"Arms Race"
Prosthetic Arm
Engineering Challenge

FINAL REPORT

by

Al Einstein

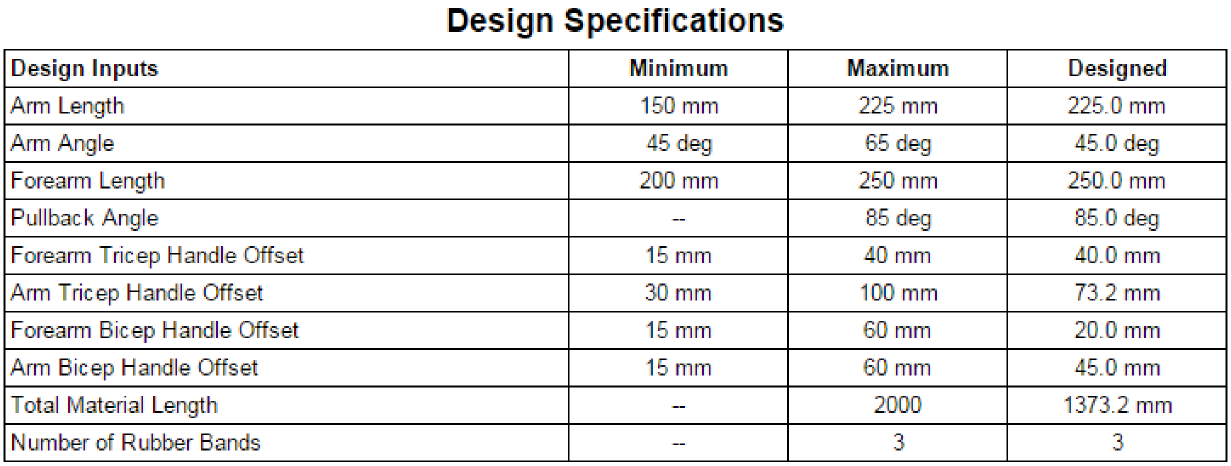
Discovery School

March, 2015

PART I. Virtual Model – Accuracy & Precision

My final virtual model on WhiteboxLearning was called “**AL4**.”

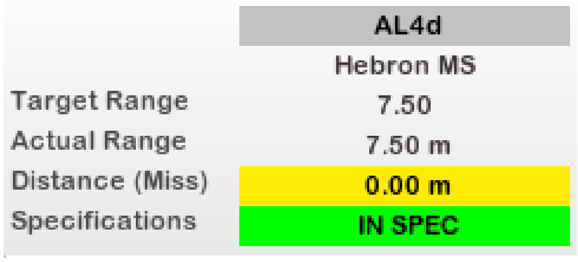
Here are the output Spec’s:



Design Specifications

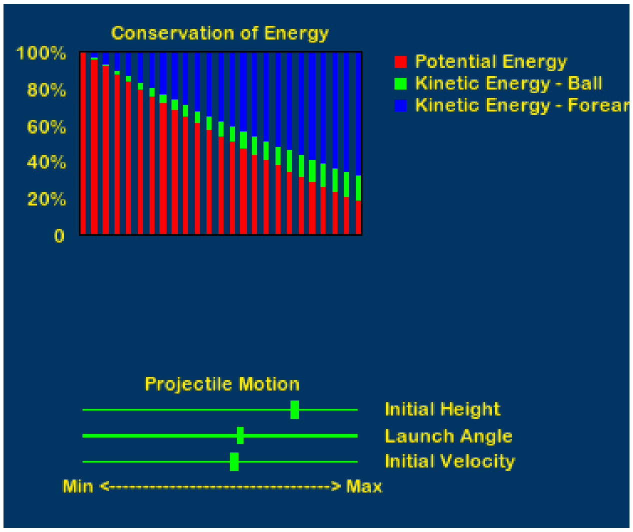
Design Inputs	Minimum	Maximum	Designed
Arm Length	150 mm	225 mm	225.0 mm
Arm Angle	45 deg	65 deg	45.0 deg
Forearm Length	200 mm	250 mm	250.0 mm
Pullback Angle	--	85 deg	85.0 deg
Forearm Tricep Handle Offset	15 mm	40 mm	40.0 mm
Arm Tricep Handle Offset	30 mm	100 mm	73.2 mm
Forearm Bicep Handle Offset	15 mm	60 mm	20.0 mm
Arm Bicep Handle Offset	15 mm	60 mm	45.0 mm
Total Material Length	--	2000	1373.2 mm
Number of Rubber Bands	--	3	3

