ASEN 2003 LAB 5: YO-YO DESPINNER

- Assigned: Monday, 20 March 2017
- Report Due: Monday, 10 April 2017 (end of lab period)

OBJECTIVES

- Use motor to spin up a satellite model, "release" satellite, measure spin rate with an encoder
- Learn one simple method of 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

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 attached pages from Thompson [1961] provide a derivation of the tangential release case. It is assumed that the cord remains taut throughout the deployment and that 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 mechanism in action, compute the expected cord lengths and times to despin, and investigate how this method has been applied to a satellite mission.

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 in each of the cables

   The derivation can be typeset or handwritten in the report.

2) The total moment of inertia of the spacecraft without the despin masses is 165 lbm-in^2 and its outer radius is 4.25 in. The two despin masses are 125 gm (0.275 lbm) each. (It is helpful to convert these values to metric units for use in your calculations & code.) 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 100 rpm.

4) Derive an expression for the length of cord needed for radial release despin. 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?

EXPERIMENT

5) Observe the operation of the yo-yo despinner. Provide a sketch of the apparatus and briefly describe how it works (1-2 paragraphs).
6) Watch the high speed video and describe how the actual mass deployment compares with theory (1-2 paragraphs).
7) Using your computed cord length for radial release, cut the cords and conduct the experiment.
8) 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.

RESULTS AND DISCUSSION

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 on the same graph as your model. Note on the graph the point at which the string reaches its full length in 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?

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?

ACKNOWLEDGEMENTS

The yo-yo despinner lab was originally developed by Robert Culp and Walt Lund, with revisions due to K.C. Park, Trudy Schwartz, Matt Rhode, and Penina Axelrad.

REFERENCES

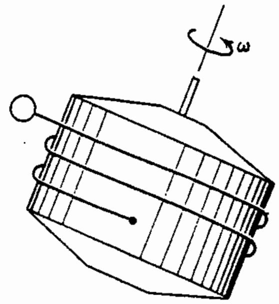
Curtis, H.D., *Orbital Mechanics for Engineering Students*, Elsevier, Burlington, MA, 2005.
Eide, D.G., and C.A. Vaughan, *Equations of Motion and Design Criteria for the Despin of a Vehicle by the Radial Release of Weights and Cables of Finite Mass*, NASA Technical Note D-1012, January 1962.
Thompson, W.T., *Introduction to Space Dynamics*, J. Wiley & Sons, New York, 1961.
Wiesel, W.E., *Spaceflight Dynamics*, McGraw-Hill, New York, 1989.

REPORT CONTENTS & GRADING

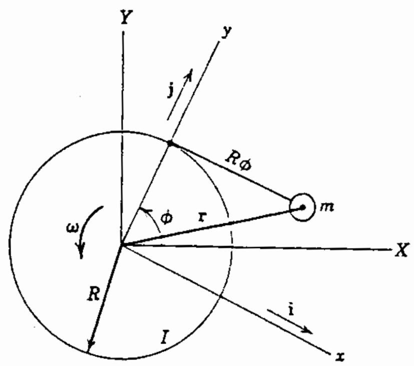
Title Page - Lab# and Title, Course Number, Student Names, Date Submitted
(5 pts) ABSTRACT
(20 pts) THEORY
(10 pts) EXPERIMENT
(20 pts) RESULTS AND DISCUSSION
(20 pts) APPLICATIONS
(5 pts) CONCLUSIONS & RECOMMENDATIONS
REFERENCES - List reference material used in professional format. Each reference must be cited in the text.
ACKNOWLEDGMENTS - Briefly describe assistance or contributions provided by classmates or others
APPENDIX - Include your code (part of the grade in the model and results sections).

