The Princess and the Frog: ME 112 Jumping Robot Report

Amanda Guerra, Susana Martinez, Mini Racker, Analese Steverson Pugh

Contents

I. Executive Summary

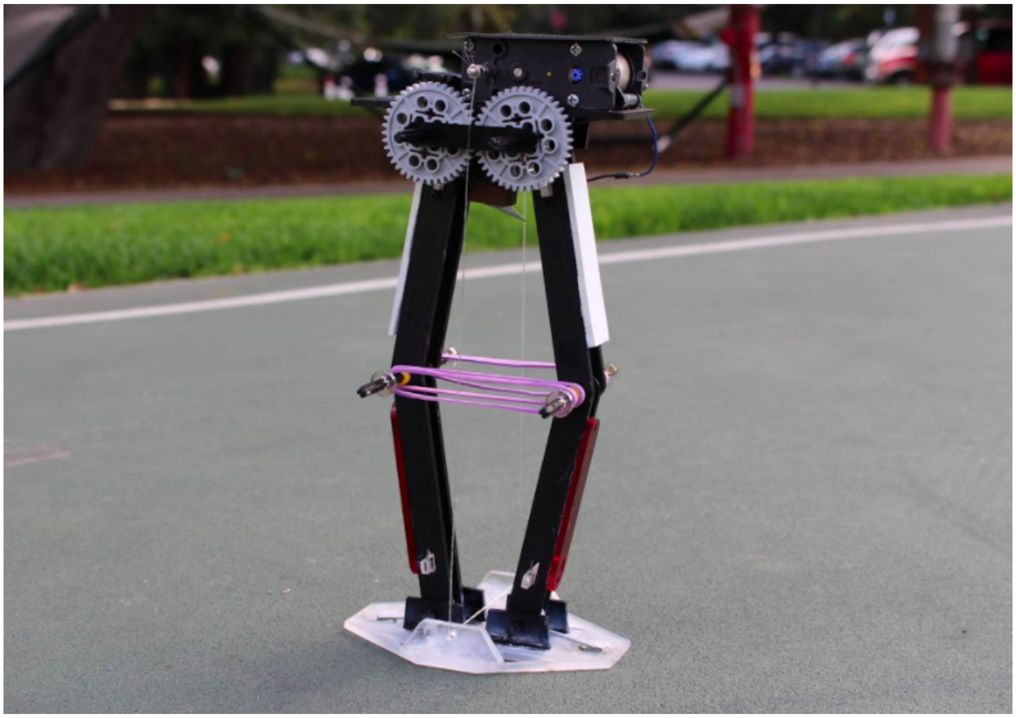

Figure 1. The Frog, in all of its glory.

In order to create a device that could jump one vertical meter, we built a biomimetic robot modelled after a frog. Our design in Figure 1, The Frog, utilizes frog-like legs, which jump by means of stressed torsion springs and rubber bands. Gears fixed to the tops of the legs help limit the robot's degrees of freedom, so it moves straight down instead of collapsing to one side as it is compressed by a motor. The motor achieves this compression by winding up a cable attached to the bottom platform; as the robot is compressed, the springs and rubber bands store energy.

At maximum compression, the robot meets the project requirements, measuring smaller than 0.1 meters in height and 0.3 meters in width. Once fully compressed, a blade attached to the undercarriage of the motor platform severs the cable, allowing the rubber bands and springs to release 5.31 J of stored energy. All in all, our design performed well, winding and releasing itself in just under ten seconds, and sticking to a surface one meter above with velcro.

From our testing, we determined a few important parameters for redesign. For one, we would better support the gears at the top of the legs to ensure they did not slip. Then, we would add gears to the bottom of The Frog's legs in order to minimize the robot's degrees of freedom even further. Additionally, using pulleys on the robot's base, instead of holes, would minimize losses to friction in the string. Finally, we would run our jumper at double the voltage (7 volts instead of 3.5 volts) or using a different motor to ensure the robot met the 5 second wind-up requirement.

II. Background

We undertook the challenge of designing, prototyping and testing a Mynock-inspired robot that could jump one meter and stick to the underside of a faux Falcon spaceship. Because these creatures are not readily available on our planet, we modeled our jumper after Earth frogs. Additionally, our design was constrained by size limits of 0.3m in width and 0.1m in crouch height. Our frog had to be completely automated, be powered by a battery, and take no longer than five seconds to jump after being activated.

To get acquainted with previous solutions to similar challenges, we examined several jumping robots produced at other universities. These included Boston Dynamics' *Sand Flea* [1], California Institute of Technology's *Frogbot* [2], and Michigan State University's *Miniature Jumping Robot* [3]. After analyzing the feasibility of implementing these designs, we settled on the last of these three options for inspiration, as it jumped nearly 1 meter and included a simple release mechanism, a one-way bearing.

Through our iterative design process, we redefined our goals to produce a jumper within the timeframe of the project. Making the one meter jump and sticking to the top platform became our primary objectives. Emulating their geometry proved straightforward and allowed us to stay within size limits. Having a release mechanism that would engage five seconds after activation of the motor was our final priority.

III. Design Description

Our challenge for this project was to mimic the behavior of mynocks. However, upon further research into mynock biomechanics, we discovered that mynocks are generally legless. Therefore, our bio-inspired design goal for this project was to build a robot that stores enough energy to jump one meter by compressing its legs and jumps by releasing that energy and extending its legs in a manner similar to that of a frog (Figure 2).

Figure 2. We studied frog biomechanics for inspiration.

We studied the jumping motion of frogs by looking at videos[1] and making sketches like the one above. The distinctive bow-legged stance they assume just before jumping is what we wanted our jumper to mimic (to an extent) at maximum compression. Furthermore, since frogs generally have more horizontal motion when they jump on land, we consulted videos of frogs swimming (Figure 3) to see how we could use this almost completely horizontal motion as inspiration to create a jumper with almost completely vertical motion.

<u>Linkages and Gears</u>

We based our linkages on a jumper created by a team at Michigan State University (MSU). Their jumper met many of the specifications outlined for this project; it was small, measuring only a few centimeters, but capable of jumping 0.9 meters. Additionally, we were pleased by how the linkages mirrored frog anatomy. With modifications, we believed we could make a similar jumper meet our design goal.

Thus, our design consists of two "legs," each composed of two links (Figure 4). Each link is composed of two parallel pieces of acrylic, and is attached with pin joints at the "hips," "knees," and "ankle. The MSU jumper utilizes torsion springs at the hips and ankles for stability. However, due to our jumper's higher mass, the springs we selected did not adequately limit the robot's degrees of freedom. Consequently, we added gears fixed to the upper two links to ensure that they would rotate at the same rate as each other, taking our jumper's degrees of freedom down from 3 to 2 (calculated using Grubler's equation, where N is the number of links, F_1 is the number of pin joints, and F_2 is the number of sliding joints):

$$DoF = 3(N-1) - 2*F_1 - F_2$$
$$DoF = 3(6-1) - 2*6-1 = 15-12-2 = 2$$

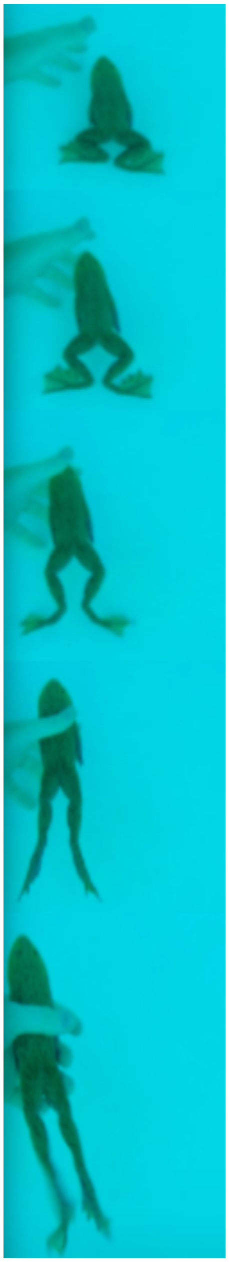

Figure 3. A frog extends its legs while swimming [5]

