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D1: DASL UAV Antenna
Torque Analysis
ME 476C-7
Tuesdays 5:30-7pm

Introduction

Torque is the measurement of a force acting on an object at a certain distance causing a rotation about an axis. This report will analyze the torque needed by the motor to successfully power the gimbal. The torque in this case is caused by the weight of the antenna and the horizontal distance from the antenna's center of mass to the rotational axis where the antenna connects to the gimbal system.

Assumptions

Since the proposed design is still in the early stages of development, there are some assumptions to be made. It will be assumed that the force of gravity is only acting in the negative y-direction and is the only force acting upon the antenna. Therefore the only necessary torque for the motor to overcome is due to the weight of the antenna and the horizontal distance from the antenna's center of mass to the axis where the antenna meets the motor and gimbal system. Another assumption made is that the center of mass for each half of the antenna will be acting at the outer edge of the "bridge." This is assumed because the mass and length of half the bridge will have a small effect as compared to the mass and length of the 2' rod extending in the positive and negative z-direction. Also due to the alignment of the antenna on the rotational axis, the two forces will result in the torques cancelling out. Since the motor will still need torque to adjust the angle, only one side of the system will be analyzed. This will be further explained in the Analysis

Analysis

The UAV system can be seen in Figure 1, where point B is the origin and rotational axis, L is the length of the bridge and points A and C are the centers of mass since it was previously assumed they were at the end of the bridge.

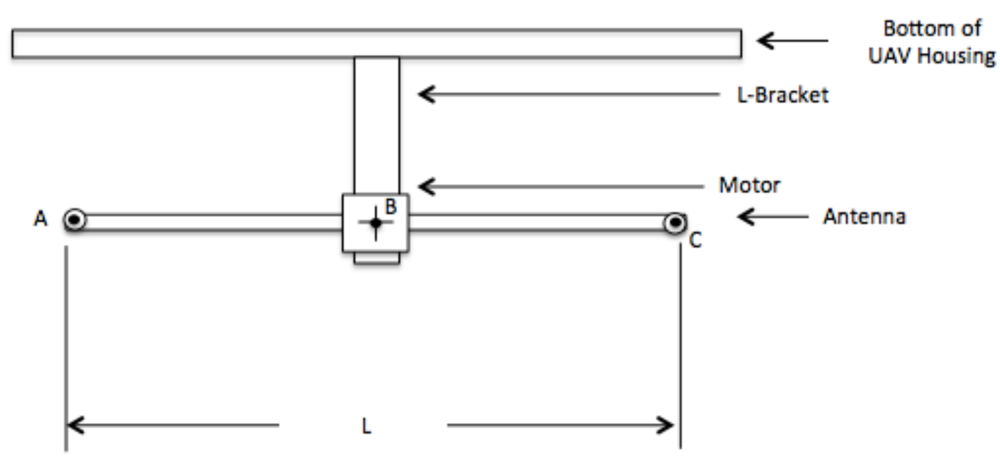

Figure 1: Side View of the Antenna and Gimbal System

The measurement L has been determined as 12 9/16 in or 319 mm. The weight of each half of the antenna will act at their centers of mass, points A and C. The weight, also known as the gravitational force on the mass of the antenna, is calculated from the equation

$$F_g = m * g \tag{1}$$

where M is the mass of the antenna, 0.845lb or 0.383 kg, and g is the gravitational constant, 9.81 m/s^2. Giving the weight of the antenna to be 3.76 N. Figure 2 is an Extended Free Body Diagram of the antenna, which displays the forces acting on the object and the corresponding distances away from the rotational axis.

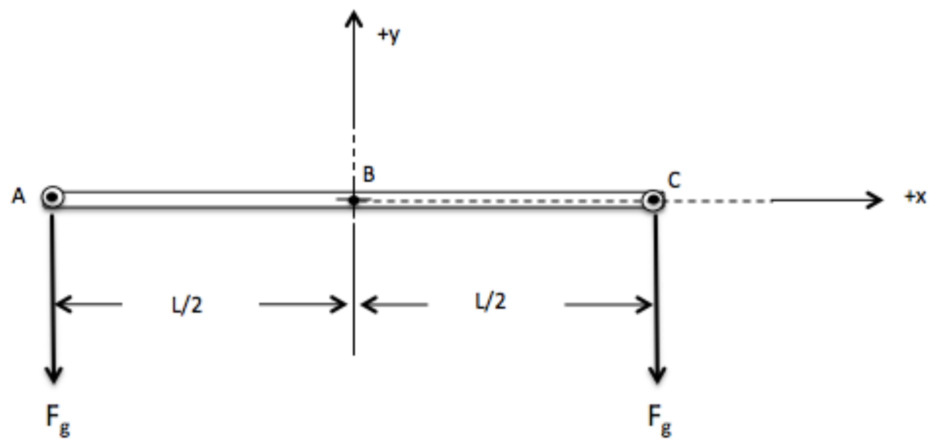

Figure 2: Extended Free Body Diagram

In this case, F_g will be 3.76 N and L/2 is 12 9/32 in or 159.5 mm. The torque at this position can therefore be calculated by