(20 pts) Style and Clarity
100 Total

[*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,

$$\phi_f = \frac{l_f}{R} \qquad (13)$$

and from Eq. 7.5–12,

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

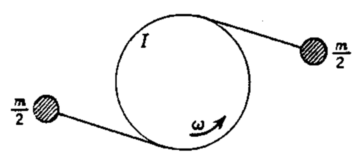
Solving for l_f, the required length of cord is,

$$l_f = R\sqrt{C\frac{\omega_0 - \omega_f}{\omega_0 + \omega_f}} \qquad (15)$$

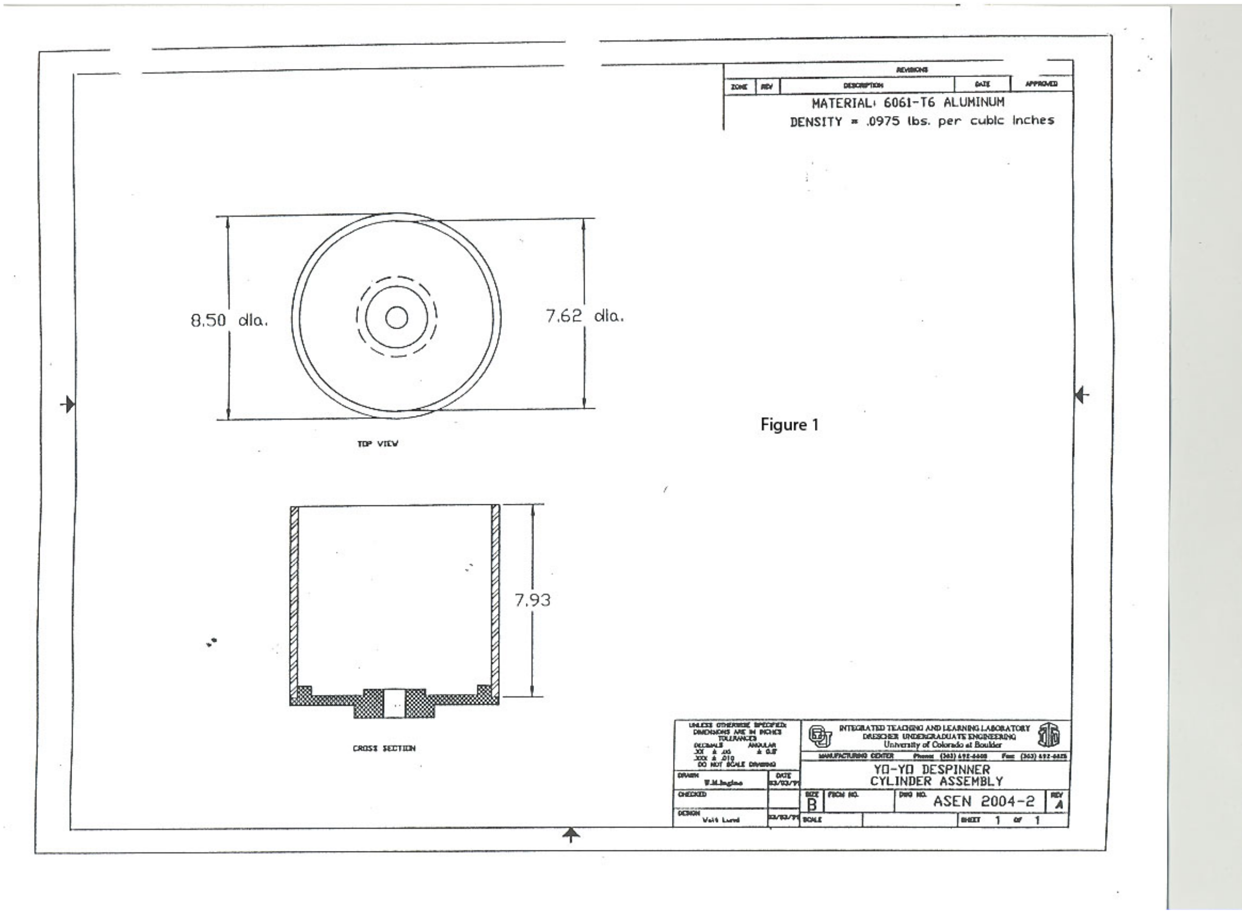
If the terminal angular velocity is to be zero, l_f becomes,

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

For symmetry, two cords with masses ½m can be used as shown figure below. the result being the same as that for one mass of value m.