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[1] National Geographic, "Frog Jumps Caught in Slow Motion." https://www.youtube.com/watch?v=yKpJElwama8

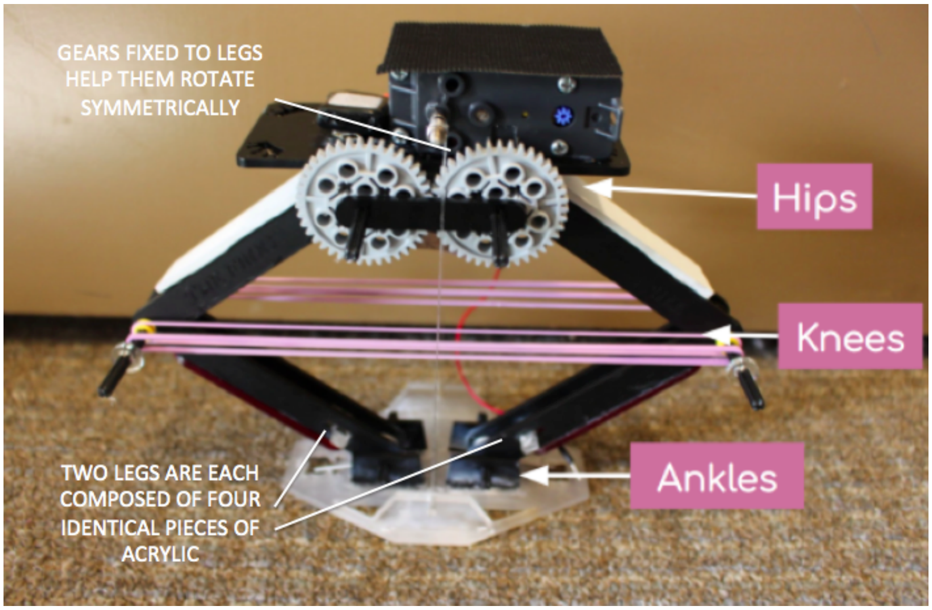

Figure 4. Our linkages are modelled directly on the legs of a frog, with gears at the upper joints to limit the robot's degrees of freedom and create stability.

<u>Energy Storage Components</u>

We used both torsion springs and rubber bands as energy storage components of our design. Two torsion springs (k = 0.5826 Nm/rad) are attached to the ankles, two torsion springs (k = 0.1928 Nm/rad) at the hips, and four rubber bands at the knees (Figure 5). We initially tried using four torsion springs (k = 0.5826 Nm/rad) at the hips and ankles to store all energy; however, the motor was not able to exert enough torque to compress so many stiff springs. Stiff springs placed only at the ankles (Figure 6) did not store enough energy to reach the required jump height, so we added rubber bands to meet the energy storage requirements. Finally, we added the weaker torsion springs, primarily to encourage the legs to bend at the same rate, at the hip joints.

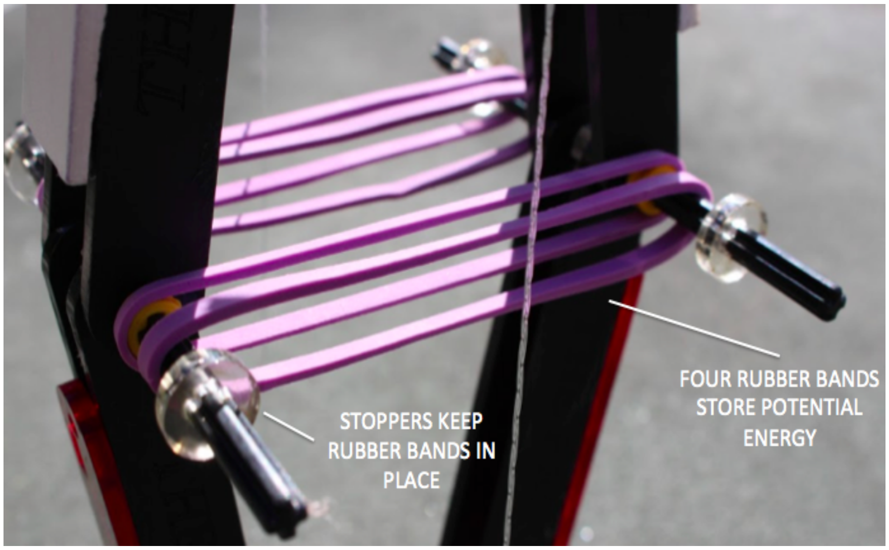

Figure 5. Two rubber bands are stretched across each side of the robot at the knees.

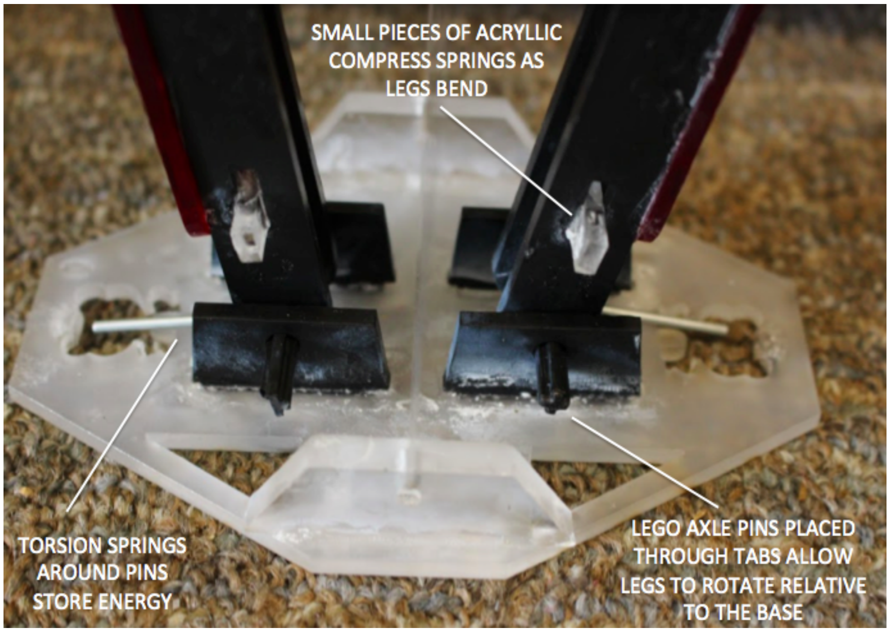

Figure 6. This image illustrates the base and ankles of our jumper, where two relatively stiff torsion springs are wound as the legs bend.

Strength

In order to improve the strength our leg linkages, we added strips of thin plastic to form C-channels across each leg (Figure 7). Without these, we found that the acrylic legs experienced too much torsion and snapped when our jumper was released; once we added them in, the legs functioned properly.

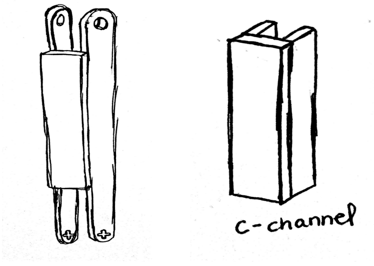

Figure 7. We created C-channels by gluing plastic across the acrylic links.

