Slingshot Spider

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The goal of this project is to design a catapult that is inspired by the slingshot spider. The slingshot spider creates a web and pulls it backwards to create a high tension slingshot. When a bug flies near the web the spider will release the web launching it at its target, and catching its prey. This occurs at a very high acceleration, about 1163 m/s^2 [1]. The difficult aspect of creating a design that is inspired by the slingshot spider is that the spider's silk is very strong compared to its small weight. The spider's silk allows for high amounts of energy to be stored. Finding a suitable material that could be used instead of spider's silk is the challenge. The design was chosen with a design matrix comparing our proposed ideas. The final design includes four different parts; a latching mechanism, a hand crank to pull it until there is high tension, the frame, and the anchor lines. These are similar to the slingshot spider's web design. Firstly the frame and anchor lines are similar to the web of the slingshot spider. Next, the latching mechanism mimics how the spider holds the web in tension and releases the line when a bug flies near. Then the hand crank allows the catapult to be pulled back, mimicking how the spider pulls its web back, and finally the web itself (Anchor lines) which we are in the process of designing. All of these components launch an object at a high acceleration much like the slingshot spider's web does.

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Nomenclature

ΔX	=	Length of extension or compression in meters
m	=	Mass in Kg
a	=	Acceleration in m/s^2
F	=	Force in newtons
k	=	The spring constant N/m
Pe	=	Potential energy in Joules
Ke	=	Kinetic energy in Joules
E	=	energy density in KJ/Kg
v	=	Velocity in m/s

I. Introduction

This paper shows the engineering design process that was used in order to show proof of concept for a catapult that is designed based on the sling shot spider. The problem is to make a catapult that is based on the sling shot spider with engineering materials. The design should achieve a high acceleration launch and show proof of concept for future work. Pranav Bhounsule is the sponsor of this project. He wanted to show proof of concept for this design in order to gain a better understanding of how the sling shot spider achieves such high acceleration. Professor Bhounsule also wants to share the findings with the scientific community through a publication.

A. Problem Statement

The goal of this project is to create a catapult inspired from the web of a slingshot spider using engineering material that can achieve directional launch with high speed/acceleration. The project is purely for research and results, not to be manufactured as a consumer product. The reason for this project is to take a biomimicry approach to advance our technology. This project can have an impact on the world by creating a basis for further research on the concepts of producing speeds and accelerations with better efficiency. If our project produces sufficient data, further research can be conducted to advance these findings outside of the scope of senior design. This project can be expanded to launch UAV's, planes and other objects that use a catapult system to gain initial speed.

B. Sponsor Background

The sponsor for the project is Pranav Bhounsule. He is a professor here at the University of Illinois at Chicago. He teaches and performs research in robotics in MIE at the university. His primary research is in design and control of robots, more specifically robots that move on legs. His interest in this project is to Adapt human/animal strategies and designs to create new robotic systems. Pranav's goal for this project is to understand mechanics/control of how a slingshot spider achieves high acceleration by recreating the system or similar system with engineered materials. A second goal is to communicate this research to the scientific community through a technical publication.

C. Literature Survey

1. Material Research

We have begun research in order to find the best suited material. Spider silk is a unique material. It is very strong and also allows for it to be stretched far and return to its original length. In a paper published by the Massachusetts Institute of Technology it states "During loading, the area under the stress-strain curve is the strain energy per unit volume absorbed by the material. Conversely, the area under the unloading curve is the energy released by the material.[2]" This means that the stress strain curves of the materials we choose should be examined and similar to the stress strain curve for spider silk. There is varying data on spider silk, This could be due to different spiders being used for the webs or similar variations in the data. One study that found mechanical properties will help guide us to find a suitable material for use in the catapult.

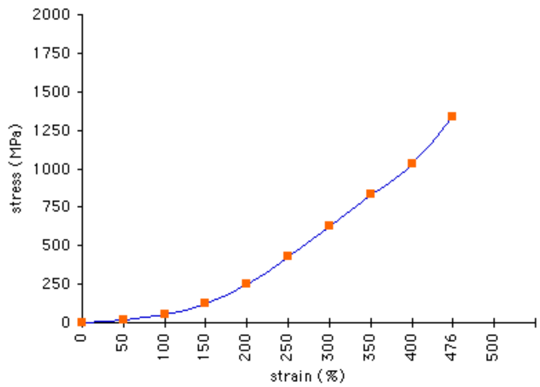


Fig. 1 Stress strain curve for spider silk

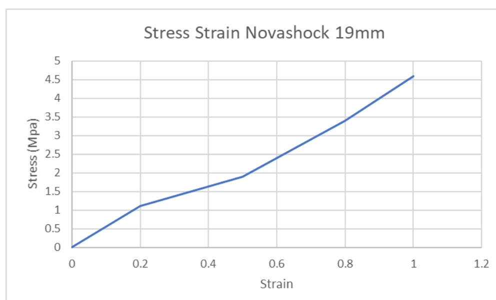


Fig. 2 Stress strain curve for Novashock

Material	Elongation at break (%)	Tensile Strength (N/m^2)	Breaking energy (J/kg)
Spider silk	35–50	5×10^9	1×10^5
Nylon	18–26	5×10^8	8×10^4
Kevlar	2–5	4×10^9	3×10^4
Silkworm silk	15–35	6×10^8	7×10^4
Steel	8.0	1×10^9	5×10^3

Fig. 3 Comparison of spider silk and other materials mechanical properties

[3]

Research scientist studied different rubber bands (varying thicknesses) to measure its affect on the speed of a slingshot launcher. On a force vs stretch factor curve, each rubber bands elasticity behavior is measured with respect to the force exerted in the slingshot within the report. Each rubber band has a unique stretch factor thus giving it its own force limit. In this analysis, all other variables are virtually the same. This leaves the rubber band type to be the only changeable variable. These rubber bands and their elasticity are investigated. This research can be used to help us choose the best material for this project. [4]

One material that has been researched is a brand called NOVABRAID. Specifically, the NOVASHOCK line. This type of weaved cord can elongate to 100% of its original length and can be ordered in a number of different diameters. It goes from 1/8 in up to 3/8 in but custom orders are also welcome[5]. The two figures show how even a material that is thought to be a replacement is not as efficient as spider silk. Tough grid was another brand that was researched. TOUGHGRID is a cousin to Paracord. However, TOUGHGRID is considered a shock cord. This cord is available in 1/8in or 3/16in, and has 12 inner rubber band strands and 100 percent nylon sheath [6]. The upside of this product compared to that of the NOVABRAID is that it is cheaper. So, analysis between the two must be determined if a better quality is actually needed for our slingshot design. After trying to find a material closest to the strength of spider silk, while also trying to stay close to the same diameter of what the spider produces, Dyneema fiber was found. “Dyneema fiber is 15x stronger than steel at the same weight, with a tensile strength up to 43 cN/dtex”[7]. Dyneema also has a very high modulus which means resistance against deformation. Also, this material comes in a wide variety of sizings as well.

Another type of material we can look at is Latex rubber tubing. This type of tubing is the most accessible and has the largest amount of elongation before breakage than the rest of the materials that we researched. This type of rubber allows us to manipulate the rubber easily to reach a desired design. There are many applications to latex rubber tubing’s such as, slingshots, catapults, surgical use, and archery. Some of the material properties goes as follows, and elongation at break is at 750 percent and allows for 3500 tensile PSI per min.