Here are my competition results:

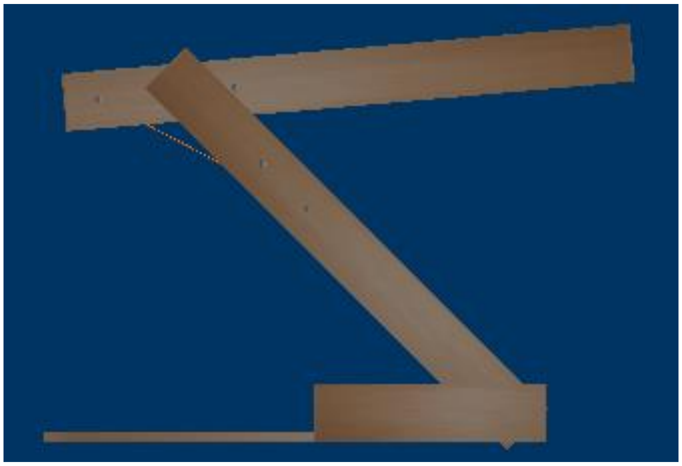


	AL4d
	Hebron MS
Target Range	7.50
Actual Range	7.50 m
Distance (Miss)	0.00 m
Specifications	IN SPEC

Here is my Data Analysis:



Here is my final model:



!!! NOTE: !!!

Including all of these images is not strictly necessary. It makes for a nicer report, but all you must do is indicate the filename of your final design and Mr. Franklin will verify it online via the Whitebox site.

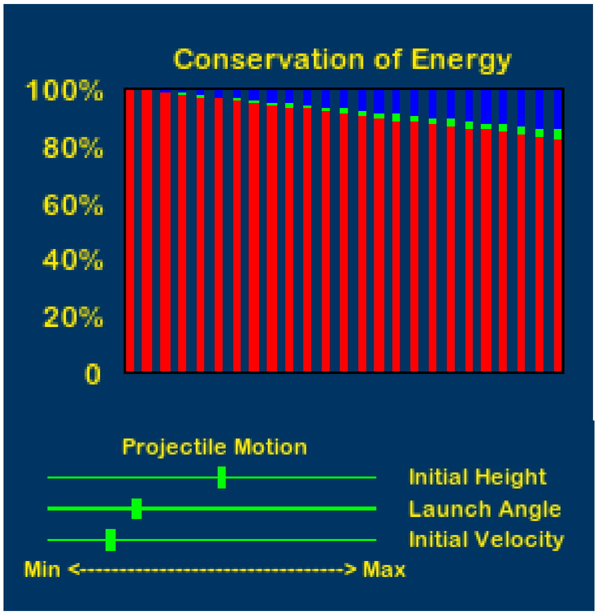
PART II. Design Evolution

Model AL1

For my first model, I decided to set everything to the maximum allowable value while still keeping it "in spec" and see how far it traveled.

With everything maxed-out,
it only went **1.99** meters,
over 5 meters from the target.

Clearly, "bigger" is <u>not</u> always better.
I knew I needed to scale it down a bit.



Looking at my graphs, I saw that
I had a ton of Potential Energy stored up
that wasn't getting converted to
Kinetic (motion) Energy.

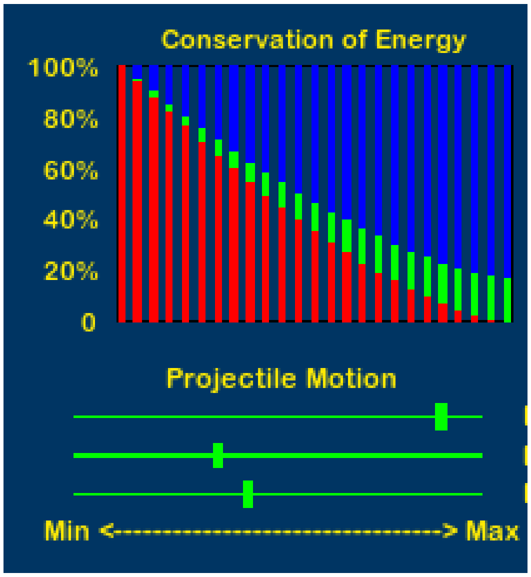
I know the bicep muscle is what stops the throwing motion, so I figured maybe the bicep was too strong. (I did max it out, afterall.) So I'll change that first.

