ASEN 2003 LAB 5: YO-YO DESPINNER EXPERIMENT

ASEN 2003: Introduction to Dynamics and Systems
University of Colorado at Boulder

Assigned Tuesday, March 10, 2020
Lab Due: Thursday Apr. 2nd, 2020 12:30 PM (All sections)

1 Objectives

- Setup and test despin operations of a mock satellite
- Learn one method for reducing or stopping satellite spin
- Use rotating reference frames to analyze motion of despin masses
- Apply conservation of energy and angular momentum to a real problem

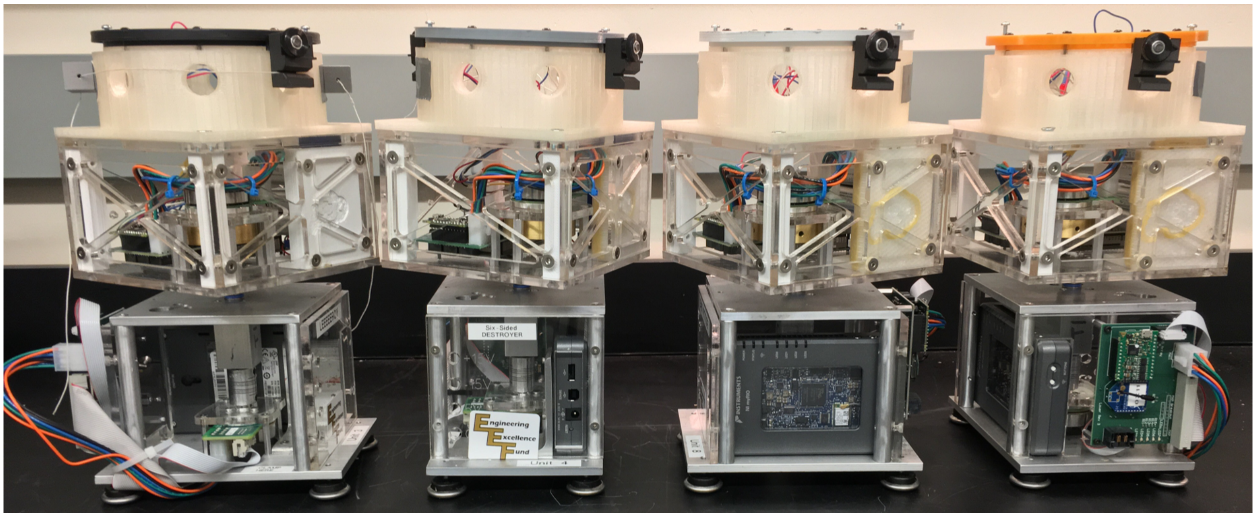


Figure 1: Yo-Yo Despinner Modules

2 OVERVIEW

The last stage of many launch systems is spin-stabilized at a high angular speed, perhaps as high as 150 rpm. This spin rate is imparted to the satellite at orbit insertion. Since most satellites operate at a slow, or zero spin rate, some mechanism is needed to reduce the insertion spin rate to a mission spin rate. One dependable device for performing this spin reduction is called a yo-yo despinner. It consists of one or two small masses on the ends of cords wrapped about the spin axis. If one mass is used, it must be wrapped in the plane containing the satellite center of mass to avoid attitude perturbations. Two identical masses avoid this problem.

When the mass is released, the cord unwinds and the mass extends away from the satellite. This causes the moment of inertia of the system to increase, but the spin angular momentum and total kinetic energy should remain constant. As a result, the angular speed of the satellite body decreases as the angular momentum is transferred to the unwinding mass. Ice skaters use this same technique to control their spin rate by extending and retracting their arms (but in that case there may be a change in kinetic energy due to their muscle use). When the cord is completely unwound, it is released and the cord and its attached mass fly away. The cord may be released tangentially or radially from the cylinder. The size of the mass and the length of the cord are selected to control the spin rate of the satellite. The supplemental pages from Thompson [1961] provide a derivation of the tangential release case. It is assumed that the cord remains taut throughout the deployment and there are no external forces or moments acting on the satellite system.