Platforms and Weight

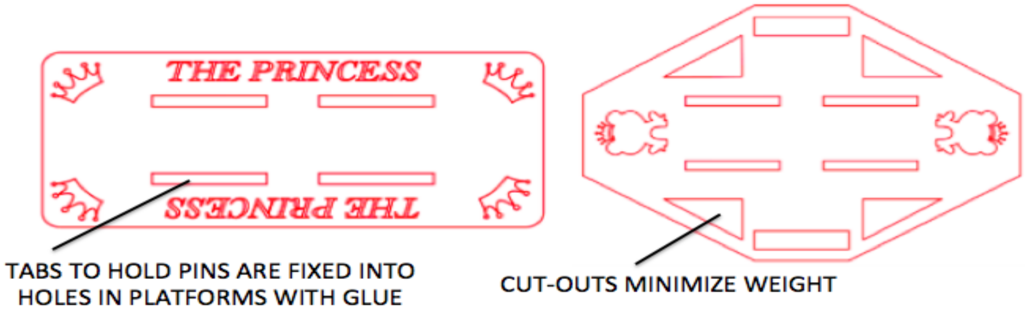

Figure 8. We designed platforms with the appropriate (themed!) cut-outs in Adobe Illustrator.

The “foot” of our biomimetic robot was implemented using an octagonal bottom platform (Figure 8). The shape of the platform was informed by the need to reduce the weight of our jumper as much as possible.

As a result, instead of the two large rectangular platforms we originally used in our design, we removed the corners on the bottom platform and reduced the dimensions as much as we could without impeding our ability to attach the linkages, springs, and release mechanism. The top platform retained its rectangular shape, however, we optimized its dimensions to accommodate the width of our motor gearbox and provide room to offset the motor’s position relative to the linkages. Additionally, both platforms have cut-outs in strategic locations, which was another way to reduce the weight while maintaining structural integrity. We chose acrylic as our primary material due to its light weight (compared to metal) and high strength (compared to duron, birchwood or basswood).

Battery and Motor Choice

We used the Tamiya RE-260RA-2670 Motor provided to us to control our device. Though we could have selected a smaller motor, we found that the power our chosen motor supplied easily made up for its weight. Additionally, the Tamiya motor connected easily with a gearbox which allowed use to achieve our desired gear ratio, a benefit which a different motor would not provide. Section IV. provides additional calculations supporting our motor choice.

Our jumper was powered by a single 3.7 volt lithium battery. We selected this battery due to its small size and low weight. While we could have run our jumper at a higher voltage, we chose 3.7 because our motor is rated to run at 1.5 volts, and we were initially wary of far exceeding this limit.

Gear Train

We selected a gear ratio of 196.7:1. This was the second-highest setting that could be easily achieved with the gearbox provided. It helped ensure the robot could easily provide the 0.167 milliNewton-meters of torque needed to compress our robot, but also that it ran at a reasonably fast speed, so we could charge the springs in as close to five seconds as possible.

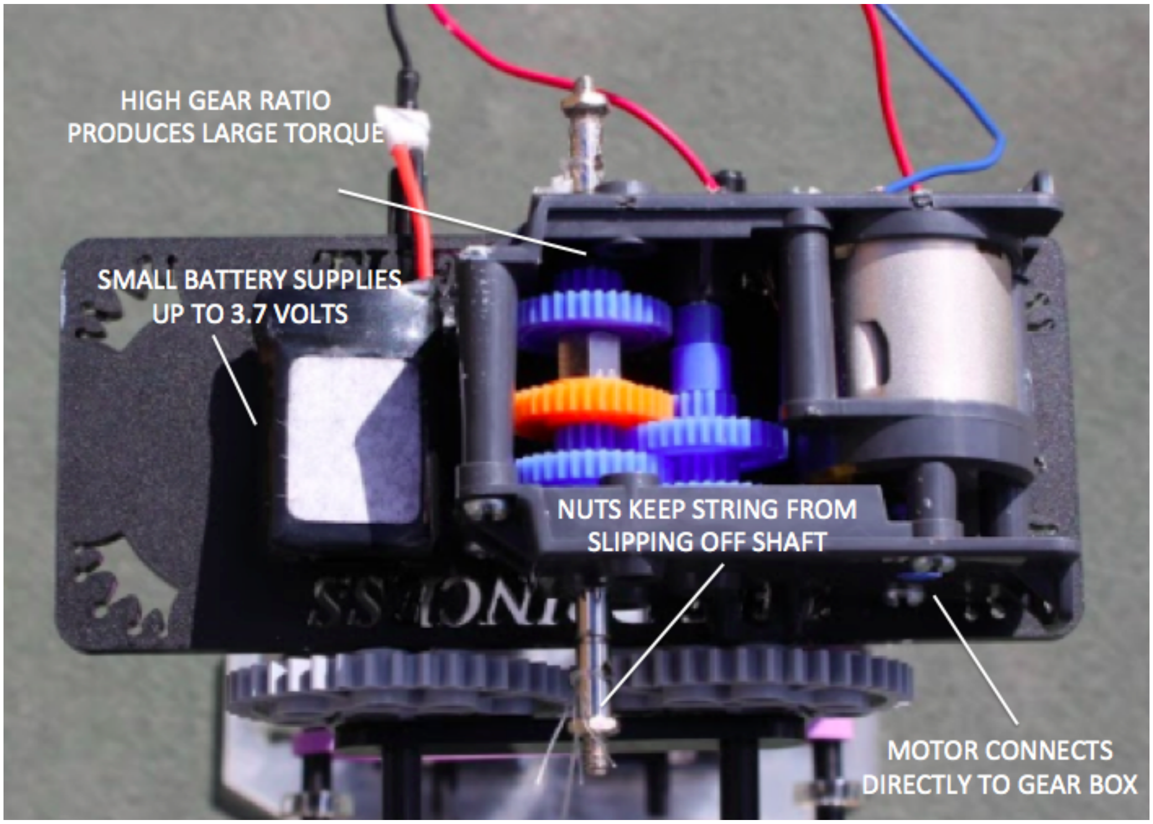

Figure 9. This photo of our robot's upper platform illustrates how we used a gearbox to ensure the motor would supply enough torque, and how the robot compressed itself by winding a string directly around the gearbox's output shaft.

String

We chose to use fishing line to wind down our jumper due to its light weight, high strength, and low friction. The line is tied to the output shaft on both sides of the gearbox (Figure 9), and kept from slipping off by two nuts. It is run through holes in two tabs on opposite sides of the bottom platform (see Figure 10). As the motor spins and winds the string up, the top platform is pulled towards the bottom of the jumper, compressing it.

Despite the fishing line being able to withstand a large amount of force, we found that it would often break during the release phase of our testing. We assessed that the sharp corners created by the geometry of our string brackets, coupled with the large tensile forces we placed on the string during each test, was causing it to wear down quickly and snap. Our solution, due to time constraints, was to braid three strands of the fishing line into one in order to make it even stronger. After we began using the braided line, we stopped experiencing breakage during the release phase.