[5], [6] ,[7],[3]

2. Release Mechanism

latch-mediated spring actuation is a framework of study that focuses on how organisms store energy within elastic structures, such as muscle fibers, and then release the energy using latches. This allows for power magnification within organic structures. In the case of the slingshot spider, its anterior legs release instantaneously to convert all of the energy stored in its conical web spring system to kinetic energy in the form of a launch. In order for this latch mechanism to be scaled up, it would need to be able to hold high tension loads and be able to release the load in a fraction of a second. For the interest of time, instead of trying to recreate the spider’s anterior leg to build a latch mechanism we focused on high tension latch mechanisms that already exist. Similar mechanisms include trigger systems for a crossbow and a quick release system used for catapults. Since both the crossbow and catapult rely on a latch mechanism that can hold high tension and quick release, we inferred that these systems most closely resemble the slingshot spider’s anterior legs. [8]

In this first idea a trigger mobilizes a piece of wood that pushes the string off of the latch that the string was held in place by. Some type of curved piece of material would be constructed to hold the string in place until ready to fire. This is a fairly simple design but since its simplicity would be a reliable mechanism to launch with a low percent of failure.[9]

The next is a release aid for a slingshot or catapult. This mechanism acts like a jaw. This design is specifically handheld and is activated via a pull-down trigger that simultaneously releases both jaws at the same time. This design seems to work better for strings or cords of a higher diameter. Also, this jaw design seems to be one of the stronger designs being able to handle very high tension. [10]

After researching the jaw mechanism, it was noticed that this type of release mechanism was favored by many who create crossbows/catapults/slingshots. The next design is a wrist strap bow release. The wrist strap bow release has a trigger that is pulled back simultaneously opening the jaws. There are different types of jaw releases for this design as well. Dual caliper, single caliper or hook release. The dual caliper has been said to wear on the bow strings over time as the seam the strings rest on creates wear. The hook release has less wear on the string or chord and can also be reset easily. The hook release is also easier because it is very fast to hook on the string, however, this really does not matter for our design. As for the single caliper release only one jaw opens instead of two. The idea of the dual caliper release is that it provides equal distribution of friction as the bow string slips through the jaws.[11],[12]

[9], [10], [11], [12]

3. Different Designs

For the actual design of the slingshot we are taking inspiration from the spider's slingshot method to capture prey. The original video of the spider slingshot was given to us as a visual aid. In these first weeks of research we all have looked at other videos and articles discussing slingshots/ catapults launching a wide array of objects. We have looked at the launching of planes, drones, as well as small everyday objects that can be launched by hand slingshots. We are in the very early stages of the creation of our design. A few members of the team have created CAD drawings. These designs take inspiration from one type of launcher that launches jets off of aircraft carriers. These launchers have a very long rail system that the item being launched rests on. Another aspect that has been taken a specific interest in is some sort of conical web part of the slingshot. The conical web is inspired straight from looking into how the arachnid catapults itself towards its prey. One company created a device called the Pocket Shot. In their design they created a circular pouch that totally encompasses the object being launched. This man made device can be looked at for inspiration in what we are doing. We staring thinking about trying to incorporate the rail system and conical system into one device.

D. Theory

The Slingshot spider's web is constructed by silk strands that follow a radial path going outward and starting from the center. More silk strands then connect each radial strand together, acting like a support. All of these strands converge onto a single point in the center, to which a drag line is fixed. This drag line enables the spider to pull the web back and create tension.

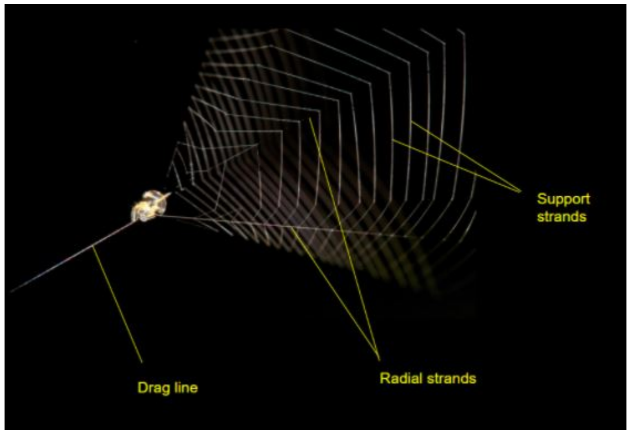


Fig. 4 The Slingshot spiders web components explained

The geometry of the web allows for several functions. The first being a net, due to the large surface area of the web, which allows the spider to catch any prey item that is within the bounds of the web. The second function is a spring or slingshot. The radial geometry of the web allows it to hold a high amount of tension in the loaded position, as shown in figure 4. Each radial strand and support strand combine their tensile strength into one web system, such that it would be able to hold much more tension than a single strand web. The more tension the web can hold, the more energy it can store and then subsequently release in the form of a launch. The radial nature of the geometry allows the stored energy to be focused on a single point, the center point. The added support strands increase the spring constant of the web system as a whole. Allowing for more tension force to be stored when the web is in the loaded position. This high potential energy is converted to high kinetic energy upon launch, creating the extreme speeds, around 130g's, that the spider can produce.

To test how differences in the web geometry compares to magnitude of energy storage, 3 different web geometries were designed in Solid works, onto a hexagonal frame, and then tested in ANSYS. Fixed supports were added to the outer frame of each geometry to hold the system in place. Then a 10 newton force was added to the end of the drag line, in the direction parallel to the drag line (in this case the +Y direction). Each analysis shows the total deformation(in inches) of the web, more deformation means less maximum tension that the web can hold. Each added strand increased the spring constant of the system

To do calculation for the sling shot spiders web first the system was drawn and the web anchor lines were modeled as a system of springs.

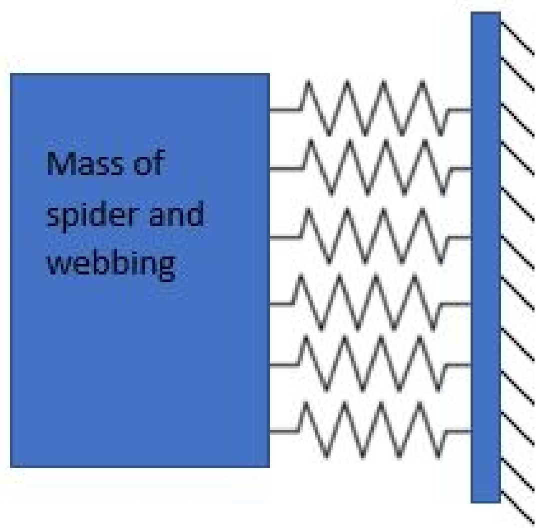


Fig. 5 This shows the spider web modeled with springs to calculate physics

With this it becomes a simple spring mass system. The force can be calculated using hooks law. Equation 1 is as follows:

$$F = K\Delta X \tag{1}$$

This equation can be applied to the ANSYS models shown above. The force was constant and the deformation values were changing. For figure 4 the total deformation is only around 1.995 inches while figure 3 is much higher. This means that the K constant with the web geometry is much higher than with the simplified case. This will result in more energy stored in the system.

The force can also be found using Newtons second law. Equation 2 is as follows:

$$F = ma \tag{2}$$

These two force equations can be combined in order to relate the mass and acceleration with the spring constant. This is shown in equation 3 as follows:

$$ma = k\Delta X \tag{3}$$

Once the spring constant for the system is found it can be used to find the amount of energy that was stored in the web. This will be useful to determine if our design will store enough energy in the material to launch the object at our desired acceleration. This is shown with equation 4 as follows:

$$Pe = 1/2k\Delta X^2 \tag{4}$$

The equation for kinetic energy is given with equation 5:

$$KE = 1/2mv^2 \tag{5}$$

Since the potential energy stored in the web will become kinetic energy when the tension line is released equation 4 and 5 can be combined. Equation 6:

$$1/2mv^2 = 1/2K\Delta X^2 \tag{6}$$

To make this equation more useful the velocity can be found. Velocity is given by equation 7:

$$v = \sqrt{(}K\Delta X^2/m) \tag{7}$$

After the velocity is found it can be plugged into the following equation to find the acceleration.

$$a = v^2/2\Delta X \tag{8}$$

E. Design Criteria

In the design criteria our team will explore any constrains that we will implement throughout the duration of our project. Part of our project is to have a system that has a latching mechanism. It is also the focus of our Sponsor that the goal is not reliability, but rather showing its worth.The performance must be able to be captured and analyzed. We will capture the performance by use of a camera. We also want to achieve a slingshot inspired by a spider that launches items at very fast speeds with the least amount of pullback. The spider was meticulously described in terms of charts, graphs, and technical literature. One very specific part that our team recognized was the impressive amount of acceleration the spider achieved. It is found that the spider achieved 130g or almost 1300 m/s^2 of acceleration [1]. Our team is also in the process of finding a material that holds enough elastic energy such that we can reach possibly a 10th of the acceleration found in the spider. Our system comes down to 3 main parts. The first being the "web" that will hold the mass and store the tension for the system. The 2nd being the latching mechanism which was mentioned earlier. The 3rd being the frame that holds the entire system together.

F. Codes and Standards

Group members must use caution when constructing and operating the prototype and wear safety googles at all times. Additional codes and standards are not applicable, since this project is showing proof of concept and will not become a marketable product.

II. Technical Content

A. Assumptions

- The object being launched will be used purely to test the speed capabilities of the launcher. It will not serve as a device to perform a function. This will allow us to focus more on the design and assembly of the launcher itself.
- Considering an average slingshot can produce speeds of 240 feet per second, anything over this would be considered a high speed. Reaching a minimum of this speed will count as a project success.
- The launcher does not need to be built for longevity, at least one video of the launcher in action will suffice.
- The purpose of this project is to test the proof of concept for a launcher inspired by the slingshot spider, it is not supposed to be a commercial or consumer product.