$$T = F_g * \frac{L}{2} \tag{2}$$

where F_g is the force of gravity in N, L is the length of the bridge in m, and T is the torque in Nm. Giving the resulting torque of one side at this position to be 0.5997 Nm. Positive torque by convention, is defined as counterclockwise rotation. The two external forces are equal in magnitude and equidistance from the rotational axis, but one causes a positive torque and the other causes a negative torque. Therefore, when the torques are summed the resulting torque acting on the system is 0. This is one strong benefit as to why this symmetric alignment was chosen. Even though at any position the net torque will equal 0, in reality the motor will still need torque to adjust the angle of the antenna. This is why the system will be analyzed as only one side to determine the maximum net torque.

Since the antenna will be rotated to different angles by the motor, the horizontal distance from the weight of the antenna to the axis of rotation will change accordingly. This can be seen in Figure 3.

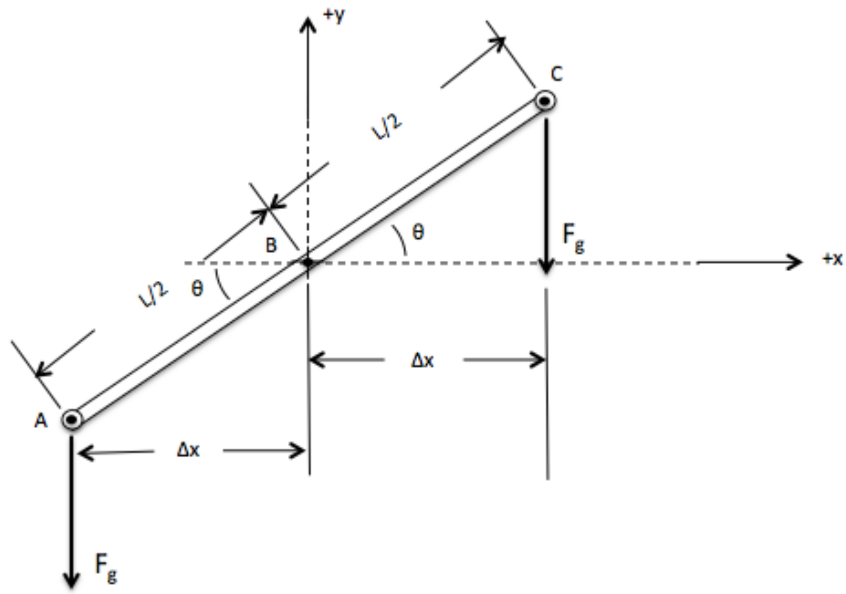

Figure 3: Extended Free Body Diagram with rotated antenna

When the antenna is rotated, the angles on each side of the origin are equal because of the Corresponding Angles Theorem. Therefore the effect on the horizontal distance is the same and can be determined form the equation

$$\Delta \mathrm{x} = \frac{L}{2} * \cos\theta \qquad (3)$$

where Δx is the horizontal distance (mm) and θ is the angle to which the antenna is rotated (degrees). The torque for the new position can then be calculated by

$$T = F_g * \Delta \mathrm{x} \qquad (4)$$

where all the variables are as previously defined. As the angle increases, the resulting Δx will decrease and therefore decreasing the torque due to the directly proportional relationship. Table 1 shows the effect on the horizontal distance and torque, when the angle is increased from 0 to 80 degrees in steps of 5. Due to the geometry of the gimbal, the antenna will not be capable of reaching 90 degrees, therefore a maximum of 80 degree is used. Equations 3 and 4 were used in the construction of this table.

Table 1: Effect of Increasing Angle on Distance and Torque

θ (degrees)	**Δx (m)**	**T (Nm)**
0	0.1595	0.5997
10	0.1571	0.5906
20	0.1499	0.5636
30	0.1381	0.5194
40	0.1222	0.4594
50	0.1025	0.3855
60	0.0798	0.2999
70	0.0546	0.2051
80	0.0277	0.1041

Result

The maximum torque, 0.5997 Nm, occurs when the angle is at 0 degrees and the antenna is resting parallel to the housing and ground. Since a crucial requirement for this system is for the antenna to be able to rotate, a factor of safety is necessary. Without the antenna rotating, the purpose of this design project would be lost. A factor of safety of N=3.5 is used since it's necessary for the motor to have the appropriate amount of torque yet still be lightweight. This gives an overall design target torque of 2.099 Nm

References

[1] A. Bicchi. (1997). *Dynamic Force/Torque Sensors: Theory and Experiments* [Online]. Available: https://www-engineeringvillag.com.libproxy.nau.edu/search/doc/detailed.url?SEARCHID=469b6b58Mc5edM4793Mbfa7M981a4982350b&DOCINDEX=3&database=1&pageType=quickSearch&searchtype=Quick&dedupResultCount=null&format=quickSearchDetailedFormat&usageOrigin=recordpage&usageZone=abstracttab&toolsinScopus=Noload.