[*Thompson*, 1961]


MATERIAL: 6061-T6 ALUMINUM
DENSITY = .0975 lbs. per cubic inches
8.50 dia.
7.62 dia.
TOP VIEW
7.93
CROSS SECTION
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DO NOT SCALE DRAWING
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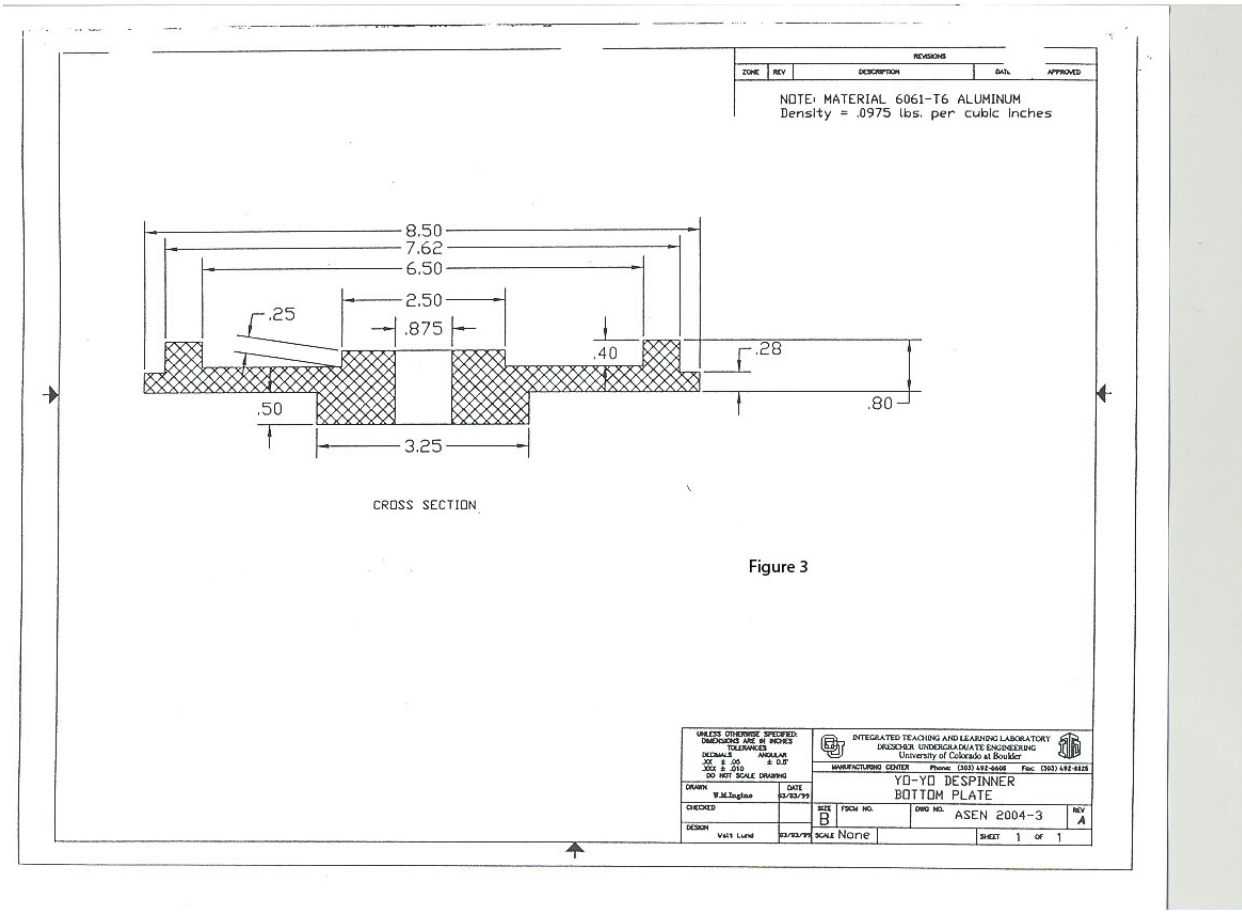
YO-YO DESPINNER
CYLINDER ASSEMBLY
ASEN 2004-2
SHEET 1 OF 1