B. Metrics

The device is designed to launch a small object a distance (x) at a high speed and our goal is to successfully launch the object. The speed of the final product will be measured with a timer and a ruler. The dimensions of the final design and object being launched will be measured with a ruler. With a timer we can measure the time it takes the object to launch a distance and measure this distance with a ruler/camera. Velocity measures the displacement of an object over time and its units can be meters per second or miles per hour.

C. Proposed Solutions

There were several designs that were considered for this project. Design option one was designed by Tom Bates. It uses what was learned about webs to produce a design that should give the most acceleration.

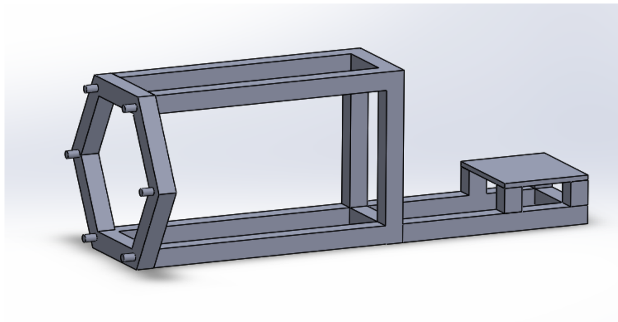


Fig. 6 Design option 1

This design consists of the frame which is aluminum square stock .75"x.75", which will be cut and welded together according to CAD dimensions. This includes something to pull it into tension and a latching mechanism to quickly release tension. The front of the frame will mount the web using screws to attach each axial web strand. This allows for easy installation and removal of the web, enabling us to more efficiently test different geometries and materials for the web system. The web is made up of either nova shock or the tough grid line.

The next design was created by Gunnar Waldvogel. It features a more simple approach to the problem and is similar to sling shots already available.

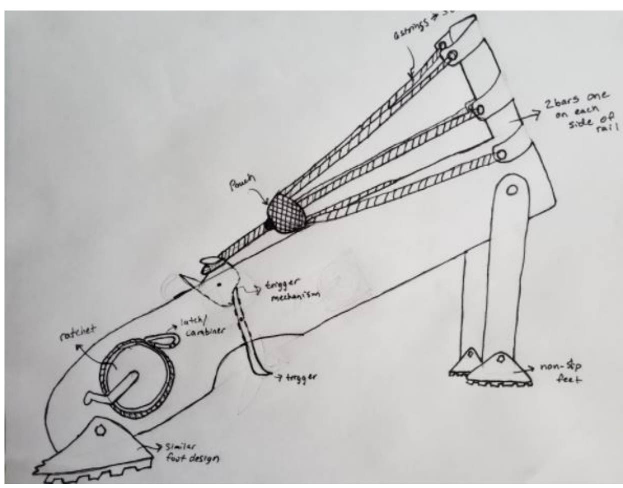


Fig. 7 Design option 2

It features a more simple approach to the problem and is similar to sling shots already available. The system is basically a rail that is hollowed out in the middle allowing the pouch to rest on the rail and provide smooth exit as it is launched. There are 4 mounted feet and angle the design to launch the item at a certain angle. Attached to the end of the rail are post that the web strings are attached to, and the strings meet all to the central pouch.

The next design was created by Manuel Avitia. It is similar to sling shots that are available now, with some adjustments. These adjustments use rollers at the base to increase the tension in the sling without adding more pull back for a quicker launch.

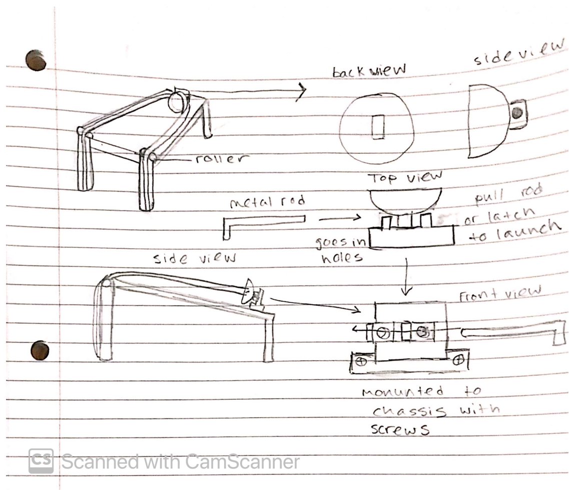


Fig. 8 Design option 3

The final design was created by John Gerig. It is a more complicated design and allows for the use of a motor to control the angle of the launch.

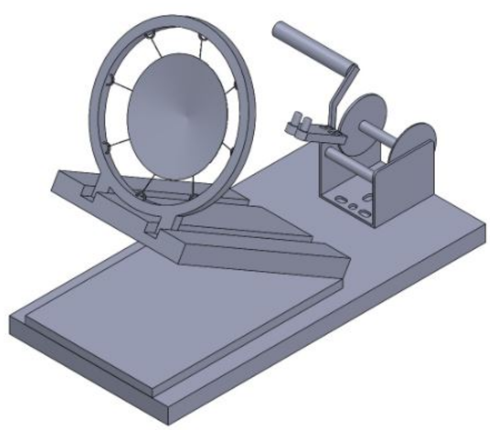


Fig. 9 Design option 4

This design consists of a circular frame which could be manufactured with aluminum square stock .75"x.75". A Latching mechanism and the winch to pull the system into tension. The anchor lines would be either nova shock or the tough grid line.

D. Decision Matrix

These design options were compared in a decision matrix to determine which design would be the best for our requirements.The Decision matrix ranks Safety, Performance, Reliability, and Build Feasibility out of a score of 10. Ten being the best overall score for design. Each category has a weighting factor that is multiplied by the overall score to give a point rank in each cell. In our decision matrix we decided to put performance ahead of all the rest of our factors. This is because our project mainly focuses on the performance of the slingshot whereas build difficulty and safety were less of a factor.

	Safety	Performance	Reliability	Build Feasibility	Rank
Weighting Factor	.20	.4	.25	.15	1.0
Design 1 (Tom)	8 / 1.6	8 / 3.2	9 / 2.25	7 / 1.05	8.1
Design 2 (Gunnar)	7 / 1.4	4 / 1.6	5 / 1.25	7 / 1.05	5.3
Design 3 (Manny)	7 / 1.4	3 / 1.2	10 / 2.5	9 / 1.35	6.45
Design 4 (John)	8 / 1.6	7 / 2.8	4 / 1	5 / .75	6.15

Fig. 10 Design matrix to compare the designs

Following Design 1 in the matrix, the design ties in safety with John's design, exceeds in performance over all other designs, only loses to Manuel's design in reliability, and only loses to Manuel's design in Build feasibility. The only reason why Tom's design, Design 1, loses to Manuel in reliability and feasibility is because Manuel's design was more simple, so the slingshot would have less moving parts. Therefore, Design 3 is more reliable and feasible. Overall, Design 1 which was designed by Tom Bates had the highest overall score. It was superior in terms of performance due to its use of the web like sling system, mentioned in the theory section. It also scored high in safety and reliability, considering that the frame was made of aluminum bar stock and the variability of the sling mount. Tom's design was revised to better support the tension of the web and to use less material, the revised design can be seen below.

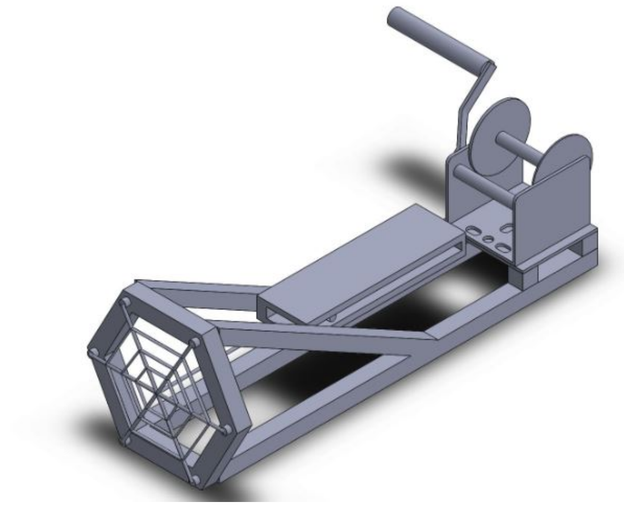


Fig. 11 Revisions made to Tom’s original design

E. Actual Solution

Figure 11 seen above is Tom’s design that was revised for last semester. After ordering parts there were some issues with this design.The design is still Tom’s design but further revised. Last semester we were going to be using .75” square aluminum stock. This has changed to 1” square steel stock. The reason for the change is because the .75” square stock is not as standard as the 1” stock. We also decided to go with steel because it is easier to weld. This will add some more weight to our design, but we are not concerned with weight. The design also became more detailed and eye bolts were added to anchor the web to the frame. The new design can be seen below.

