Astro 331 Prelab 4: Attitude

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Documentation:

- DFAS writing guide (I used to write these instructions—you should read it but don't need to list it in your documentation statement)
- Cite references as necessary, but don't include course notes, course text (SMAD), or these instructions as documentation
- Don't forget to update your own documentation statement when you write your prelab report!

Overview

In this lab you will analyze FlatSAT's reaction wheel. You will confirm its physical properties and ensure that it can achieve its maximum specified speed. (These steps include verifying provided information, but do not list these steps as assumptions.)

You will calculate the torque and angular momentum storage of the reaction wheel to verify that it can counter disturbance torques in its 500 km circular orbit.

During the lab, you will suspend FlatSAT and its reaction wheel from a single hook and spin the rotor at varying speeds while observing FlatSAT's response. You will use recorded inertial measurement data to determine FlatSAT's moment of inertia and wheel performance.

Format

Include the sections required in a Short Summary Report from the USAFA/DFAS writing guide, with the addition of a Nomenclature section. Do not include a cover sheet for prelabs.

- Objectives
- Nomenclature
- Approach
- Assumptions
- Math Technique
- Theoretical Predictions
- Experimental Setup
- Discussion
- Conclusion and Recommendations
- Appendices

This assignment will be no more than four typed pages. This assignment is individual effort, but you may use websites and textbooks provided that you cite all sources used (see the References section in the DFAS Writing Guide).

Nomenclature

I = moment of inertia ($kg\,m^2$)

T = torque (N m)

ω = angular speed (rad/s)

Subscripts

D = total disturbance

Drag = aerodynamic drag

g = gravity gradient

m = magnetic

s = exposed to sunlight

SRP = solar radiation pressure

Content

Calculate the reaction wheel's torque and angular momentum storage.

Calculate the disturbance torques listed in SMAD Table 11-9a in FlatSAT's 500 km circular orbit.

Compare the wheel's capabilities to FlatSAT's torque and angular momentum requirements.

Comment on your results and what changes you would suggest to the design to improve its performance. Recall that spacecraft typically have three to four reaction wheels. Be sure to explain each equation, define all variables and include units, and state any assumptions you made in order to use those equations. You must show all work to arrive at your answers, though this work may be either in the main body of the prelab or attached as an appendix. It must be clear to the reader how you arrived at your answers. This prelab should be a stand-alone document that any engineer without prior exposure to this course could read and understand. At a minimum, you will need the following equations:

Wheel performance

Torque:

$$T = I\alpha \tag{1}$$

Angular momentum:

$$h = I\omega \tag{2}$$

Mass moment of inertia about the axis of rotation for a uniform cylinder:

$$I_{cylinder} = \frac{1}{2}mr^2 \tag{3}$$

Disturbance torques

Calculate the total worst-case disturbance torques using the following equations.

Gravity gradient:

$$T_g = \frac{3\mu}{2R^3}\left|I_{yaw} - I_{other}\right|\sin(2\theta) \tag{4}$$

Solar radiation pressure:

$$F_{SRP} = \frac{S}{c}A_s(1+q)\cos i \tag{5}$$

$$T_{SRP} = F_{SRP}\left(c_{ps} - cg\right) \tag{6}$$

Magnetic field interaction:

$$T_m = DB \tag{7}$$

$$B \cong \frac{2M}{R^3} \tag{8}$$

Aerodynamic drag:

$$F_{Drag} = 0.5\rho C_d A V^2 \tag{9}$$

$$T_{Drag} = F_{Drag}\left(c_{pa} - cg\right) \tag{10}$$

To calculate worst-case disturbance torques, sum them:

$$T_D = T_{drag} + T_g + T_{SRP} + T_m \tag{11}$$

To find the amount of torque required by the reaction wheel to overcome disturbance torques, use the following equation. You may assume a margin factor of 1.25.

$$T_{req'd} = (T_D)(Margin\ Factor) \tag{12}$$

Angular momentum
Then use the following equation to compare against your estimate of the reaction wheel's momentum storage is enough to withstand the worst-case disturbance torques over the course of an orbit:

$$h_{req'd} = T_D \left(\frac{P}{4}\right)\left(\frac{\sqrt{2}}{2}\right) \tag{13}$$

In your theoretical predictions section, complete Tables 1 and 2 with your model results. In your final report, add an additional row to Table 2 for your measured results.

Table 1 Disturbance Torques

	torque (N m)
gravity gradient	
solar radiation pressure	
magnetic	
aerodynamic	
total	

Table 2 FlatSAT reaction wheel performance

	torque (N m)	angular momentum (N m s)
requirement		
prediction		
margin		

If any terms are not given, assume worst-case values. Explain how you determined which value to use for a worst-case term. Atmospheric density is based on altitude, and can be found in a table the back of SMAD.

Appendix A: System Properties

Table 3 Reaction Wheel Properties

rotor mass	0.65 kg
rotor radius	0.05 m
max wheel speed	1000 RPM
max wheel acceleration	50 RPM/s

Table 4 Spacecraft Properties

z-axis MOI	$3\,\mathrm{kg\,m^2}$
x-, y-axis MOI	$1\,\mathrm{kg\,m^2}$
size	$15 \times 15 \times 15\ \mathrm{cm^3}$
magnetic dipole	$0.8\,\mathrm{A\,m^2}$
CG offset	0.04 m
reflectance factor	0.6
drag coefficient	2.2