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In This Issue

What Length of Elastic Shock Cord?

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What Length of Elastic Shock Cord?

By Bruce and Nicholas Fette

I recently began a downscale build of the Gila Monster [1] design, scaling all dimensions to match a 5.5" body tube. I previously built a half scale model in Arizona, but I needed a smaller version for East Coast use (considering the rocket eating trees). The original Gila Monster was built by the "HillBilly Rocketry from Arizona" and flown at Superstition Space Modeling Society, Turkeyfest in Nevada, and other western ranges (see Figure 1). As I was completing the build, the question of how long and how strong the shock cords should be came up. So I did some research to derive an analysis-based answer.

Figure 1 – Gila Monster – Build and flown by the "Arizona Hillbillies" of Superstition Space Modeling Society.

Background: For rockets using A,B and C motors and weighing less than a pound, and with parachutes less than 12 inches, a ¼" rubber band about 2 feet long seems appropriate (www.ApogeeRockets.com/Building_Supplies/Parachutes_Recovery_Equipment/Shock_Cord/3_8in_x_6-foot_Rubber_Ribbon). But as we get into larger rockets with F & G motors weighing up to 3 pounds, a real shock absorbing shock cord makes sense. Even more so, for Level 1 and Level 2. Then the recommendations change again for Level 3. In this article, I hope to walk through my logic of shock cord design.

Many folks have different ideas on how to design or select a shock cord. Studying the question on the web I found a common recommendation that the shock cord should be 3 times as long as the overall rocket length. I also found use of Kevlar of various sizes. But it seemed to me that for rockets under 10 pounds, perhaps the shock cord could absorb the shock of ejection and parachute inflation. I was already planning and expecting to use elastic strap as my shock cord, having previously used it successfully in all of my Level 1 and Level 2 rockets. 1" elastic strap can be found in Joann's Fabrics and Craft, and G Street Fabrics, and can be purchased (cut) from a roll in most reasonable lengths for shock cords.

I typically like to make a strong coupler sized tube by cutting a small slice out of a body tube and epoxying it back together, then epoxying a ½" nylon strap about 1 foot long to the inside, and use a few T nuts to bolt it to the inside of the body tube just above the fin case (see Figure 2). I attach my 1" elastic shock cord to this using a loop tied into the elastic strap, and to the nose cone, or to the electronics bay at a ¼ x 20 steel eye bolt. But I decided to calculate how long this elastic shock cord should be.

First, I needed to know the properties of the elastic

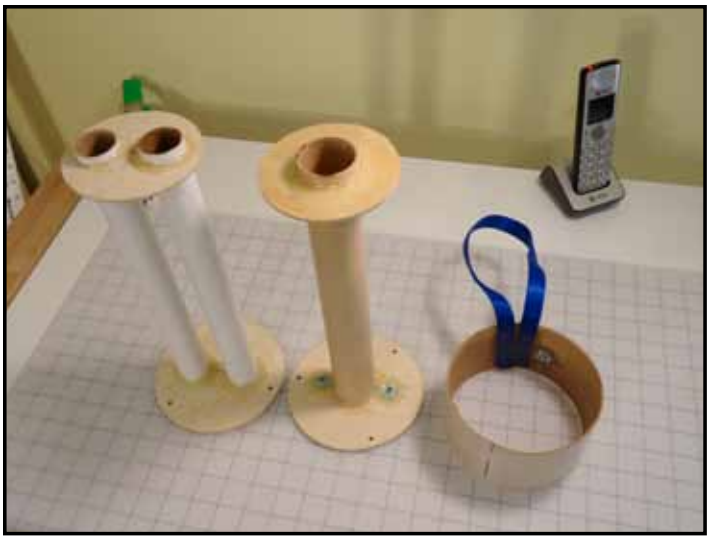

Figure 2 – A coupler tube with a nylon loop is bolted to the body tube above the fin case, and the elastic shock cord is looped around the nylon loop. This simplifies repair and refurbishment.

Continued on page 3

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Continued from page 2

What Length Of Elastic Shock Cord?