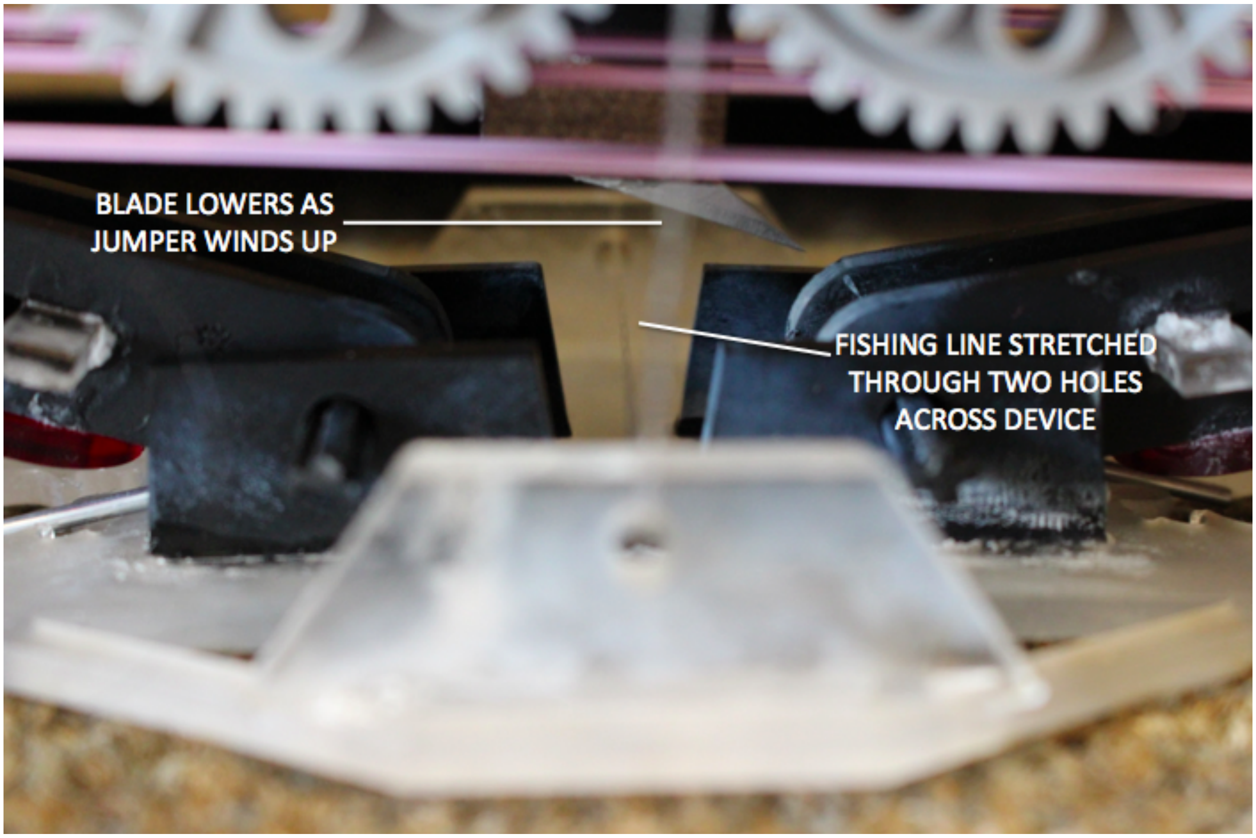

Figure 10. The fishing line winding the robot is stretched taut above the bottom platform. As the top platform moves toward the bottom one, the blade attached to it moves toward the string. At full compression, the blade hits the string and cuts it, releasing the robot.

Release Mechanism

Our release mechanism consists of a small blade fixed to the underside of the motor platform. As the fishing line winds, compressing the robot, the blade moves closer and closer to where the fishing line is stretched across the robot. Upon maximum compression, it severs the cable to initiate the jump.

Further documentation of our design process can be found in Appendix A.

IV. Analysis of Performance

The potential energy associated with getting our crawler to a specified height was given as:

$PE = m*g*h$

Since height was given to us, h = 1 meter. The gravitational acceleration, g, is a constant, 9.81 $m/s^{2,}$ and the final mass of our jumper was 250 grams, or .25 kg. Thus, the potential energy necessary to reach the required jump height was:

$PE = 0.25\ kg * 9.81\ m/s^2 * 1m = 2.45$ Joules

However, in actuality, our energy storage components needed to store a lot more than 2.45 joules due to energy losses. In order to determine the magnitude of these losses, we performed several tests on our device, as well as analysis of a jumper created in Working Model (WM2D). Working Model was helpful in making decisions throughout our design process and invaluable to our final analysis. A full explanation of our model can be found in Appendix B.

Friction and Energy Losses in the Motor

Our design features 90° torsion springs at the hip joints, which have $kt_1 = 0.1928$ Newton-meters/radian, as well as 90° torsion springs at the ankles, which each have $k_{t2} = 0.5826$ Newton-meters/radian. Additionally, we used four rubber bands stretched across the knee joints to store potential energy. We modelled these four rubber bands as a single spring, for which we measured $k_e = 296$ Newtons/meter.

The energy stored in all five "springs" was given by:

$PE = 2\ [\frac{1}{2}k_{t1}\theta_1^{\ 2} + \frac{1}{2}k_{t2}\theta_2^{\ 2}\ ] + \frac{1}{2}k_e x^2$

where θ_1 and θ_2 are the respective angles of twist in radians, and x is the distance, in meters, the rubber bands were stretched from their unstressed position. All torsion springs were initially at 90°, or 1.57 radians, while our unstressed rubber bands measured 0.1 meters. We found the stressed states of our energy storage elements from the geometry of our jumper in its compressed state; all torsion springs were compressed to 0.17 radians and the rubber bands were stretched to 0.26 meters. Thus, the potential energy stored by all five elements was given by:

$PE = (0.1928\ Nm/rad)((1.57 - 0.17)\ rad)^2 + (0.5826\ Nm/rad)((1.57 - 0.17)\ rad)^2 + \frac{1}{2} * 296\ N/m * ((0.26 - 0.1)m)^2$

$= 5.31$ Joules

In Working Model, we found the force needed to compress the jumper by adding a force to our model and increasing it until it was unable to jump. We found this required force as 16.5 Newtons.

We then solved for the torque required from our motor by:

$T_{MOTOR} = F * R/\text{Gear Ratio}$

where we found F = 16.5 N and R is the radius of the output shaft, which we measured as $2.0 * 10^{-3}$ meters. Our selected gear ratio was 196.7: 1. Thus, we found that our required motor torque was:

$T_{MOTOR} = 16.5\ N * 2.0 * 10^{-3}m\ /\ 196.7 = 1.67 * 10^{-4}$ Newton-meters = 0.167 milliNewton-meters.

This was well below our motor's stall torque of 6.7 mNm, which meant we could use our chosen motor to achieve the desired effect.

In order to determine the actual force needed to compress our jumper, we attached a weight to the end of our string, still attached to our motor, and ran the motor at the same voltage (3.5 volts) and current (0.48 amps) at which it operated when tensioning our device. We used the same kind of braided string attached to both shafts, as if it was compressing the device, and attached the mass at the end of the two strings. We incremented the mass until the motor was running at 0.48 amps. We found that the mass required to run at this voltage and current was 1.551 kg. We then used this mass to find the amount of force needed to compress the device, 15.22 Newtons. To estimate the power required to compress the mynock, we measured the time it took for the motor to lift the mass a specified distance. The motor was able to lift the mass 21 cm. in 12.2 seconds. We then found power with the following equation:

$$\text{Power} = \frac{Force*Distance}{Time}$$

This resulted in a power consumption of 0.2619 W.