Design Inputs	Minimum	Maximum	Designed
Arm Length	150 mm	225 mm	225.0 mm
Arm Angle	45 deg	65 deg	65.0 deg
Forearm Length	200 mm	250 mm	250.0 mm
Pullback Angle	--	85 deg	80.0 deg
Forearm Tricep Handle Offset	15 mm	40 mm	40.0 mm
Arm Tricep Handle Offset	30 mm	100 mm	100.0 mm
Forearm Bicep Handle Offset	15 mm	60 mm	60.0 mm
Arm Bicep Handle Offset	15 mm	60 mm	40.0 mm
Total Material Length	--	2000	1373.2 mm
Number of Rubber Bands	--	3	2

Model AL2

So in my second model, I backed the Bicep positions down on both arms from 60 mm to 40 mm so that the Bicep rubberband wouldn't be stretched out so much, stopping the throw.

Immediately I saw an improvement in my Energy Graph. A lot of the red Potential Energy got converted to Kinetic, and my Initial Velocity went up, too.



When I ran it in competition,
it went **4.45** meters,
more than double from last time,
but still not good enough
(about 3 meters short of my goal).

I noticed my Initial Height was pretty high, so I thought about changing the angle of the upper arm to make it smaller and closer to the ground. Also, why not add more power by adding rubber bands?

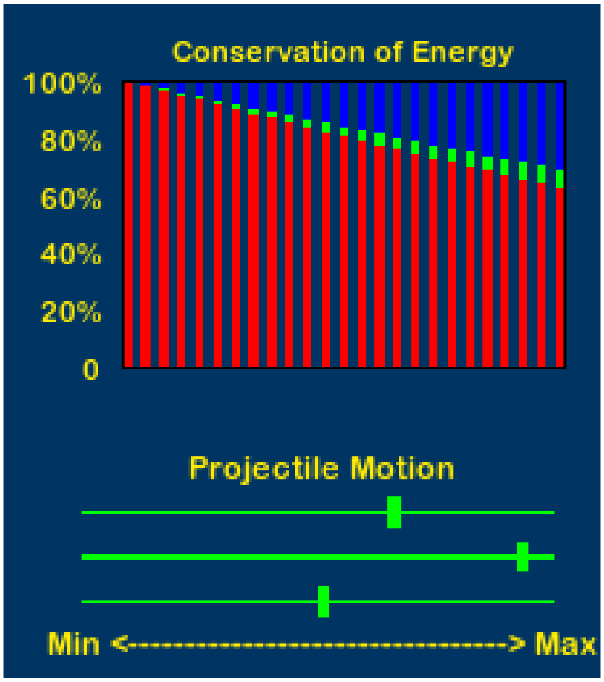
Design Specifications

Design Inputs	Minimum	Maximum	Designed
Arm Length	150 mm	225 mm	225.0 mm
Arm Angle	45 deg	65 deg	65.0 deg
Forearm Length	200 mm	250 mm	250.0 mm
Pullback Angle	--	85 deg	80.0 deg
Forearm Tricep Handle Offset	15 mm	40 mm	40.0 mm
Arm Tricep Handle Offset	30 mm	100 mm	100.0 mm
Forearm Bicep Handle Offset	15 mm	60 mm	40.0 mm
Arm Bicep Handle Offset	15 mm	60 mm	40.0 mm
Total Material Length	--	2000	1373.2 mm
Number of Rubber Bands	--	3	2

Model AL3

For model 3, I changed the upper arm angle from the maximum, 65, to 45. (I had read in my background research that 45 is the optimal launch angle, and even though the upper arm angle is not the same as the overall launch angle, I still thought I'd give it a try).

Also, I'm allowed up to 3 rubber bands, and so far I've only been using 2! So I went ahead and added an extra rubber band to my tricep to give it more power, and I switched all of the rubber bands to the smallest (size 30) so they would stretch the most.