Figure 3 – Test Stand for measuring spring constant and break point properties of elastic strap.

cord. I clamped a 70 pound scale and ruler to a 2x4 (see Figure 3). I took a 10 foot length of strap, and wrapped it into 4 loops with a total of 8 parallel strands from my finger up to the weight scale. The scale measured the force on the 8 strands as I pulled down, and the ruler measured how long the 8 strands were stretched out, from the scale hook to my finger. I recorded the stretch length at each increase of 5 pounds, until it didn't stretch any more (see Figure 4 on the next page). I also did the same with 8 wraps of 10' x ½" elastic and with 30' x ¼" elastic.

Next I pulled as hard as possible on just a single loop (effectively two lengths in parallel to the scale), and recorded the force that would break the loop, for the ½" and ¼" elastic straps. Data for these measurements is shown in Table 1, and the corresponding graphs. Yes, it is a little amazing how strong it is beyond the point where it doesn't stretch any more.

The Two Forces On Shock Cords

The shock cord must endure two forces:

1) The force as the nose or electronics bay reaches the full length of the shock cord following ejection.

2) Then immediately after, the force of the parachute opening while the rocket wants to fall much faster than the parachute will allow.

Let's look at each factor, and the effect on the shock cord.

Continued on page 4

Continued from page 3

What Length Of Elastic Shock Cord?

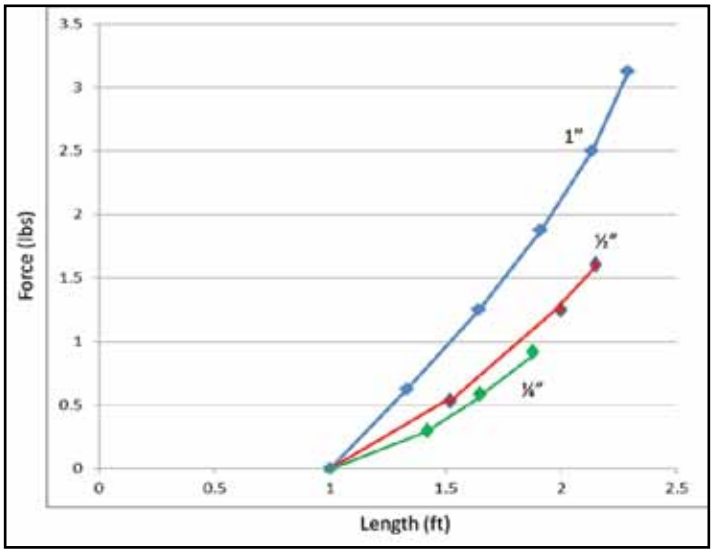

Figure 4 – Spring force measurement curves for elastic strap of ¼", ½" and 1" width. All curves normalized to a length of 1 foot, and stopped at the point where it was no longer easily stretching. The ¼" elastic broke at 26 lbs and the ½" broke at 27 lbs. The 1" sustained 34 lbs (scale limit of 70 lbs for 2 strands) without breaking.

Ejection Separation Force

Ejection and stretching the shock cord to its limit is the first thing that happens. The ejection force is a little like a cannon shooting something out of a barrel. Here I will explore the arithmetic to determine how much energy must be absorbed as the nose cone or electronics bay speeds away from the lower half of the rocket rocket with the fin case. The goal is to absorb this energy rather than just letting the rocket parts be abruptly halted by a shock cord with no stretch. If the shock cord doesn't stretch when it fully extends, then often some plywood breaks or some steel eye bolt attachment will get bent out of shape *(which is why a forged eye bolt is often used: www.ApogeeRockets.com/Building_Supplies/Misc._Hardware/1_4-inch_Forged_Eye_Bolt).*

Bear with me as we walk through the math of calculating this energy and how long the shock cord should be to absorb it.

First we need to know how much black powder is spent in ejection. I measured the black powder in an Aerotech G motor, and to the resolution of my scale it looks like 0.9 gram. I have not found data on larger motors, and I am not going to tear them apart to measure. On Vern Knowles web site [2], there is a discussion of how much BP to use for ejection charges, and the corresponding equations that enable calculating the pressure in the ejection cavity as a function of cavity volume, surface area of the bulkhead, and the amount of black powder.