For this lab students will observe a mockup of a yo-yo despin satellite in action, compute the expected cord lengths and times to despin, and investigate how this method has been applied to a satellite mission.

3 THEORY

1. Review the derivations of the **tangential** despin deployment. In terms of the initial angular velocity (ω_0), the moment of inertia of the satellite (I_s), the outer radius of the satellite (R), and the combined despin mass (m) derive expressions for:
   (a) the angular velocity of the spacecraft as a function of time and as a function of the length of cord deployed,
   (b) the angular acceleration of the spacecraft as a function of time and as a function of the length of cord deployed,
   (c) the tension of each cable.

   The derivations can be typeset or handwritten in the report.
2. The total moment of inertia of the spacecraft without the despin masses is 0.0063 ± 0.0001 kg-m^2 and its outer radius is 0.076 m (3 inches). The two despin masses are 54g each. Compute the following:
   (a) the length of cord required to bring the satellite to a stop with, tangential release
   (b) the time required for deployment.
3. Compute and plot the theoretical angular velocity, angular acceleration, and cord tension as a function of time for the given parameters and an initial angular velocity of 130 rpm.
4. Derive an expression for the length of cord needed for radial release despin. Students are encouraged to use the provided reference (Eide and Vaughan, 1962) as a guide to perform the derivation. Compute the length of cord required to bring the satellite (parameters given above) to a stop with radial release. **This is the cord length you will use in your experiment.** How does it compare to the cord length required for tangential release?

4 EXPERIMENT

Refer to the full experimental procedure in Appendix B

5. Observe the operation of the yo-yo despinner. Provide a sketch of the apparatus and briefly describe how it works.
6. Watch the high speed video(s) and describe how the actual mass deployment compares with theory.
7. Run an experiment without releasing the despin masses. Record the angular velocity as a function of time. Estimate the moment caused by friction on the spacecraft using the experimental data.
8. Using your computed cord length for radial release, adjust the cords and conduct the experiment. Observe the angular velocity as a function of time, the .vi records the angular velocity as a function of time.

5 RESULTS & ANALYSIS

9. Plot the experimental ω as a function of time for the case without using the yo-yo despin mechanism.
10. Plot the experimental ω as a function of time for the case when the yo-yo despin mechanism is activated, on the same graph as your model prediction. Note on the graph the point at which the string reaches its full length is tangential deployment.
11. Compute the angular acceleration based on your experimental data and compare to theory. When (at what string length) is the acceleration and the tension the greatest?
12. Compare the experimental and theoretical angular velocity results. How accurately does the model predict the despin profile? Was your string the correct length to stop the spacecraft spin? Does friction play a significant role in this experiment?

6 APPLICATIONS

13. Find an interesting example of a satellite or launch vehicle that used a yo-yo despin mechanism. You may use a website and at least one other reference (journal article, conference presentation, brochure) to gather information. Describe how the mechanism was used for the mission including the starting and ending spin rates and if you can, the mass and dimension of the despinner. Explain the advantages and disadvantages of this despin approach. What are other alternatives?

7 REFERNCES

Curtis, H.D., *Orbital Mechanics for Engineering Students,* Elsevier, Burlington, MA, 2005.

Eide, D.G., and Vaughan, C.A., *Equations of Motion and Design Criteria for the Despin of a Vehicle by the Radial Release of Weights and Capbles of Finite Mass,*NASA Technical Note D-1012, January 1962.

Thompson, W.T., *Introduction of Space Dynamics,* J. Wiley & Sons, New York, 1961.

Wiesel, W.E., *Spaceflight Dynamics,* McGraw-Hill, New York, 1989.

8 ASSESSMENT CONTENTS

The final grade will be a combination of the quad chart presentation/QA and the details in the 2-page supporting document. The quad chart should follow the provided template and contain enough detail to quickly answer reviewer's questions during the allotted time. Use the supporting document to give succinct answers. (The supporting document is limited to 2 pages of content, appendices are not counted in the page limit.) The supporting document should be used in support of the quad chart, do not restate figures, equations, etc. in the supporting document but reference them from the quad chart. The intent of the supporting document together with the quad chart is to allow a stand-alone report of your findings for this lab assignment. In other words, a grader should be able to glean your level of understanding of the lab assignment's primary objectives from 1. the quad chart presentation/QA without reading the supporting document or from 2. the supporting document and the quad chart slide without listening to the quad chart presentation.