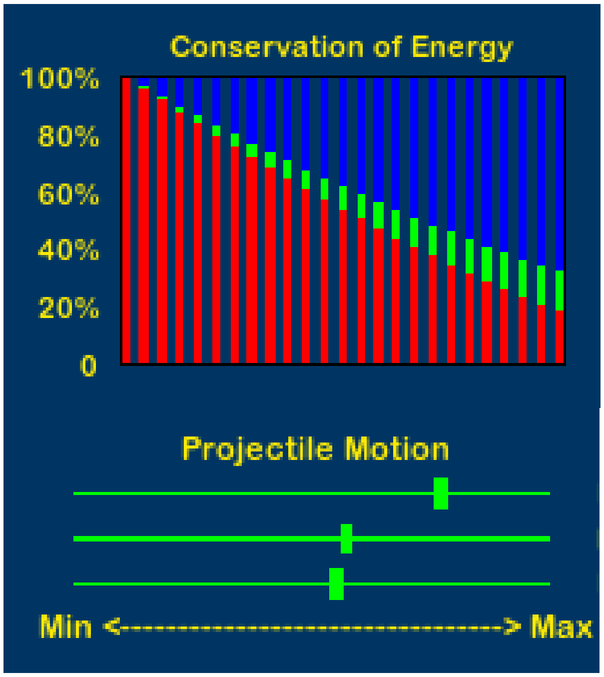
When I tested it, this model went 6.98 meters – I'm on the target! Only a half a meter to go.

Since boosting the strength of the tricep got me this far, I'm probably going to adjust the placement of the tricep to make the rubber band stretch out a little more.

Design Specifications

Design Inputs	Minimum	Maximum	Designed
Arm Length	150 mm	225 mm	225.0 mm
Arm Angle	45 deg	65 deg	45.0 deg
Forearm Length	200 mm	250 mm	250.0 mm
Pullback Angle	--	85 deg	85.0 deg
Forearm Tricep Handle Offset	15 mm	40 mm	40.0 mm
Arm Tricep Handle Offset	30 mm	100 mm	100.0 mm
Forearm Bicep Handle Offset	15 mm	60 mm	40.0 mm
Arm Bicep Handle Offset	15 mm	60 mm	40.0 mm
Total Material Length	--	2000	1373.2 mm
Number of Rubber Bands	--	3	3

Model AL4



For my final model, I adjusted the placement of muscle "tendons" to provide more initial power to the throw, and to limit the launch angle (by using the bicep to slow the throw).

As I made adjustments, I kept an eye on the Engineering Analysis graph to try and convert some of my stored up Potential (red) into Kinetic, to keep the Initial Velocity high, and to make sure the launch angle wasn't too high or too low.