Figure 1


REVISIONS
ZONE
REV
DESCRIPTION
APPROVED
NOTE: MATERIAL 6061-T6 ALUMINUM
Density = .0975 lbs. per cubic inches
8.50
7.62
6.50
2.50
.25
.875
.40
.28
.50
.80
3.25
CROSS SECTION
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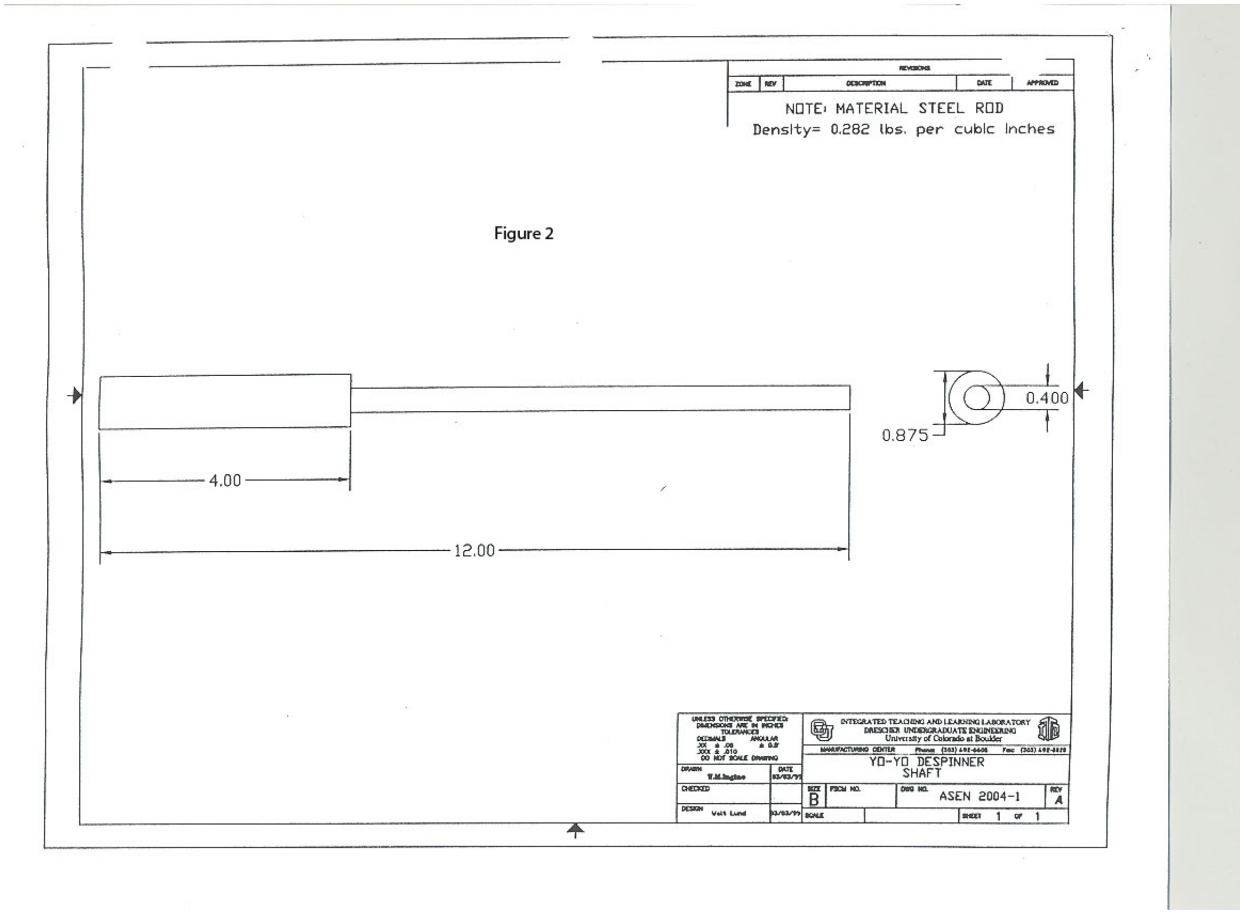
YO-YO DESPINNER
BOTTOM PLATE
B
ASEN 2004-3
A
None
SHEET 1 OF 1

Figure 3



NOTE: MATERIAL STEEL ROD
Density= 0.282 lbs. per cubic inches
0.400
0.875
4.00
12.00
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DRESCHER UNDERGRADUATE ENGINEERING
University of Colorado at Boulder
YO-YO DESPINNER
SHAFT
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Figure 2