From the amount of pressure, we can calculate the force on the bulkhead that will propel the nose cone / electronics bay. The length of the coupler tube defines what distance the nose cone/electronics bay will travel when being pushed by this pressure. If you use shear pins, then the energy to accomplish the shear must be subtracted

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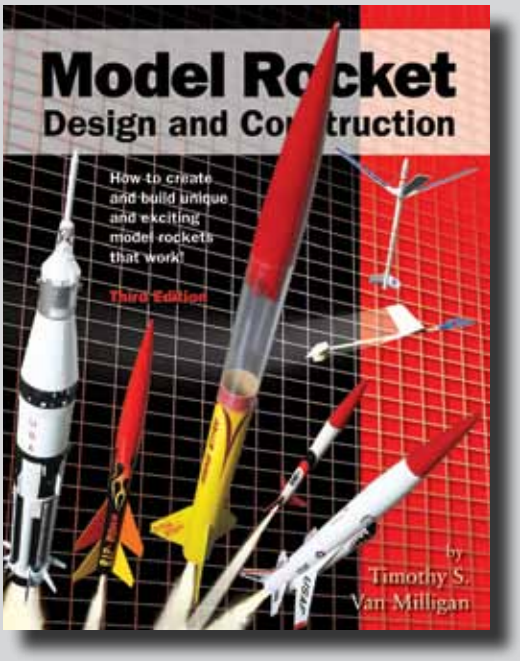

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Continued from page 4

What Length Of Elastic Shock Cord?

from the available energy propelling the nose cone/electronics bay.

So the electronics bay is accelerated from the fin case by a force applied over a distance, and thus develops kinetic energy. This energy can be measured in foot pounds or Newton meters. Energy in Newton meters is directly equal to energy in Joules. Please note that using more BP than required to assure safe ejection results in considerably more force and more energy to absorb, so while many may use 4 g of BP, 2 g is surely enough for Level 1 rockets without shear pins.

That energy can be absorbed into the elastic shock cord. The force of the shock cord pulling back on the nose cone/electronics bay increases as the cord stretches, just like most springs. The energy absorbed is captured in an equation based on this spring constant and the distance it stretches. The shock cord should be long enough to absorb all of this energy before it reaches its stretch limit.

Forces on the Level 1 Rocket

So here are the properties of my Baby Gila Monster, which we will use to analyze the ejection:

- Body Diameter – 5.36" / 0.136 m
- E-Bbay Surface area – 22.56 sq in / 0.014647 sq m
- Cavity Length to base of electronics bay – 14.5" / 0.369 m
- Length of E-Bay coupler – 6.25" / 0.159 m
- Spring constant of 1" elastic – 3.125/lbs for a stretch of 1.29 ft = 2.42 lbs/ft of stretch, or 13.89 n for a stretch of 1.28m or 10.86 n/m
- Black Powder – 1g
- Weight of Rocket (dry) – 7 lbs

Converting the elastic spring constant to metric is a little more complicated. If we take a 1 meter length and stretch it to 2.29 m we will also get 3.125 lbs. We convert 3.125 lbs to Newtons by multiplying by 4.445 so the metric spring constant is 13.89 Newtons/m.

Vern Knowle's web site derives the equations for converting grams of BP to pressure starting with:

PV=NRT

This is the ideal gass equation from physics:

Pressure * Volume = Mass * $R_{\text{gas constant}}$ * Temperature.

Vern Knowles gives us the burning temperature of Black Powder as 3307 degrees. He also provides the simplifying equation:

$N=0.006*D^2*L$ (grams) and $N=0.00052*F*L$

where N is grams of BP, D is diameter in inches, L is

Continued on page 6

Continued from page 5

What Length Of Elastic Shock Cord?

length of cavity in inches, F is force applied to the bulkhead.

The first equation defines how much BP will produce 15 psi, where D and L are in inches. However, 15 psi results in 338 lbs of force, far more force than I expect to need. My rocket weighs about 10 pounds, so less than 100 lbs of force will overcome the friction of the electronics bay coupling, including wind resistance on the nosecone. 1g of black powder will produce 132.6 lbs of force.