Kinetic Energy at Liftoff

We used Working Model (Figure 11) to analyze the jumper when the mechanism released but The Frog was still on the ground. From Figure 11, we saw that the jumper achieved its peak upward velocity the moment it left the ground and that this velocity was equivalent to roughly 6.2 meters/second.

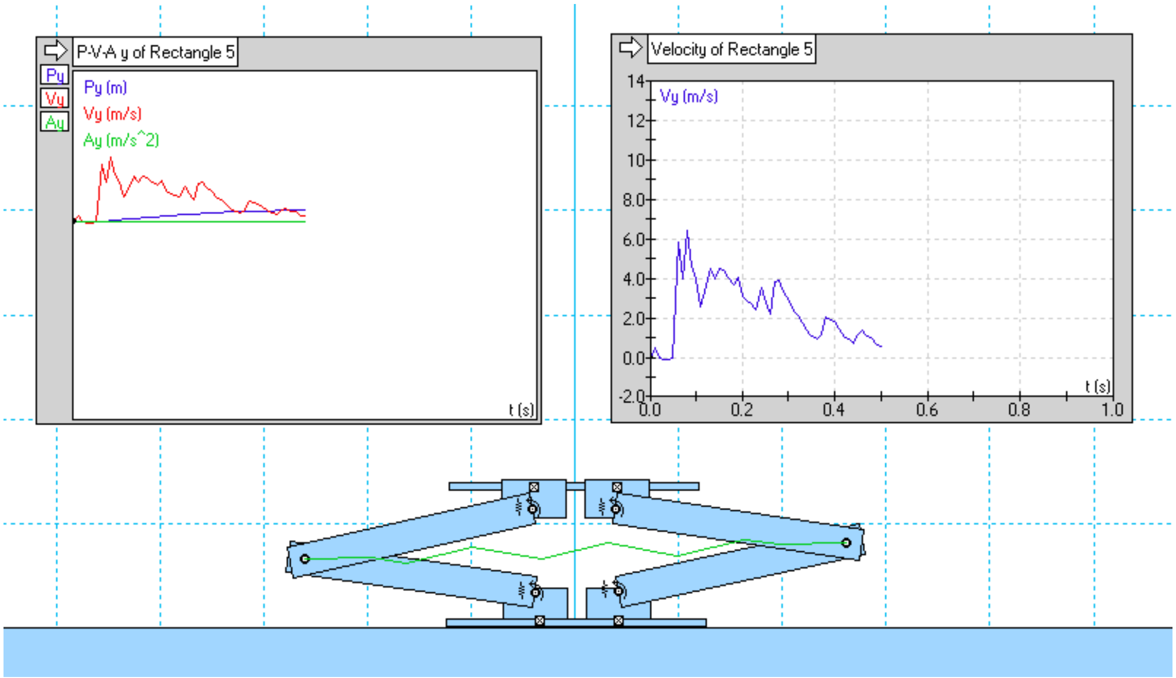

Figure 11. Our WM2D model leaves the ground at 6.2 m/s.

Using this velocity, we calculated kinetic energy at lift-off as:

$$KE = \frac{1}{2}mV^2 = \frac{1}{2} * 0.25 \text{ kg} * (6.2 \text{ m/s})^2 = 4.81 \text{ Joules}$$

However, since we found this kinetic energy using a simulation, it was likely significantly higher than the real-world kinetic energy. We checked the accuracy of our result by measuring the force our real-world robot exerted on the ground as it jumped.

In order to take this measurement, we used a force plate that recorded data for three seconds. Our period of interest was between 500 milliseconds and 600 milliseconds, when the robot had been released, but had not yet left the ground. Our raw force data for this period can be found in Appendix D; we calculated the average force as 13.77 Newtons. We then used these values to calculate kinetic energy at liftoff as:

$F = ma$

where F is the force measured in Newtons, m is the mass of the jumper in kilograms, and a is the acceleration in meters/second^2. Thus, to find impulse velocity, δV, we used impulse time, δt, as follows:

$F = m\frac{\delta V}{\delta t}$

$\delta V = \frac{F \delta t}{\delta m}$

$\delta V = \frac{(13.77\ N)(0.6\ s - 0.5\ s)}{0.25\ kg} = 5.51$ m/s

Using 5.51 m/s as our measured liftoff velocity, we find kinetic energy at liftoff as:

$KE = \frac{1}{2}mv^2 = \frac{1}{2} * 0.25$ kg. * $(5.51\ m/s)^2 = 3.8$ Joules

Though smaller than the kinetic energy calculated in Working Model, this value was still larger than the energy specified to jump a meter, 2.45 Joules; this was due to energy lost in the air.

Energy Lost in the Air

After the jumper left the ground, the main sources of energy loss were to air drag and rattling between the various components of the robot. Some of the upward kinetic energy was also lost to rotation.

We found drag force as:

$F_{AERO} = 0.5 * rho * C_d * A * V^2$

We knew the density of air, rho, is 1.225 kg/m^3 and estimated C_d at 1, a conservative value. We used V at liftoff, 5.51 m/s to find our worst-case drag force, as well as the largest upward-facing area, the full area of our bottom platform, which measured $8.4 * 10^{-3}$ m^2. Thus, we found the aerodynamic drag force is:

$F_{AERO} = 0.5 * 1.225\ kg/m^3 * 1 * 8.4 * 10^{-3}\ m^2 * (5.51\ m/s)^2 = 0.156$ Newtons

Then, we found the energy lost to drag as:

$E_{DRAG} = F_{AERO} * d$

where d was the upward distance, 1 meter. Thus the energy lost to drag was:

$E_{DRAG} = 0.156\ N * 1\ m = 0.156$ Joules

From this calculation, we noted that relatively little kinetic energy was lost to drag. Our jumper has 3.8 joules of kinetic energy at liftoff, but theoretically required only 2.45 joules to jump a meter. As a percentage of energy lost in-air, then, drag only accounted for:

$$\%E_D = \frac{0.156\ J}{3.8J - 2.45J} = 11.55\%$$

Thus, in a redesign, while we could attempt to reduce our jumper's area to decrease drag, we would likely achieve more significant improvements by making the parts fit together better to reduce rattling, or by limiting the jumper's rotational motion.

V. Conclusions and Redesign

Our final iteration of The Frog successfully completed its mission. The motor handled the loading and the blade released the jumper after 9.5 seconds, running at a voltage of 3.5 volts. The Frog was able to jump the full meter to the underbelly of the spaceship and stick to the surface. Although it was a moderately heavy jumper, with a mass of 250 grams, it had enough force to stick to the felt without falling. With our redesigned braided string and supported legs, The Frog consistently succeeded in three tests before the final demonstration.

There are some design factors that could be improved going forward, which are discussed in-depth at the end of this section. Upon activating the motor, the robot wobbles slightly as it compresses itself and often deforms the bottom platform. Using a motor that would allow a single string in tension in the middle of the device would prevent this rocking and would constrain the forces to only the vertical axis of symmetry. It was not possible to do this with our Tamiya RE-260RA-2670 motor without largely offsetting the center of mass, in which case we would have had to introduce additional mass to balance it, which would require more force to jump 1 meter. Focusing on compression with no horizontal movement would make the jumper descend faster and more efficiently.

Although we did not fully compress and release after 5 seconds, running our motor at a higher voltage would have made it faster. The nominal voltage of our motor was 1.5 volts, and already running at 3.5 volts decreased the longevity of our jumper, making it unsuitable for continuous spacecraft use. Therefore, we would ideally use a different motor, one that can supply a large torque and still run quickly.

Aside from improvements for the stability and speed of our jumper, our design worked well and met our expectations at the final demonstration. Its sleek and sophisticated design makes it a compelling device for space travel and mynock-simulating needs.