Abstract - Briefly summarize the rest of the report including the objectives of the lab, what was actually done, the most important qualitative and quantitative results, and your conclusions. The abstract should be less than 200 words.

Theory - Present a succinct summary of derivation and models for items 1-4. The derivations do not need to be typeset, neatly handwritten expressions with clear drawings are acceptable. The appendix should include a detailed step-by-step derivation that can be understood by a typical engineering sophomore; refer to the appendix in your summary.

Experiment - Describe the experimental setup and your observations from the various tests. Make sure to include the functional block diagram of the hardware and identify the inputs and outputs from the hardware (such as voltages and data to and from the computer).

Results & Analysis - Present the required plots and tables comparing the models and experiments. Describe the results obtained, answer the questions posted, and explain the sources of error/ discrepancies.

Applications - Address item 13.

Conclusions and Recommendations - Summarize your lab experience and what was learned. Which experiment performed best? Worst? Suggest possible improvements to the experimental setup or procedures.

Acknowledgements - Describe assistance or contributions provided by classmates or others (not including group members who authored the report).

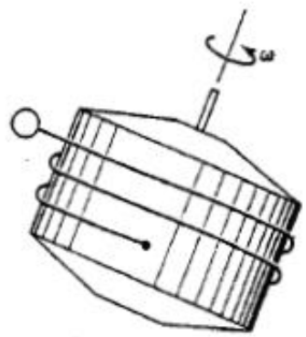
Appendix A - List the contributions of each member of the group and have group members initial this page.

Appendix B - Detailed step-by-step derivation.

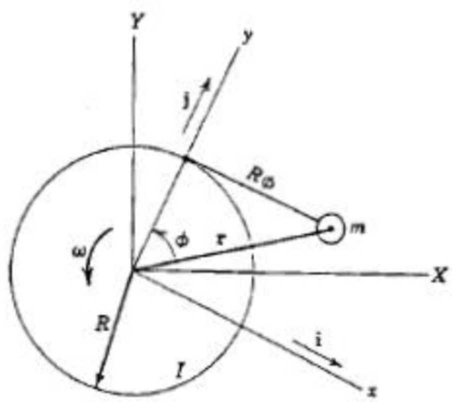
8.1 Report Grading

	Title Page
5	Abstract
	Table of Contents
15	Theory
15	Procedure and Experimental Setup
30	Results and Analysis
5	Conclusions and Recommendations
5	References & Acknowledgements
15	Appendix A
10	(Style and Clarity - includes title page, table of contents, organization, grammar, spelling)
100	

Appendix A: Thompson 1961



Despinning device for a satellite.



Unwinding of mass *m*.

The device may be analyzed as follows. Since m is small, the body may be assumed to spin about the geometric axis of symmetry of the body 0, with moment of inertia I and angular velocity ω. We attach the X, Y coordinate axes to the body and allow a second set of axes x, y to rotate relative to the body so that the y axis always passes through the tangent point of the cord.

We will assume that initially m was in contact with the cylinder at the X axis, in which case the length of cord extending beyond the tangent point is equal to the arc length $R\phi$. The position of m is then,

$$\mathbf{r} = R\phi\mathbf{i} + R\mathbf{j} \tag{1}$$

Since the axes x, y are rotating with speed $(\omega + \dot{\phi})\mathbf{k}$, the velocity of m is

$$\begin{aligned} \mathbf{v} &= \dot{\mathbf{r}} + (\omega + \dot{\phi})\mathbf{k} \times \mathbf{r} \\ &= R\dot{\phi}\mathbf{i} + (\omega + \dot{\phi})R\phi\mathbf{j} - (\omega + \dot{\phi})R\mathbf{i} \\ &= -R\omega\mathbf{i} + R\phi(\omega + \dot{\phi})\mathbf{j} \end{aligned} \tag{2}$$

[*Thompson*, 1961]