That force is applied over a distance of the length of the coupler. In metric equivelant of 132 lbs is 587 newtons, 6.25" is 0.159m so the energy applied to eject the E-bay is 587*.159 = 93.4 newton meters (or Joules)

The shock cord absorbs energy by the equation $E=1/2 * K * DL^2$ or $DL = SQRT (E/(0.5*K))$

Where K is the spring coefficient of the shock cord and DL is the stretched distance of the shock cord.

DL = sqrt (93.4/(0.5*10.86)) = 4.14 m

So 4.14 meters when stretched, is 1.82 m when not stretched. To be conservative, we need at least 2 m of shock cord to absorb the ejection energy of 1g BP in my Baby Gila Monster cavity. I will be happier with more length because of the inexact measurement of black powder, since my scale doesn't have very fine resolution.

Measuring BP

Recently I purchased a PerfectFilte Stratologger (www.ApogeeRockets.com/Electronics_Payloads/Altimeters/PerfectFlite_StratoLogger_Altimeter). The corresponding manual [4] is excellent and includes an equation for figuring out just how much BP is a gram, since it is very hard to come by a scale that can measure 1.0 gram (the closest thing seems to be an Ozeri Digital Kitchen Scale model ZK14-B, which can resolve thousandths of a pound, and 1 gram is 0.0022 of a pound and so it shows 1 gram as 0.002). The Stratologger manual says specific gravity of BP is 0.95 grams/cc, so if you have a "yellow nozzle cap plug measure the inside diameter and depth in centimeters, then calculate volume," and from the volume calculate the grams as follows:

Grams BP = "(0.7854*diameter*diameter*depth)*0.95"

Table 1 provides the depth measurement in mm for a yellow nozzle cap, for a Coca Cola red bottle cap, a PVC end cap, and a small vial for BP amounts from 1 to 4 grams.

Continued on page 7

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Continued from page 6

What Length Of Elastic Shock Cord?

Figure 5: Measuring black powder without a scale by calculating volume of the container. Here is a yellow nozzle cap, a Coca Cola red bottle cap, a PVC end cap, and a small medical vial.

		BP depth mm			
	cap dia (mm)	1g	2g	3g	4g
yellow cap dia - cesaroni 29 & 38 mm nozzle cap	20.25	3.3	6.5	9.8	13.1
red Coca Cola 12 oz bottlecap	26.25	1.9	3.9	5.8	7.8
Small PVC end cap	21.2	3.0	6.0	8.9	11.9
clear plastic vial	9.1	16.2	32.4	48.6	64.7

Table 1: The container measurement depth for calculating the amount of black powder.

Chute Opening Forces

If you design your rocket and delay perfectly, and there is absolutely no wind, the rocket will pop the chute exactly at apogee and with zero velocity. This doesn't happen very often. If the delay is early or late, the rocket has substantial velocity when the chute pops. And if there is any wind, the rocket weather cocks toward the wind and has substantial velocity as it reaches apogee. I am reminded of this because it seems that when I switched from an Aerotech G motor with 7 second delay to a Cesaroni G drilled down to a 7 second delay, the Cesaroni motor seemed to be about 2 seconds later than apogee, and kept me very excited until the chute popped.

So I did a study to see what velocity the rocket would have at what delay after apogee. Using Rocksim V9, I programmed the motor delay in 1 second steps beyond apogee, from 1 second late, to 4 seconds late, and recorded the velocity at ejection as reported by Rocksim (a handy feature) see figure 6.