In-depth Redesign:

Improvements for the next version of the The Frog to make it adequate for use in conditions of low gravity can be encapsulated in five critical components of the design: the rubber bands, the motor, the gears, the bracket system, and the string tabs (all outlined in red in Figure 12). These adjustments would make the jumper more robust and reliable.

Use Fewer Rubber Bands

The Frog 2.0 will be used in conditions where gravity is about one half what it is on Earth. The energy required to get our crawler one meter up would also be halved as it depends linearly on the planet's resulting acceleration due to gravity ($PE = m*g*h$). Fewer springs (or in this case rubber bands) would then be needed to achieve the same vertical ascent. We would test the redesign by experimenting with only two rubber bands instead of four.

Exchange the Tamiya RE-260RA-2670 Motor for a Smaller Alternative

The torque required from the motor would decrease, as the force that is necessary to compress a lower number of springs would be reduced ($T_{MOTOR} = F * R / \text{Gear Ratio}$). We would keep the gear ratio for the new motor as close to the original one of 198 but would run it at a higher voltage to achieve a faster compression and release.

Add Gears on Lower Links

A big flaw in the reliability of our frog arose from the propensity of the legs to buckle inwards. The whole structure would also become off-centered and lean towards one side. Ideally, the torsion springs would have prevented this tendency; in actuality, one tended to bend farther than the other. In order to eliminate these limitations, we would add gears on the lower links to decrease the number of degrees of freedom of the system. This would ensure smooth vertical movement of the top platform

Include Bracket System

Because the gears in our design were placed on cantilevered shafts, they would often unmesh and cause immediate failure. Other times, they would quickly mesh again, but would make the mechanism jerk. The new design would feature a bracket as pictured in Figure 12 to securely support the rods. The brackets woud be designed so that they do not impede the links as the jumper winds down.

Replace Tabs with Pulleys

To remove the risk of breaking the string and reduce the required torque, we would replace the tabs through which the string passes with pulleys. This would create a smooth surface for the string.

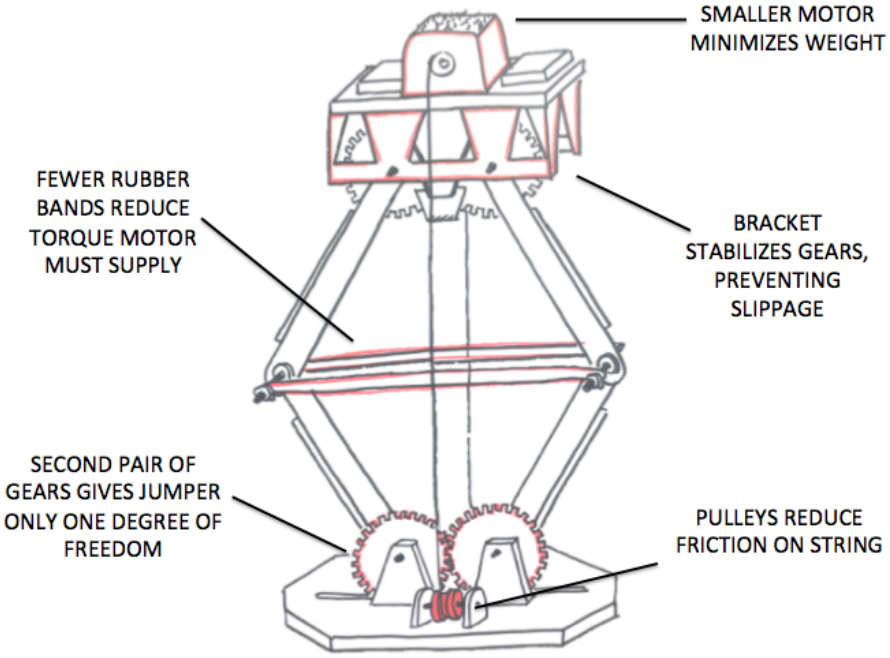

Figure 12. The Frog 2.0 is our redesigned jumper.

VI. Bibliography

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[3] Zhao, Jianguo et al. MSU Jumper: A Single-Motor-Actuated Miniature Steerable Jumping Robot. 2018. Accessed 1 Mar 2018.

[4] M. Azizi, T. Roberts, E. Abbott. “Frog Jumps Caught in Slow Motion.” *YouTube*. https://www.youtube.com/watch?v=yKpJElwama8. Accessed 1 Mar 2018.

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VII. Appendix

Appendix A: Process Images

The figures in this Appendix illustrate our prototyping process.

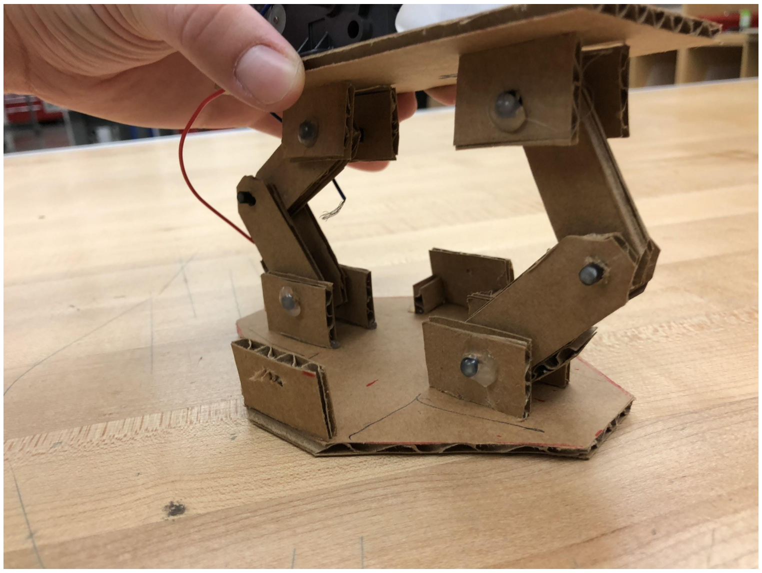


Figure 13. A cardboard prototype helped us visualize The Frog's geometry.

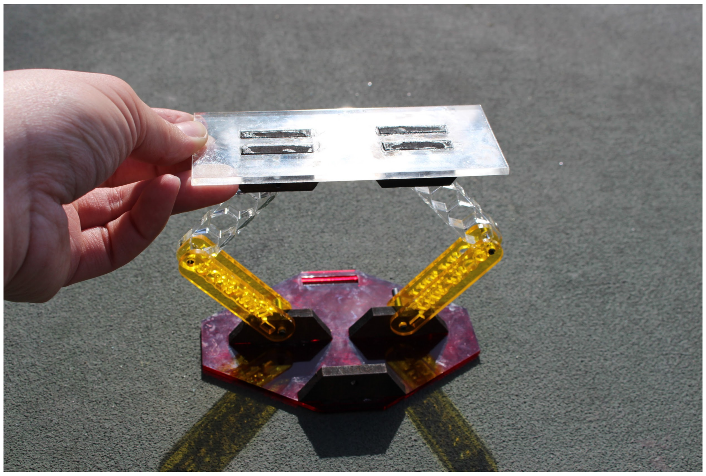
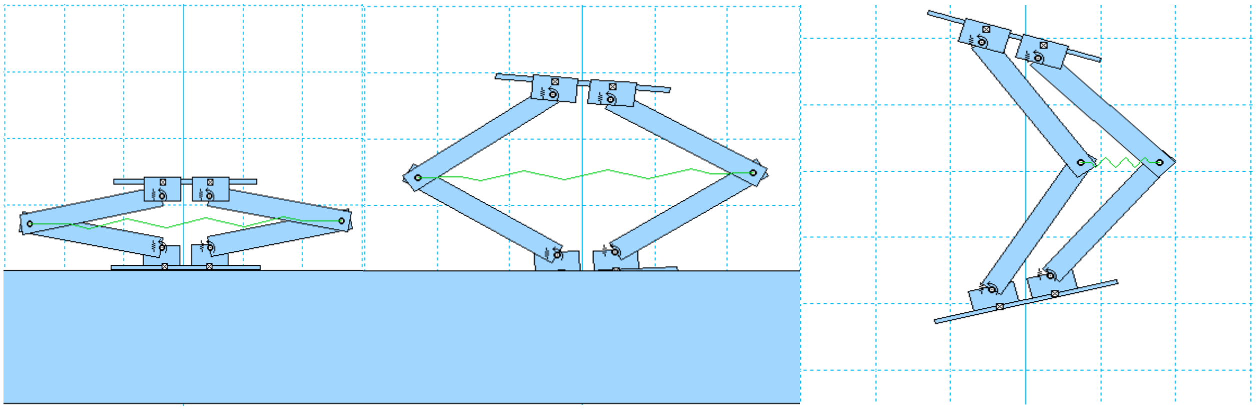