The angular momentum of the mass m is,

$$\begin{aligned}\mathbf{h} &= \mathbf{r} \times m\mathbf{v} \\ &= (R\phi\mathbf{i} + R\mathbf{j}) \times m[-R\omega\mathbf{i} + R\phi(\omega + \dot{\phi})\mathbf{j}] \\ &= mR^2[\omega + \phi^2(\omega + \dot{\phi})]\mathbf{k}\end{aligned} \qquad (3)$$

and the total angular momentum is

$$\mathbf{H} = \{I\omega + mR^2[\omega + \phi^2(\omega + \dot{\phi})]\}\mathbf{k} \qquad (4)$$

The system kinetic energy T is the sum of the kinetic energy of the satellite and m.

$$\begin{aligned}T &= \tfrac{1}{2}I\omega^2 + \tfrac{1}{2}mv^2 \\ &= \tfrac{1}{2}I\omega^2 + \tfrac{1}{2}m\{(R\omega)^2 + [R\phi(\omega + \dot{\phi})]^2\} \\ &= \tfrac{1}{2}I\omega^2 + \tfrac{1}{2}mR^2[\omega^2 + \phi^2(\omega + \dot{\phi})^2]\end{aligned} \qquad (5)$$

Since the system has no external forces and no dissipation of energy, the kinetic energy and angular momentum must remain constant and equal to their initial values. Letting the spin rate at $t = 0$ be ω_0,

$$T = \tfrac{1}{2}(I + mR^2)\omega_0^2 = \tfrac{1}{2}I\omega^2 + \tfrac{1}{2}mR^2[\omega^2 + \phi^2(\omega + \dot{\phi})^2] \qquad (6)$$

$$H = (I + mR^2)\omega_0 \quad = I\omega + mR^2[\omega + \phi^2(\omega + \dot{\phi})] \qquad (7)$$

Dividing through by mR^2 the two equations become,

$$C(\omega_0^2 - \omega^2) = \phi^2(\omega + \dot{\phi})^2 \qquad (8)$$

$$C(\omega_0 - \omega) = \phi^2(\omega + \dot{\phi}) \qquad (9)$$

where

$$C = \frac{I}{mR^2} + 1 \qquad (10)$$

Dividing the first equation by the second, we find,

$$\omega + \omega_0 = \omega + \dot{\phi}$$

Therefore,

$$\begin{aligned}\omega_0 &= \dot{\phi} \\ \omega_0 t &= \phi\end{aligned} \qquad (11)$$

which tells us that the mass m unwinds at a constant rate. Substituting for ϕ and $\dot{\phi}$ in Eq. 5–9, the spin rate at any time becomes

$$\omega = \omega_0\left(\frac{C - \phi^2}{C + \phi^2}\right) = \omega_0\left(\frac{C - \omega_0^2 t^2}{C + \omega_0^2 t^2}\right) \qquad (12)$$

The spin may be reduced to any desired value ω_f by choosing the proper length of cord, and releasing it when completely unwound. If l_f is the length selected, the terminal value of ϕ is,

$$\phi_f = \frac{l_f}{R} \tag{13}$$

and from Eq. 7.5–12,

$$\omega_f = \omega_0\left(\frac{C - \phi_f^2}{C + \phi_f^2}\right) = \omega_0\left(\frac{CR^2 - l_f^2}{CR^2 + l_f^2}\right) \tag{14}$$

Solving for l_f, the required length of cord is,

$$l_f = R\sqrt{C\frac{\omega_0 - \omega_f}{\omega_0 + \omega_f}} \tag{15}$$

If the terminal angular velocity is to be zero, l_f becomes,

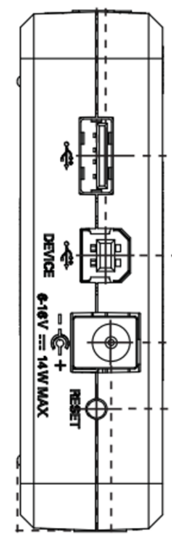
$$l_f = R\sqrt{C}$$
$$= \sqrt{R^2 + \frac{I}{m}} \tag{16}$$

For symmetry, two cords with masses $\frac{1}{2}m$ can be used as shown figure below. the result being the same as that for one mass of value m.