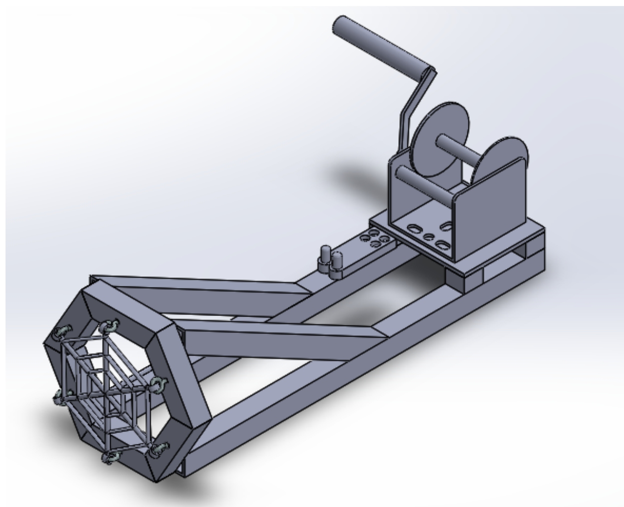


Fig. 12 Final design

This design is bulkier than before due to the increase in the size of the steel stock. The overall dimensions did not change. The over length, width, and height remained constant.

F. Exploded View and BOM

The exploded view of the chosen design without the revisions is shown below. This is done to show the difference compared to with the revisions made.

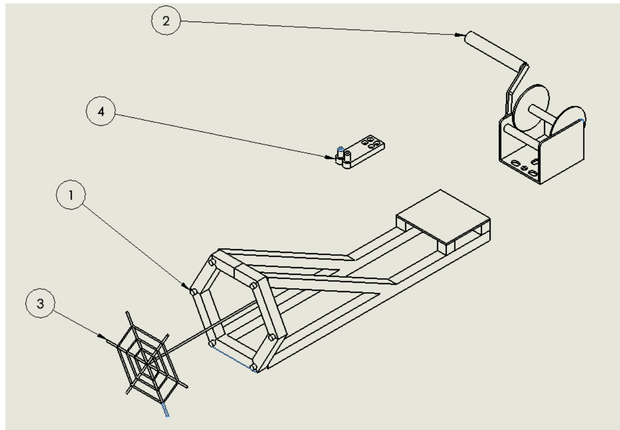


Fig. 13 Exploded View of the old design

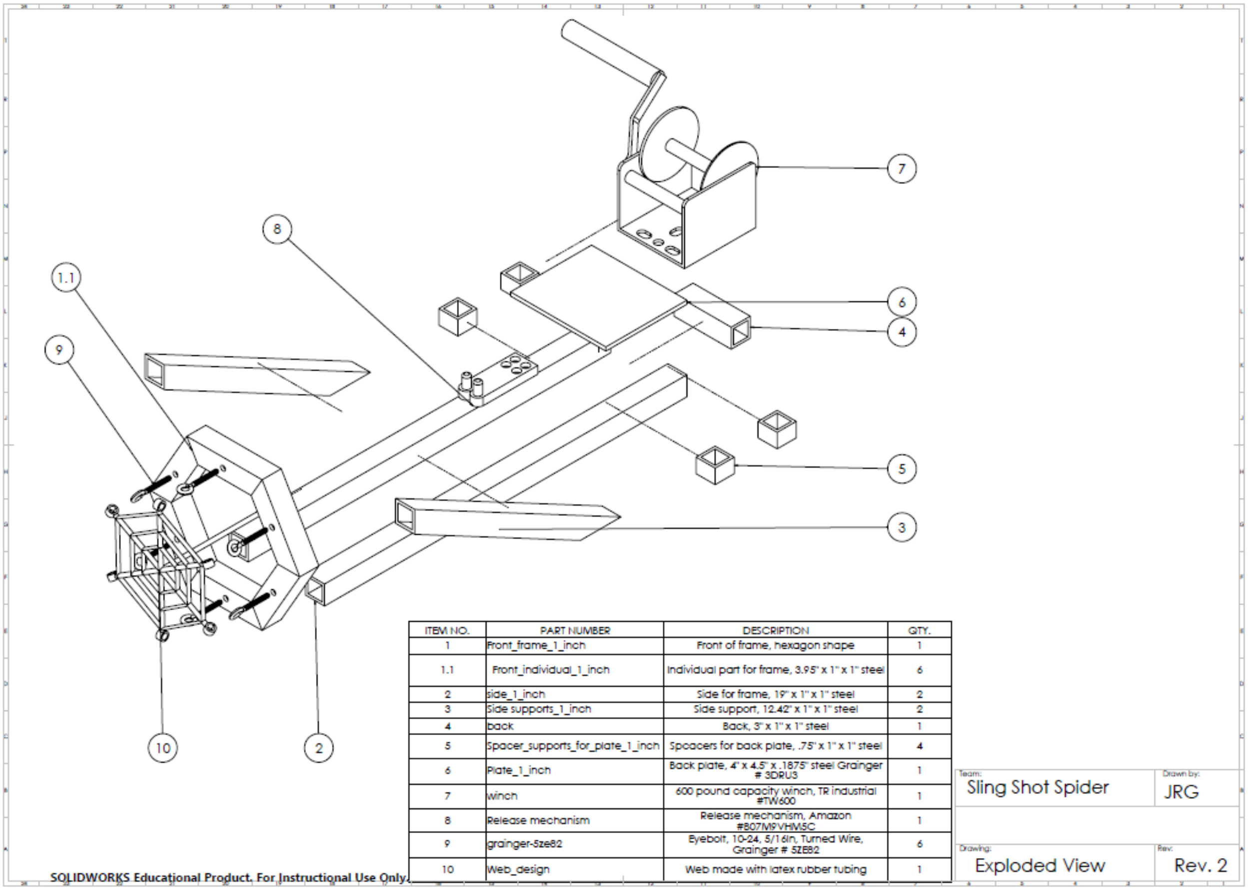
It consists of 4 parts, the web, the chassis that holds the web, the trigger mechanism, and the hand crank, which gets broken down in the bill of material shown below.

Part number	Description	Quantity	Price
1	3/4" X 3/4" ALUMINUM 6061 SQUARE FLAT BAR	5 units 4x12" pieces per unit	5 x $19.89
2	TR industrial 600 lb. trailer winch	1 unit	1 x $24.99
3	TOUGH-GRID 750lb Paracord/Parachute Cord	50 ft coil	1 x $9.85
4	Baovery Slingshot Release Device	1 unit	1 x $19.99
Total price			$154.28

Fig. 14 Bill of material

Figure 14 shows the materials needed to create the old design.The total cost for materials is $154.28. This is well within but the aluminum is more difficult to weld and the .75" steel tubing was difficult to find. The Tough grid line is sold in a 50 ft increment, and this will allow us room to test out different ways of creating the web design. There will be additional costs for manufacturing the design, this includes the price of welding as well as the cost of certain tools we may be required to use. These materials are expected to be affordable and should not affect the budget considerably.

A new more detailed exploded view drawing was done with the revisions made. This helped understand how it will all come together for the final design. It also allowed for further breakdown of the bill of materials. Below the figure shows the exploded view and the new bill of materials.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Front_frame_1_inch	Front of frame, hexagon shape	1
1.1	Front_individual_1_inch	Individual part for frame, 3.95" x 1" x 1" steel	6
2	side_1_inch	Side for frame, 19" x 1" x 1" steel	2
3	Side supports_1_inch	Side support, 12.42" x 1" x 1" steel	2
4	back	Back, 3" x 1" x 1" steel	1
5	Spacer_supports_for_plate_1_inch	Spoacers for back plate, .75" x 1" x 1" steel	4
6	Plate_1_inch	Back plate, 4" x 4.5" x .1875" steel Grainger # 3DRU3	1
7	winch	600 pound capacity winch, TR industrial #TW600	1
8	Release mechanism	Release mechanism, Amazon #B07M9VHM5C	1
9	grainger-5ze82	Eyebolt, 10-24, 5/16in, Turned Wire, Grainger # 5ZE82	6
10	Web_design	Web made with latex rubber tubing	1

Fig. 15 Final design exploded view and bill of material

This exploded view shows the individual components and how they come together. The previous exploded view had the frame as one piece. It is helpful to see the individual parts of the frame and how they come together.