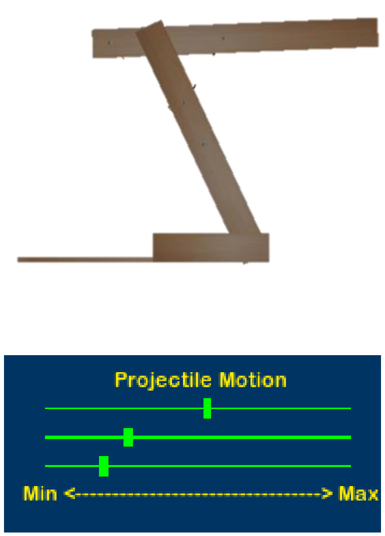
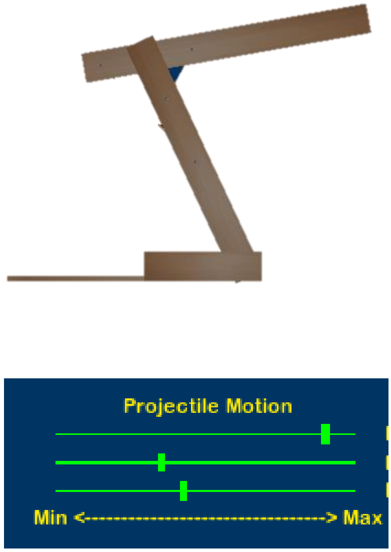
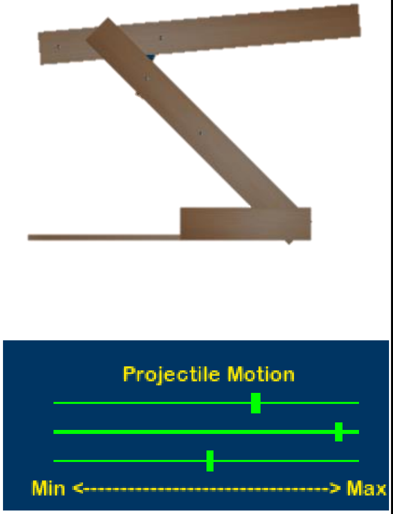
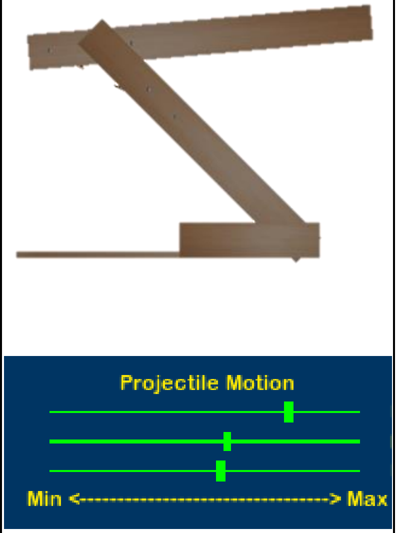
I found that by decreasing the bicep forearm position in half (from 40 to 20) and then compensating a bit by increasing the bicep arm position from 40 to 45, I could get all of those values where I wanted them.

This throw went almost exactly 7.5 meters. From here I just slightly tweaked numbers by tenths of degrees and millimeters until I got it just right!

Design Specifications

Design Inputs	Minimum	Maximum	Designed
Arm Length	150 mm	225 mm	225.0 mm
Arm Angle	45 deg	65 deg	45.0 deg
Forearm Length	200 mm	250 mm	250.0 mm
Pullback Angle	--	85 deg	85.0 deg
Forearm Tricep Handle Offset	15 mm	40 mm	40.0 mm
Arm Tricep Handle Offset	30 mm	100 mm	73.2 mm
Forearm Bicep Handle Offset	15 mm	60 mm	20.0 mm
Arm Bicep Handle Offset	15 mm	60 mm	45.0 mm
Total Material Length	--	2000	1373.2 mm
Number of Rubber Bands	--	3	3

DESIGN EVOLUTION SUMMARY

!!! NOTE: !!! You do not necessarily need to replicate this sample exactly. What you do need is (1) a **Visual**, (2) **Mathematical**, and (3) **Verbal** Description of at least 3 changes you made. This is just one example of how you could do that.				
Design Inputs	AL1	AL2	AL3	AL4
Structure - Arm Length	225	225	225	225
Structure - Arm Angle	65	65	45	45
Structure - Forearm Length	250	250	250	250
Structure - Pullback Angle	~~87.64~~	85	85	85
Tricep - Forearm	40	40	40	40
Tricep - Arm	100	100	100	75
Bicep - Forearm	60	40	20	20
Bicep - Arm	60	40	45	45
Total Material Length	1373.2	1373.2	1373.2	1373.2
Number of Rubber Bands	2	2	3	3
Design Outputs				
Actual Range	1.99	4.74	9.97	7.69
Distance (Miss)	5.51	2.76	-2.47	0.19

PART III. Potential Energy & Work Calculations

An object can store energy as the result of its position. For example, a pendulum at its maximum height stores energy as a result of its elevated position. When in this elevated position, the stored energy is referred to as potential energy because the pendulum has the potential to do work. Another form of potential energy is elastic potential energy where energy is stored by the stretching or compressing of elastic materials. In the prosthetic arm, the pulling back motion adds energy to the rubber band. The energy is then stored in the stretched rubber band until the arm is released. The work done by the rubber bands (muscles) is equal to the change in potential energy between the pullback and launch position.

$$Work = PE_i - PE_f$$

In general, the potential energy of a spring is:

$$\mathrm{PE} = \frac{1}{2}\mathrm{k}\mathrm{x}^2$$

Where k is a spring constant associated with the rubber band and x is the stretched length of the rubber band minus the relaxed length of the rubber band.