[*Thompson*, 1961]

Appendix B: Yo-Yo Despinner Operational Procedure

Setup Procedure:
NOTE: The lab assistants have likely completed these steps correctly but everything should be confirmed prior to operation. The order of operations for power up is **IMPORTANT!**. Follow these steps carefully and in the correct order listed:



1. Use the clamp provided to secure the spin model base to the cage. Place the clamp on the base plate at the spot labeled "clamp here".
2. Check that you have completed step 1. Seriously, if you do not clamp the spin module down and you run the motor is will fly off the table and be damaged!
3. Connect the USB cable Type B end to the NI myRIO port labeled "DEVICE". The other Type A end connects to the lab station computer. (Do not connect to the Type A top port on the myRIO.)
4. Connect the power adapter to the barrel connector. The power light on the myRio should now be illuminated blue.
5. Wait 1-2 minutes until the status light on the myRIO turns from orange to off.
6. Connect the power adapter to the lower board connector. The power light on the lower board should now be illuminated (either green or blue).
7. Confirm the 9V batter pack has been plugged in.
8. Then plug in the power connector with red and black banana cables. The polarized black Samtec connector plugs into the base printed circuit board (PCB), while the red banana connects to the Output (+) and the black banana connects tot eh Output (-). Once verified, turn the Output ON.
9. Wait for the lower board motor controller to flash its green LED.
10. Once the above steps have been completed, turn on the satellite board power located on top, inside the spin module chassis using the red toggle switch.
11. Verify the board goes through a series of states LEDs shown near the toggle switch. The remaining LED under the switch should be Yellow and the Alive LED should be green.
12. Open the `All_Spin_Module_Labs.vi` located in your current semester's class folder but do not run the VI yet.
13. Take note of the status indicators in the bottom right corner of the VI. Here the "battery voltage" meter is displaced. If this battery voltage of the satellite's onboard battery pack drops below 14V turn off the top satellite board with the red toggle switch and request staff assistance for new batteries. This is **VERY IMPORTANT** as the battery pack does not have a built-in safety cutoff implemented.
14. The green indicators show if the myRIO (on the base) and the Arduino DUE (inside the satellite) are properly connected and communicating.
15. The "Link Speed" dial is used to show the quality of the Xbee wireless communication link. A good typical speed if 1.5 or higher. If you see frequent dropouts to zero the Xbee channel may be experiencing too much interference from other wireless sources OR the battery voltage is too low.

Operational Procedure:

1. Make sure the `All_Spin_Module_Labs.vi` is open (located in your current semester's class folder) and select the Despinner tab.
2. Attach desired weights, if necessary, to spinner magnets. Pull tether string fairly taut and wrap around the cylinder. Adjust ball capture mechanism as needed to accommodate string length. (String should wrap counter-clockwise.) DO NOT allow the string or knots to catch in the slot of other mechanisms. Ensure the steel cubes are fully covering the ferrous surface of the electromagnets.
3. Tighten ball capture mechanism in place using nut. Repeat for other weight. Limit string lengths to one cylinder wrap or less to avoid tangles.
4. Place the Despinner mock spacecraft unit under the safety cage.
5. Place cover on top of safety cage and verify there are no holes or gaps in the cage.
6. Confirm all nearby lab users are wearing safety glasses. Use caution, on rare occasions the weights can still fly out of the cage. DO NOT stand directly beside the cage when the weights are released.
7. Slowly increase the motor speed using the "Base RPM" dial to 130rpm.
8. Once the module is spinning at 130 rpm, select the "Release" button to release the masses and allow the module to spin freely.
9. Once the "Release" button has been pressed, the "Take Data Despinner" button will also change to green indicating data is being collected. The VI will then automatically write the data to a file after 1,000 data points have been taken and the spin rate is less than 1 rpm. If desired, the "Take Data Despinner" button can be manually selected and "Write To File Despinner" button can be selected to save data to file.
10. Open file and verify data was collected and saved properly. Repear test as necessary.