G. House Of quality

The house of quality is a format used in manufacturing to relate customer needs and how the design will meet them.

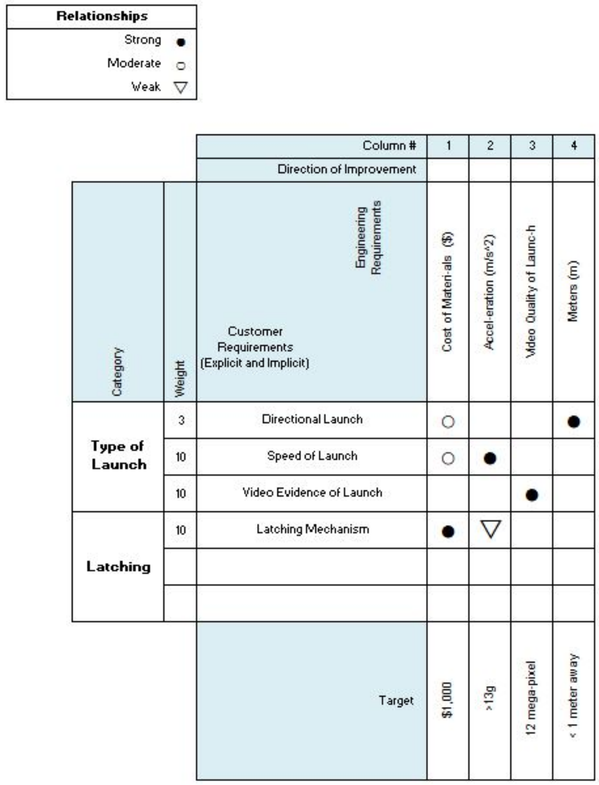


Fig. 16 House of Quality

On the left is the categories sections shown as the Type of Launch and Type of Latching. The Type of Launch is then defined according to the customer requirements, these requirements are shown as the Directional Launch, Speed of Launch, and Video Evidence of Launch. It is then correlated to an Engineering requirement that has a target value directly below it. The relationship between all the shapes is also shown in Fig.15 above. The next category is the Type of Launch which is then related specifically to the Latching Mechanism.

III. Methodology

To complete this project, different methods were used in order to ensure the product would work. Preliminary calculations were done to gain a better understanding of the physics involved with the slingshot spider's web. Information on the slingshot spider web was limited therefore approximated values were used. The spider's mass was estimated as well as the size of the web. This information would have been useful and allowed for better, more accurate calculations to be done. ANSYS simulations were also performed to determine how well the design would work.

A. Preliminary Results

Different web like structures were tested in Ansys to see what the web structure does to the spring constant. It is suspected that the spring constant increases which would allow for more energy to be stored in the web. Figures 14-16 are the different web structures that were analyzed. The force was held constant and the deformation is what is measured on the left hand side of the figures. The first geometry to be tested has only two radial lines connecting the drag line to the frame. This geometry symbolizes the design of a regular slingshot, where two rubber bands connect each arm of the slingshot frame to the pouch.

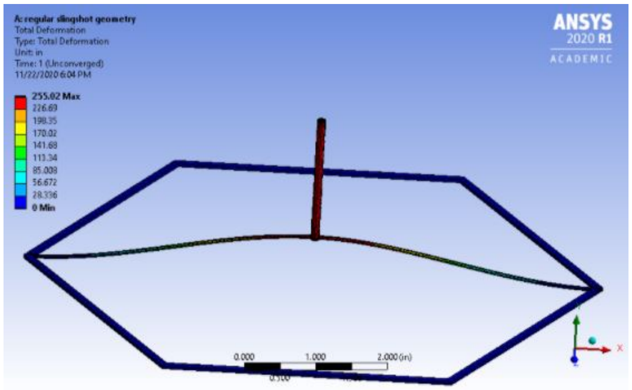


Fig. 17 Conventional slingshot geometry total deformation

Figure 17 shows a conventional sling shot configuration as a web design. The force was applied and the maximum deformation that was reached by this web was 255 inches.

The second geometry differs from the first in that four more radial strands are added. Note that the total deformation of the web is three times less than the conventional slingshot geometry

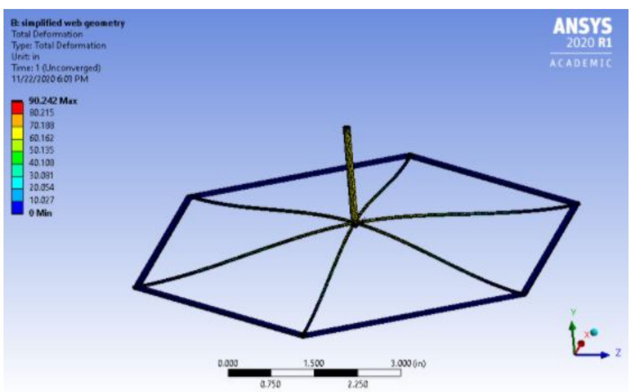


Fig. 18 Simplified web geometry total deformation

In figure 18 it shows that the maximum deformation that was reached is 90 inches. This means that much more force is needed to get to the same deformation as before.

The final geometry models the complete web geometry on to a hexagonal frame. Note that a perfect web geometry is very difficult to make in solid works and even more difficult to analyze in Ansys, due to open contours and inconsistencies in the body meshing. Due to this, the maximum total deformation is likely to be higher than 1.665 inches. Despite these difficulties, the analysis still proves that the added support strands increase the maximum tension that the web can store.

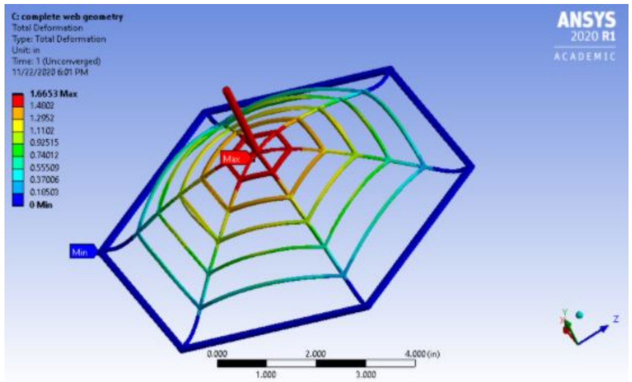


Fig. 19 Complete web geometry total deformation

Figure 19 shows how much of a difference the web designs have on the deformation. The first web design that was tested had such a high deformation and now with the same force this web design only deforms 1.66 inches. The spring constant increases as more strands are added to the web. This will be useful to be able to achieve a high acceleration. This relationship is important to note, therefore the spring constants of each web design were plotted below.

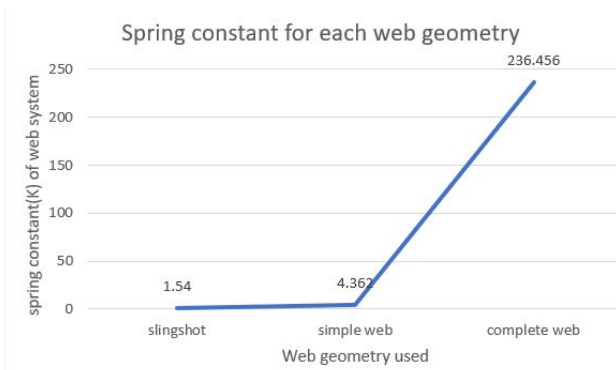


Fig. 20 Relationship between K and the web geometry

Figure 20 shows the relationship between the spring constants and the web geometry. It is very clear that the web design allows for a higher spring constant K to be achieved. The complex web increased the spring constant for the entire system and allows for greater energy to be stored in the complex web. This is what allows the spider to reach a high acceleration.

B. Ansys Simulation

Ansys was used to simulate the forces involved for our design. It allowed for different materials to be analyzed and also allowed for theoretical calculations to be made. The following Ansys simulation involved pulling back on the tension line to see the safety factor. This was done to ensure that the frame was strong enough and would not fail under the load.