We can also add a variable N to the equation to accommodate more than one rubber band:

$$\mathrm{PE} = \frac{1}{2}\mathrm{Nkx}^2$$

Using the values in the table, the potential energy stored in the triceps muscle at the pullback position is calculated as follows.

$$PE_t = \frac{1}{2} * 1 * 35.0 * 0.0359^2 = 0.02\ Joules$$

Since the triceps and biceps muscles oppose one another, the total potential energy at the pullback position is the potential energy of the triceps muscle minus the potential energy of the biceps muscle. Since the biceps muscle is loose at the pullback position, its potential energy is zero. So the total potential energy at the pullback position is just that of the triceps muscle.

$$PE_{pullback} = PE_t - PE_b = 0.02 - 0.0 = 0.02\ Joules$$

At the launch position (or just a moment before launch), both the triceps and biceps muscles are loose. Therefore, there is no potential energy in the system at the launch position.

$$PE_{launch} = PE_t - PE_b = 0.0 - 0.0 = 0.0\ Joules$$

And the total work done by the muscles between the pullback and launch position is therefore calculated as follows:

$$Work = PE_{pullback} - PE_{launch} = 0.02 - 0.0 = 0.02\ Joules$$

Potential Energy & Work

Calculate the work done by your prosthetic arm and the potential energy of the bicep and tricep muscles by referencing the information on the left.

Be sure to show your math.

Work =

PART IV. Kinetic Energy & Velocity Calculations

All moving objects have kinetic energy. Just like potential energy, there are many forms of kinetic energy like vibrational (the energy due to vibrational motion), rotational (the energy due to rotational motion), and translation (the energy due to movement along a straight line). For our prosthetic arm, the work done by the rubber bands will cause the forearm and ball to move. Thus these two components will have kinetic energy.

The kinetic energy of the ball with mass *m* and velocity *v* is defined as:

$$KE = \frac{1}{2}mv^2$$

The prosthetic arm also has kinetic energy and we should actually take this into account. However, to simplify the problem we will neglect the kinetic energy associated with the rotating arm and assume that all of the system's kinetic energy is from the ball. Thus, we will assume that the total kinetic energy in the system at a given time is as follows:

$$KE = \frac{1}{2}mv^2$$

As before, we need to calculate the kinetic energy in the system at the pullback position and the launch position. At the pullback position (just before the arm is released) the ball and forearm are motionless (or velocity is zero). Thus, there is no kinetic energy in the system at the pullback position.

$$KE_{pullback} = 0.0\ Joules$$

At the launch position, the ball and forearm are moving, so some of the system's energy is in the form of kinetic energy. And since we know that this total kinetic energy is equal to the work done by the rubber bands, we can utilize the following formula:

$$Work = KE_f - KE_i$$

Since the initial (pullback) kinetic energy is zero, this formula reduces to the following:

$$Work = \frac{1}{2}mv^2$$

In other words, the work done by the rubber bands is equal to the total kinetic energy in the system. Energy is conserved.

Now rearrange the terms to isolate velocity:

$$v = \sqrt{\frac{2 * Work}{m}}$$

We have already calculated the work done by the rubber bands and the mass (m) of the ball is given. So we can now calculate the velocity of the ball when it leaves the hand.

$$v = \sqrt{\frac{2 * Work}{m}} = \sqrt{\frac{2 * 0.02}{0.00175}}$$

$$v = 4.78\ m/s$$

Kinetic Energy & Velocity

Calculate the work done by your prosthetic arm and the potential energy of the bicep and tricep muscles by referencing the information on the left.
Be sure to show your math.

Velocity =

V. Schematic Blueprint:

Directions: Print off your “Engineering Drawing” under the Outputs tab.

Label the following:

- ✓ **Forearm**
- ✓ **Upperarm**
- ✓ **Elbow joint** *(there are 2!)*
- ✓ **Shoulder joint**
- ✓ **Bicep tendon** *(there are 2!)*
- ✓ **Tricep tendon** *(there are 2!)*

- ✓ **Humerus**
- ✓ **Radius**
- ✓ **Ulna**

- ✓ **Fulcrum**
- ✓ **Effort**
- ✓ **Load**