Figure 14. We were able to test our springs with an acrylic prototype.

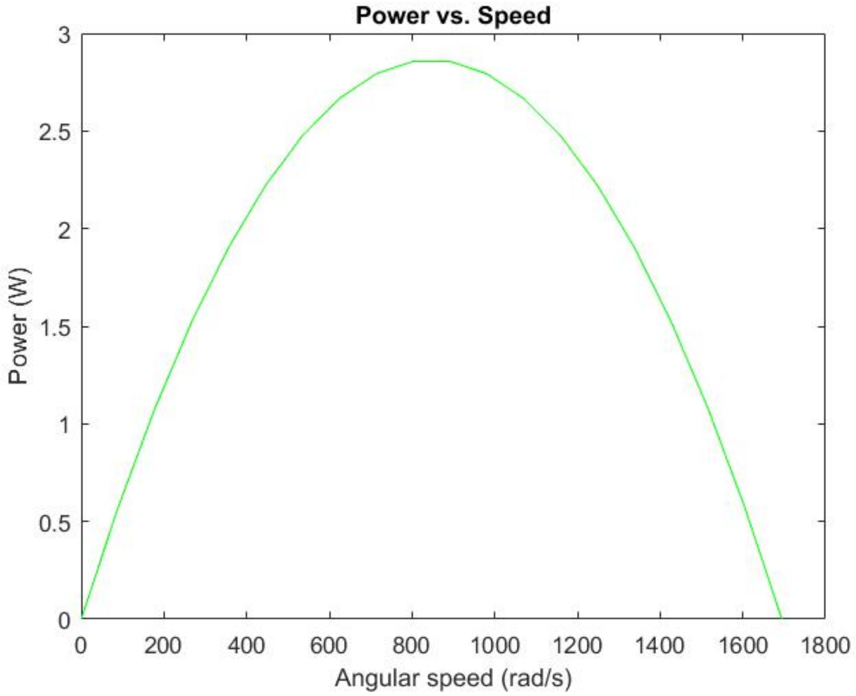
Appendix B: Working Model

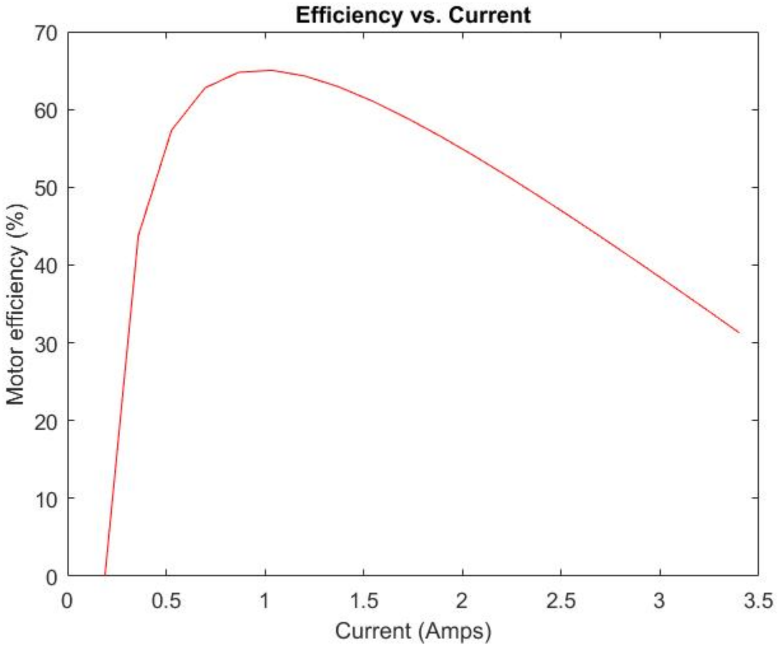


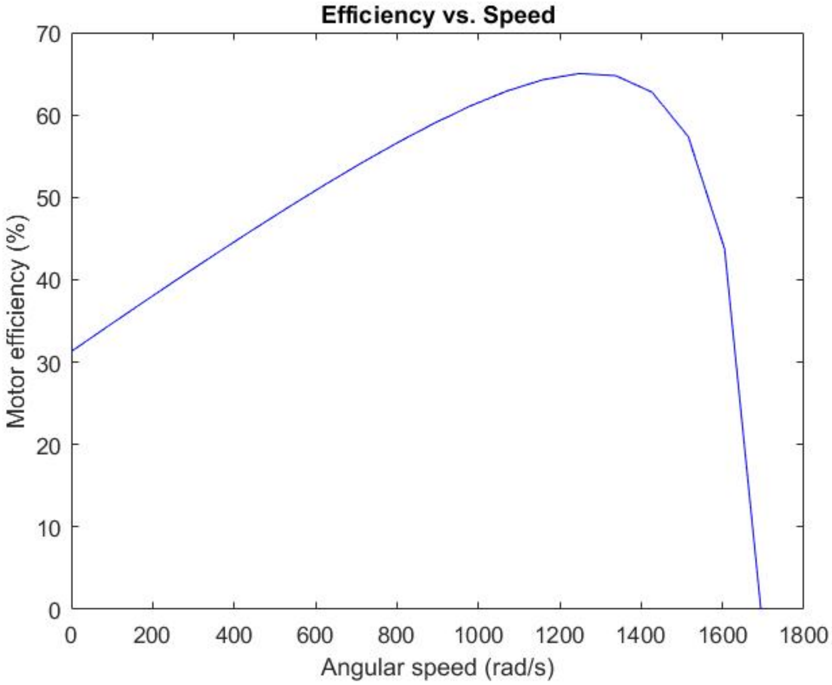
Initially, we used Working Model (WM2D) to determine what kinds of springs we needed to make our jumper function. Our first model, designed after the MSU jumper, consisted of small, thin legs attached at the hips, knees, and ankles with pin joints. We used the measurements of each link to estimate the mass of the components based on the density of acrylic, our pre-selected material. We added additional weight to the top platform in our model based on the real-world measured masses of the motor, gearbox, and battery. We utilized four torsion springs, two at the hips and two at the ankles. In Working Model, we found that if we used four identical torsion springs, they would each have to have k values of about 1 Newton-meter/radian.