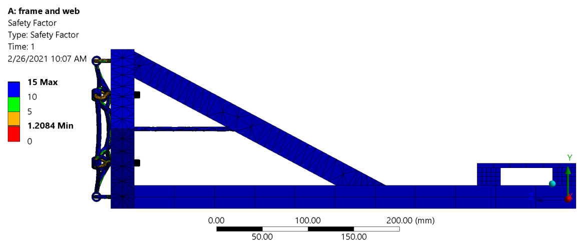


Fig. 21 Safety factor of the frame

Figure 21 shows the Ansys simulation for the frame. It is showing the safety factor. Blue represents a safety factor of 15-10, green represents a safety factor of 10-5, orange represents a safety factor of 5-1. Anything that is red is very likely to fail. It can be seen that the frame doesn't have any areas that are not the blue color. This means that the frame is very safe and will not fail when tension is added to the web design.

The web design was also ran in Ansys separately. The webbing was made with Pa 66 material which is also known as nylon 6.6. This is what the Novabrad and Tough Grid lines are made of. This was done to see the maximum force and displacement that the web can be stretched to.

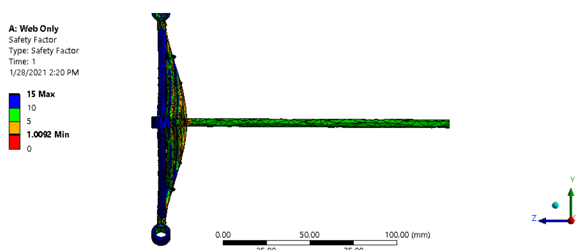


Fig. 22 Safety Factor of the web design

Figure 22 shows that the web has areas with a low safety factor. This is expected because we want the most amount of acceleration which means that this web design will be pulled to the maximum tension where it is about to fail. This will ensure that the maximum force is being applied and thus the maximum energy is being stored in the web.

The deformation that occurred during this load was also ran in ANSYS. This gives us a good idea of how far we can stretch the webbing back.

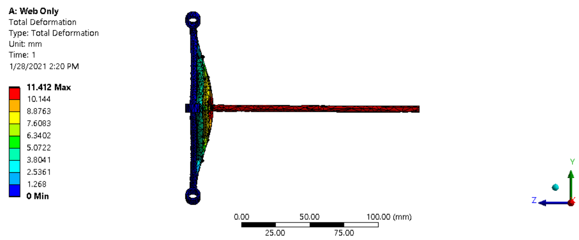


Fig. 23 Deformation of the web design

Figure 23 shows that the maximum amount of deformation is 11.412 mm. This can be used in our calculations to estimate the theoretical maximum acceleration this design can achieve.

C. Calculations

First the spring constant of the web was found using the force and deformation from the Ansys simulation. The force was 138 N and the maximum deformation was about 11.412 mm. Plugging in these values to equation 1 gives the following

$$K = 138/.011412 \tag{9}$$

The value of K is found to be 12092.53 N/m.

The mass of the web was shown through Ansys and was equal to 21.34g. The mass of the object being launched is approximated to be 6.5g. Thus, the total mass is 27.84g. These values can be plugged into equation 7 to solve for the velocity.

$$v = \sqrt{(}12092.53x.0114^2/.02784) \tag{10}$$

This gives the velocity as 7.513 m/s for the design.For the actual sing shot spider According to Alexander and Bhamla they found the velocity as 4.16 m/s[1].

Now that the velocity is found the acceleration can be solved for using equation 8.

$$a = (7.51^2/2x.01141) \tag{11}$$

This gives an acceleration of 329.24 m/s^2 or 33.56G's of acceleration.

IV. Preliminary Conclusion/Future Works

The preliminary calculations show that this design should be able to achieve the desired acceleration which is 13 m/s^2. The design we chose will be easy to build and manufacture. This is due to the simple frame which will be welded together. The acceleration will most likely be slightly lower due to how the energy will get transferred from the web to the launched object. Not all of the energy in the system will be transferred to the launched object. The next steps in this project will be constructing and testing our design. There are a few different ways that we have brainstormed for making the web design. We will try different ways of creating it with the tough grid line and see which works the best. We will also need to think of the way we will measure the acceleration of the launched object for testing.

A. Material Analysis

When we began our material analysis we looked into many different variations of paracord. We reserached NOVABRAID, NOVASHOCK, TOUGHGRID, and Dyneema fibers. These different brands were closely related to parachord and used multiple fibers to create a strong cord. Most were able to elongate to 100 percent of their original length and were very strong. Having a very high tensile strength and being able to stretch we believed these fibers would make a great web. Upon testing however, we realised that paracord did not have enough stretch for our design. The elongation of paracord could only be achieved with a very high tensile force. We then looked into latex rubber tubing. Latex rubber tubing has a tensile strength of 3500 psi. The paracord we used had a tensile strength of 750 pounds(this varies on the type of paracord). Latex rubber tubing was easily accessible and could stretch way more than the paracord. Latex rubber can stretch from 200 to 750 percent its original length. We determined that the elasticity of the latex rubber was greater than the paracord. The material with the greater elasticity would be better for our design. The more drawback we could create with our web the more acceleration our design achieved. Therefore, latex rubber tubing provided us with great elasticity and also great tensile strength. The project was carried out using Latex rubber tubing as the web material.

V. Testing procedure

The testing process will consist of multiple trials with two different web design. Testing was concluded after a total of four trials were performed for each web deign. More trials were performed prior to this for calibration purposes, however these trials were not included in the data analysis. Each trial was recorded using a high speed camera to determine the projectile speed and acceleration. The amount of tension added to the web started low, then increased incrementally over the course of multiple launches. This is important because if the tension is so high that the web breaks, then we would still have a recorded launch from the previous tension increment. We kept track of the amount of tension by counting the total angle of rotations of the winch or the total elongation of the web. We then analyzed the footage by counting the amount of frames it takes for the projectile to travel a known distance based using the foot long increments of the background. By comparing the number of frames elapsed to the distance covered by the object, we were able to accurately calculate the velocity of the object during flight. The acceleration of was also calculated using this same principle. This process was streamlined by the use of the Tracker video analysis software.

The following components will be used during testing.

- A target block that absorbs the projectile and minimize bounce back for safety purposes. The target block consists of a cardboard box with plywood backing. This target is large enough to intercept a range of different trajectories. The target block was also placed in front of a large dirt pile to further increase the area of interception, making it nearly impossible for the projectile to go astray.
- A white background with black stripes spaced one foot apart in order to be able to gauge the speed of the projectile as it travels through the air. The background board will consist of cardboard with black tape lines to indicate each distance increment in feet.
- A Samsung note 10 to be used as the high speed camera, it features a slow motion video recording mode capable of 1000 frames per second. The camera will be angled to show both the slingshot and the entire length of the background. The camera must be close enough to the background so that the object is visible during flight.
- Daisy Powerline steel slingshot ammunition was used for the projectile, each shot had a 1/4th inch diameter and a weight of 0.9 grams. Using traditional slingshot ammunition was critical due to the fact that each shot had the same dimensions and mass, which allowed for more accurate data to be collected.

- Web 1, also known as the simple web, which is consists of a more basic web like geometry.

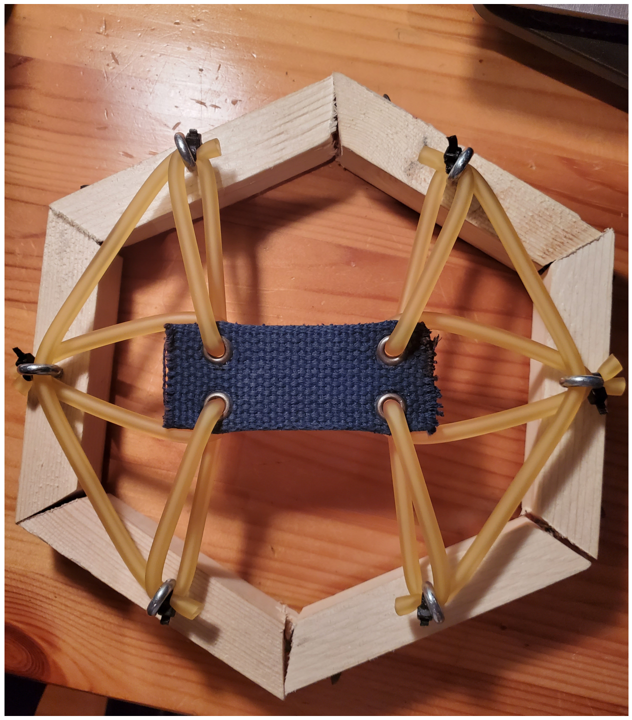


Fig. 24 Web 1

- Web 2, also known as the complex web, that more closely mimics an actual spiderweb.