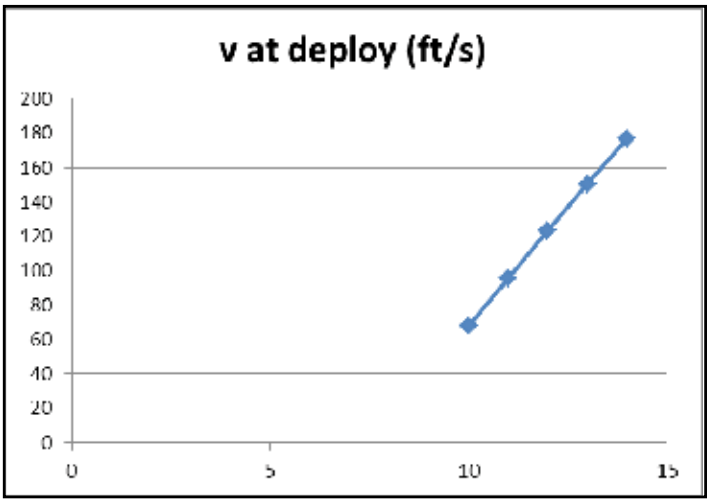

Figure 6 – Velocity of my rocket (ft/s) at moment of ejection in 1 second steps after apogee from Rocksim.

Since all things are accelerated by gravity the same way, these will approximately estimate velocity for any rocket that has low aerodynamic drag. As we can see, just a little excess delay can result in considerable velocity.

Then I used the Coefficient of Drag from Rocksim's parachute model, and the equations from Wikipedia[3] to

Continued on page 8

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Continued from page 7

What Length Of Elastic Shock Cord?

calculate drag force for several sizes of drogue parachute ranging from 12 inch to 48 inches at the velocity of the rocket at the time of ejection. The drag force will apply immediately to the shock cord as soon as the parachute pops and the shock cord stretches out.

Yes, eventually the rocket slows down until the velocity of the rocket and parachute drag matches the weight of the spent rocket. So there is a substantial spike in stress on the shock cord until it slows down. As we can see in Table 2, using a large drogue chute can create enough force to break an elastic shock cord. Similarly, having the ejection delay be more than 4 seconds later than apogee can result in a very large force.

Chute Diameter (in)	force at 95.7 ft/s	force at 123.2 ft/s	force at 150.4 ft/s	force at 176.9 ft/s
12	6.37	10.56	15.73	21.76
20.7	18.95	31.41	46.81	64.76
36	57.32	95.00	141.58	195.87
48	101.91	168.89	251.70	348.22
60	159.23	263.90	393.29	544.09
75	248.80	412.34	614.51	850.14

Table 2. Pounds of force on the parachute at ejection for various deployment velocities. Breakage tension on a single piece of 1" elastic strap is somewhat above 34 pounds.

Cdrag = dragforce/(0.5*rho*V^2 * A) or dragforce = 0.5 * Cdrag * rho * V^2 * A (all metric units)

Note that Rocksim reports a Cd for the parachute of 0.75, Wikipedia reports a rho of 1.2 kg/m^3, and it takes a great deal of care to convert everything to metric units, and back to pounds of force.

So we now see that the elastic shock cord can easily experience sufficient force to break if the ejection is late, or if the chute is large. With long shock cords, the rocket will lose momentum due to air friction drag after ejection, so longer than minimum length is better.

My Level 2 Rocket

I was able to use this same design methodology for my Level 2, which was small enough and light enough. However, I recognize that for a body over 10 lbs, it is really important to be sure that all forces can stay sufficiently below breakage.

Level 3

For my Level 3 Rocket, I used 1" nylon strap risers (greater than 1200 lbs breakage tension) 20 feet long for shock cord both above and below the electronics bay. Note that this gives the entire rocket and electronics bay a considerable jolt when it reaches fully stretched, and at this point, yes, it is a good idea to get welded or forged eyebolts, and to use at least ¾" of birch plywood. For those really big projects everything just has to be built really strong. But if you can put about 10 loops of 1" shock cord as the last 2 feet, then the shock can be sufficiently reduced to reduce likelihood of breakage at full extension.

References

[1] Web sites regarding the Gila Monster Photos: http://www.ahpra.org/gila.htm

[2] Vern Knowles Web site about BP and ejection charges: http://www.vernk.com/EjectionChargeSizing.htm

[3] Wikipedia Drag Coefficient: http://en.wikipedia.org/wiki/Drag_coefficient

[4] Stratologger SL100 Users Manual, PerfectFlite, p. 36