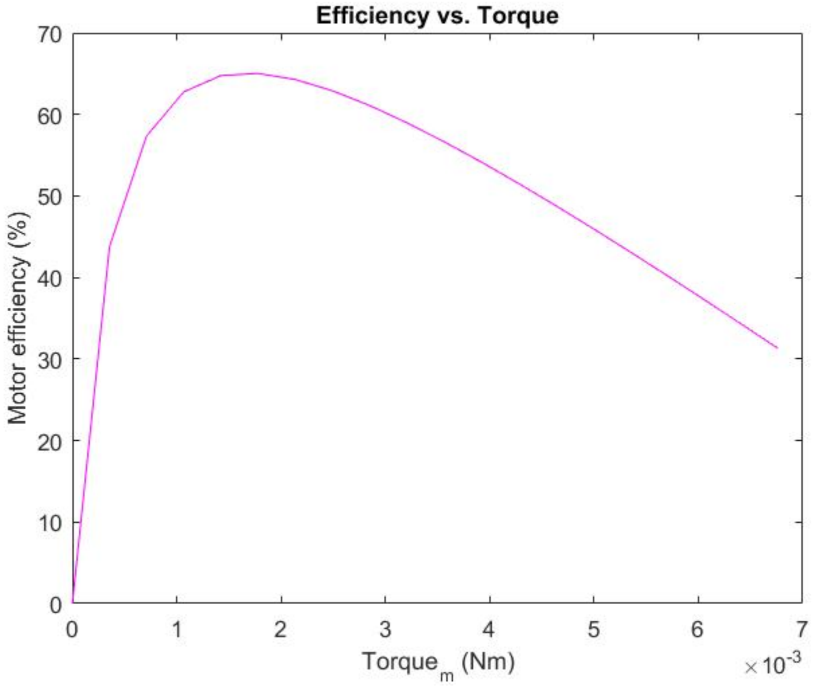
However, in real life, we found that such springs were too large or too stiff to use, so we switched to using a combination of torsion springs and rubber bands. By modeling rubber bands as a spring in Working Model, we were able to determine how many we would need to achieve the required jump height. For our final model, we assigned weight to each of the linkages based on their size and the density of acrylic, then added weight to the top platform based on our measured total mass.

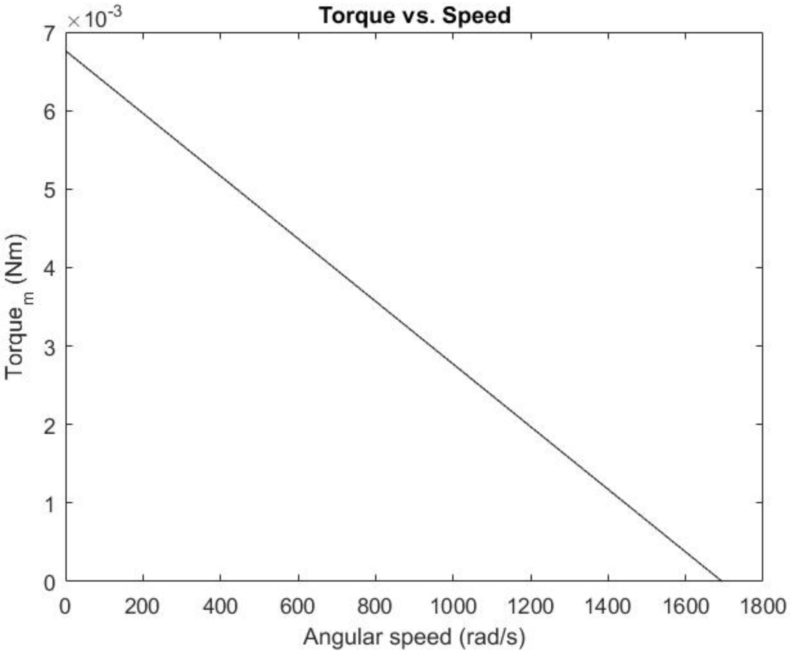
Appendix C: Motor Characterization






Efficiency vs. Speed
Motor efficiency (%)
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
Angular speed (rad/s)


Efficiency vs. Torque
Motor efficiency (%)
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
$\times 10^{-3}$
Torque_m (Nm)



```
% ME 112
% Jumper Motor
clc; clear all; close all;
% Motor type: RE-260RA-2670
gear_ratio = 196.7;
R = 0.6882287982;          % ohms
km = 0.002106745778;
i_nl = 0.19;               % amps
V = 3.5;                   % volts
w_nl = (3.5 - 0.19.*R)./km; % rad/sec
output_w = w_nl./gear_ratio;
i_stall = 3.4;             % amps
T_f = km.*i_nl;            % Nm

i1 = linspace(i_nl, i_stall, 20);   % amps
omega = (V - i1.*R)./km;   % rad/sec
Powerin = V.*i1;           % watts
TL = km.*i1 - T_f;         % Nm
Powerout = TL.*omega;      % watts
Eff = (Powerout./Powerin).*100; % percent
w = linspace(w_nl, 0, 20); % rad/s
Power = TL.*w;             % watts

% Plotting power, efficiency, torque, as function of current or speed for
% any operating voltage
figure(1)
plot(w, Eff, 'b')
xlabel('Angular speed (rad/s)')
ylabel('Motor efficiency (%)')
title('Efficiency vs. Speed')

figure(2)
plot(i1, Eff, 'r')
xlabel('Current (Amps)')
ylabel('Motor efficiency (%)')
title('Efficiency vs. Current')

figure(3)
plot(w, TL, 'k')
xlabel('Angular speed (rad/s)')
ylabel('Torque_m (Nm)')
title('Torque vs. Speed')

figure(4)
plot(w, Power, 'g')
xlabel('Angular speed (rad/s)')
ylabel('Power (W)')
title('Power vs. Speed')

figure(5)
plot(TL, Eff, 'm')
xlabel('Torque_m (Nm)')
ylabel('Motor efficiency (%)')
title('Efficiency vs. Torque')
```

Appendix D: Force Plate Data

Time(ms)	Force (N)
500	16.82
501	16.72
502	16.62
503	16.59
504	16.51
505	16.48
506	16.48
507	16.44
508	16.32
509	16.23
510	16.22
511	16.05
512	15.89
513	15.83
514	15.73
515	15.51
516	15.44
517	15.32
518	15.14
519	14.93
520	14.88
521	14.85
522	14.83
523	14.82
524	14.79
525	14.75
526	14.73
527	14.67
528	14.76
529	14.87
530	14.82
531	14.85
532	14.85
533	14.6
534	14.71
535	14.72
536	14.65
537	14.56
538	14.68
539	14.56
540	14.66
541	14.71
542	15.01
543	14.79
544	14.68
545	14.9
546	14.74
547	14.58
548	14.77
549	14.89
550	14.89
551	14.88
552	14.85
553	14.92
554	14.98
555	15.03
556	15.04
557	15.09
558	15.17
559	15.11
560	15.31
561	15.55
562	15.58
563	15.58
564	15.55
565	15.55
566	15.5
567	15.42
568	15.42
569	15.36
570	15.3
571	15.33
572	15.34
573	15.43
574	15.49
575	15.58
576	15.58
577	15.78
578	15.67
579	15.48
580	15.19
581	15.13
582	15.01
583	14.85
584	14.53
585	14.35
586	14.08
587	13.52
588	12.57
589	11.68
590	10
591	7.52
592	5.07
593	2.16
594	0.54
595	0.12
596	0.3
597	0.25
598	0.13
599	-0.12
600	-0.18