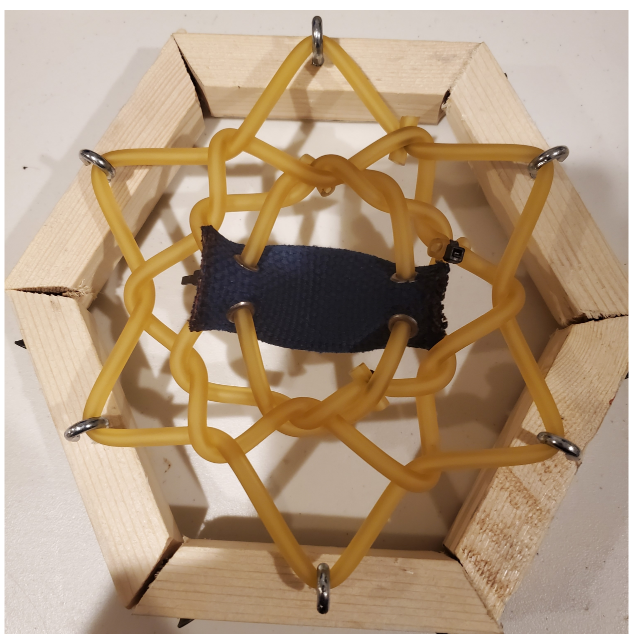


Fig. 25 Web 2

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VI. Data Analysis

After the web designs were tested the data had to be analysed. This started with the analysis of the videos. These videos were uploaded into tracker software to obtain the velocity. This program takes video and frame by frame the projectile is marked. Then the frame rate of the video is put into the software. Also a known distance in the video is needed. This allows the tracker software to know how much time each frame is as well as the distance of each pixel.

The deformation was measured using a ruler. Now that the deformation and velocity is found the acceleration can be obtained for each web design using equation 8. This data showed that the maximum acceleration found was 850 gs with web design 1. This exceeded our initial goal of 13 gs by a large amount. This also made us realize this is not a fair comparison. The slingshot spider's web is much smaller then our design. This data doesn't compare them as if they were the same size. To do this the energy density was found. This is just the potential energy divided by the mass of the web.

To find the potential energy the force of the web was measured using a scale. After this equation 1 can be used to find the spring constant of each web design. Now the spring constant and deformation of each design are known and can be plugged into equation 4 for the potential energy. Finally, dividing by the mass and also diving by a factor of 1000 to get the energy density in KJ/Kg. This can be compared to the slingshot spider. Our web design 1 is $1/5^{th}$ the energy density of the slingshot spider. This shows a much better way of comparison. It also shows that the initial goal of was exceeded. All of this data can be seen in the table below. It shows the maximum data achieved from each web design that was tested.

	Displacement (m)	Velocity (m/s)	Acceleration (m/s^2)	Acceleration (gs)	PE (J)	E (KJ/Kg)
Web Design 1	0.3556	77.01	8340	850	16.33	0.72
Web Design 2	0.4318	66.41	5107	521	23.85	0.60
Sling Shot Spider	0.0268	4.16	1163	130	-	3.92

Fig. 26 Data analysis

VII. Final Conclusion

Upon receiving the tough grid line, we found that the material was not as elastic as we would've anticipated in designing a web. The material that was then used to create the web designs was the latex rubber tubing. This was used because of its high elasticity and high tensile strength. once the web was assembled and attached to the frame, the testing produced a maximum acceleration of 850 gs which exceeded the goal of 13 gs. Furthermore, to create a better comparison between the real slingshot spider web and our own, we found the energy density for both. We found our web to exceed the energy density of the real slingshot spider web and thus are senior design goal was met.

Funding Sources

Funding comes from the University of Illinois at Chicago and from Pranav Bhounsule

Appendix

A. Building Process

The first step of the building of this project was to cut the metal square tubing. The cutting was done with a reciprocating saw and a grinder equipped with a cutting wheel. These tools both cut through the metal very well. Some of the tube that was cut is shown below.

Fig. 27 Cuts of the design

After cutting the material a MIG welder was used to weld the pieces together. A grinder equipped with a sanding wheel was also used to smooth out the welds and to make it look better. The figure shown below shows the welded and sanded project.

Fig. 28 Welding and sanding of the project complete

This welded frame was then painted with a primer. Since the metal is pure steel it will rust without a protective coating. This painted version can be seen below.

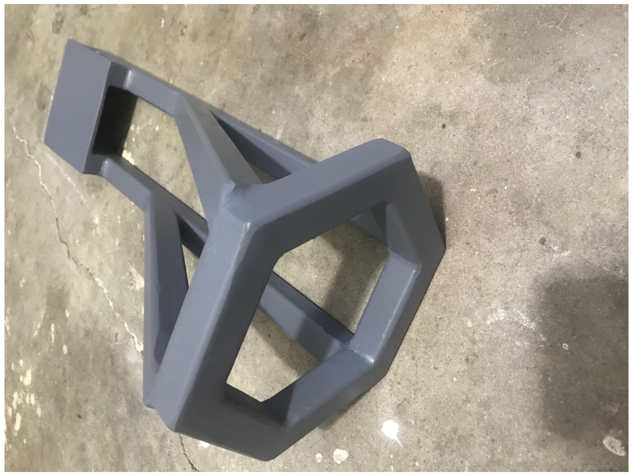

Fig. 29 Finished frame painted

After painting the project the next step done was drilling holes in order to fasten the winch and the eye bolts. This was done using a drill and the winch and eye bolts were attached. This can be seen in the figure below.

Fig. 30 Finished build without the webbing attached

Web 1 incorporates the same design elements as web 2. However instead of inter weaved rubber tubing, two strands of rubber tubing are fixed from each anchor point, eye bolt, to the pouch at the center. Web 2 also has two strands coming from each anchor point, however we wanted to test the difference in data if the lateral strands were removed.

