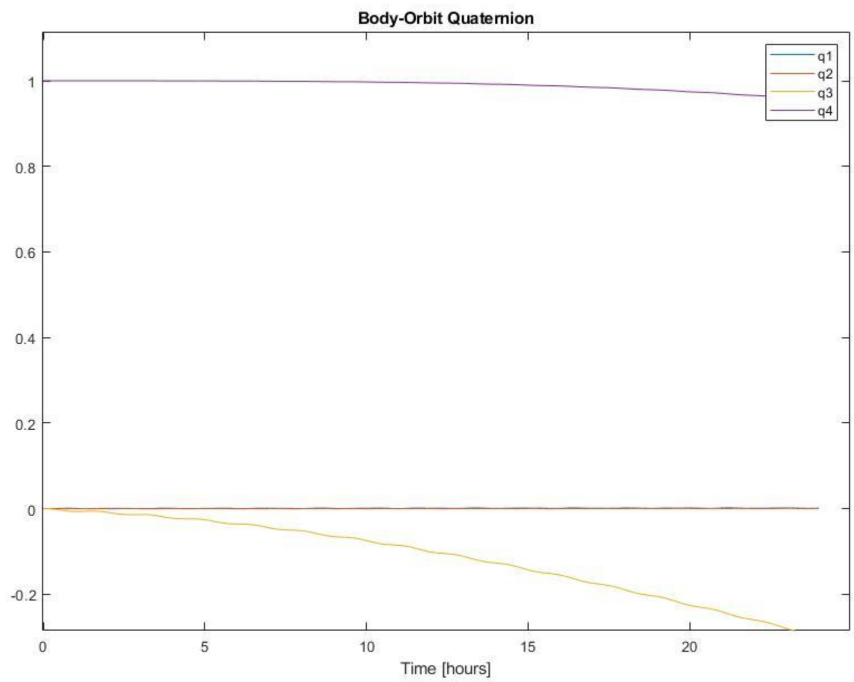
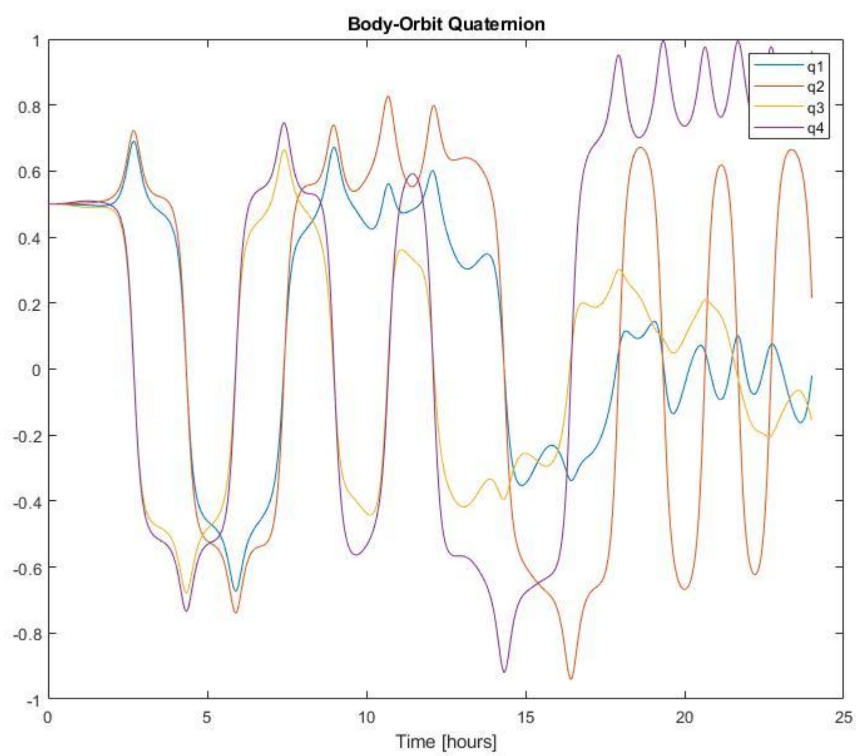


Fig.5: Starting from [0.5;0.5;0.5;0.5]



- While Fig. 4 and Fig. 5 do not exactly replicate the provided figures, both exhibit roughly the same oscillations and general amplitudes. For instance, while the amplitude of oscillation in the q_3 component in Fig. 4 is slightly lower than that of provided Fig. 1, the overall frequency of oscillation appears to be roughly the same. Also, the downwards trend of the q_3 component matches that of provided Fig. 1. Furthermore, the exact behaviors of Fig. 5 and provided Fig. 2 are noticeably different, the general frequencies of oscillation of all quaternion components appear relatively similar and the approximate magnitude remains the same, at about 1.

Notes/Comments

1. Within the code, I have included an optional closed-loop, 30-degree cross-track slewing maneuver that takes into account the disturbance torques. It was interesting to note that in order to achieve the steady state angle of 30 degrees, an additional 2.4 degrees of offset had to be added, as inputting a change of 30 degrees instead of 32.4 degrees would result in the spacecraft undershooting the slew by roughly 2.4 degrees. This was perhaps a consequence of the disturbance torques applied on the spacecraft.