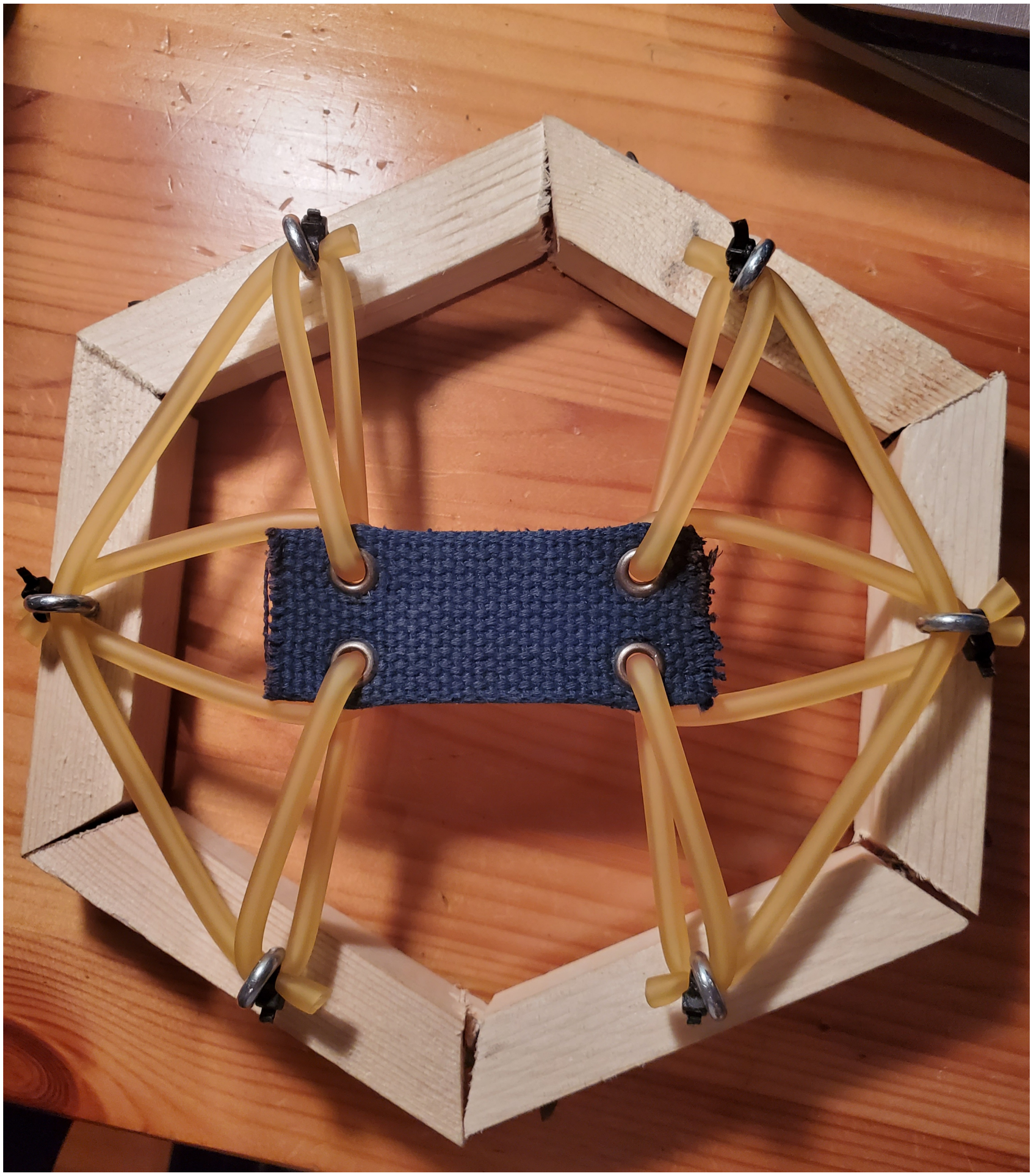

Fig. 31 Web 1

Web 2 consists of a 1/5 inch natural, latex, rubber tubing that is weaved together to form a web style geometry. This is done with 4 concentric strands of tubing that interlock with each other. The ends of each strand is bound with small Nylon PA66 plastic zip ties that have been tightly fastened together. The pocket at the center is made of thick cloth with metal grommets at each hole to prevent fraying

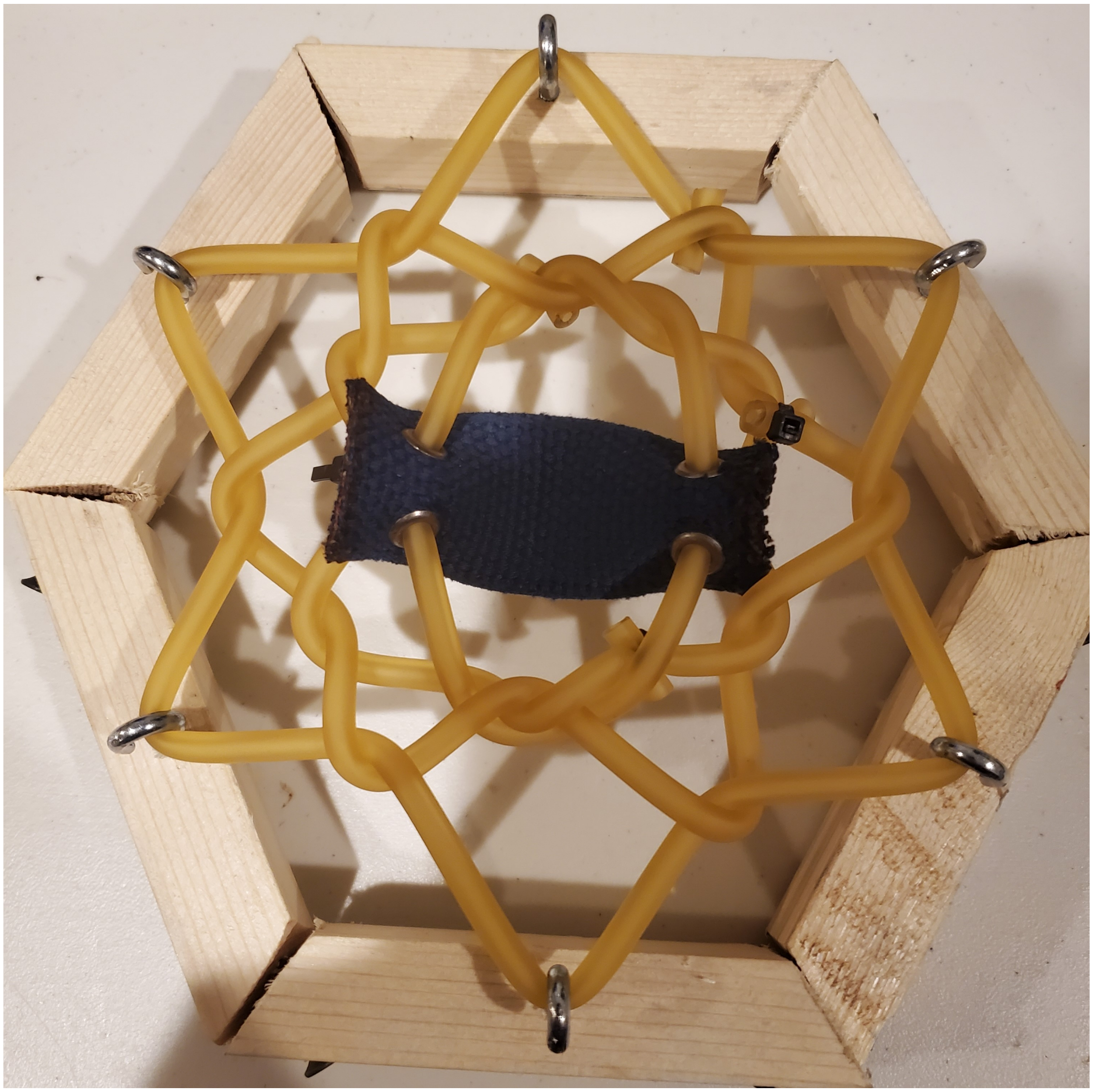

Fig. 32 Web 2

B. Individual Contributions

1. Tom Bates

I created the original CAD design idea that would eventually become the final design after several changes where made. I was the one who proposed to use latex rubber for the web material, just in case the original idea of paracord did not work out. I then went about designing and creating the web itself out of the latex rubber. I also came up with the testing process and how to accurately measure the position of the projectile during launch.

2. John Gerig

I worked on the CAD model that was originally created by Tom Bates. This design was revised to make it easier to be manufactured. I also worked on the Ansys simulation for the paracord. This simulation gave me values that I used to find a theoretical acceleration. Finally, I completed the data analysis. I used a software called tracker which allowed me to find the velocity. Using equations I was able to find the acceleration and energy density of the web.

3. Tesfay Legesse

This is Tesfay Legesse and as 1 part of a team of 6 we worked together very well to reach our desired goal, even surpassed it. I was very happy that we all worked together and for the most part we did not have many problems as a group. Everyone came together and put in the effort at every stage of the process and the result came out nicely. Personally, I contributed every week during our team meetings and heavily during our research phase.

4. Gunnar Waldvogel

I began the research on the original web materials. I also created one of the original design ideas in the beginning stages of the project. We scheduled meetings every week and I attended the meetings contributing to the discussion, and decided how to break the project between the members. I created some of the figures in the report and put my efforts into the literature survey and more of the sections related to our final report.

Justin Washington I researched heavily and communicated with the team on a weekly basis. Working with 6 other engineers has been a fruitful experience! Everyone made good contributions This year I made contributions for my group in different ways. My task was to find if paracord would be a better material than latex for the webbing. I tried to compare the materials using ANSYS analysis. One material was paracord and the other was latex (rubber). However, I ran into problems with the analysis because I was having issues with assigning the latex to the webbing. Plus, the numerical calculations within ANSYS-Mechanical did not make any sense. I asked my team members for help and everyone had the same issue. Alonso assured us that this was okay because we had the build we needed and testing was the final step. I also a

C. Lessons learned

1. Tom Bates

The most valuable takeaway that i learned from this project is how to more effectively work as a team, especially how to delegate tasks and collaborate efficiently. Another key take away is to always prepare for a possible failure.

2. John Gerig

I learned many valuable things from working on this project. I used Ansys more and learned more about how to use Ansys. I also learned how to communicate more efficiently with my group. The greatest challenge was the teamwork that goes into a project like this.

3. Tesfay Legesse

I learned a lot about working with this wonderful team during senior design. Everyone has personally taught me a lesson that I will take with me post-graduation in my career. One of the difficulties I found was expressing ideas over zoom, whether it was poor internet connection or just the lack of speaking to someone face to face I think there was something lost by completing our project over zoom. All in all, I had a very enjoyable experience and I am happy/proud to have worked with amazing team members.

4. Gunnar Waldvogel

I realized that communication was so vital in the project. We first started this project by sitting down and getting to know each other. From there we made a schedule for the upcoming year of every time we would meet. I learned that this level of communication really made the project come together so much easier.

Justin Washington I realized the limitations that working online has with a project but I also learned the importance of communication and understanding. I really enjoyed working with this team and the experience that it brought. I definitely plan to use the skills I have learned in my career!

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