# *"Arms Race"* Prosthetic Arm Engineering Challenge: <u>**FINAL REPORT**</u>

After designing, testing, revising, building, re-testing, and modifying your final Prosthetic Arm, each student is required to prepare a Report that details the process, difficulties, and learning that took place during this project.
The Final Report should include each of the following components, and will be worth <u>**100 points altogether.**</u>

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## I. Virtual Model – Accuracy & Precision: *Print off your final design Outputs. Mr. Franklin will verify that your model is within Spec. and will check the distance from your target.*

- ☐ 3 points – All variables are within Spec. and Distance from Target is 0.00 meters.
- ☐ 2 points – All variables are within Spec. and Distance from Target is less than 0.25 meters.
- ☐ 1 point – One variable may be Out of Spec. or Distance from Target is greater than 0.25 meters.
- ☐ 0 points – More than one variable is out of Out of Spec and/or Distance from target is greater than 0.50 meters.

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## II. Design Evolution: *Show evidence of how you modified and/or revised your Virtual Design based off the results of testing. Data Tables (such as the example template Mr. Franklin passed out), Written Descriptions, and Diagrams/Sketches showing progressive changes to the model are all appropriate.*

- ☐ 3 points – 3 or more stages/models in the evolution of the design (not including the final design) described using all available resources (Diagram/Drawings, Data Tables, <u>AND</u> Written Descriptions)
- ☐ 2 points – 3 or more stages/models in the evolution of the design (not including the final design) described using <u>multiple</u> resources (Diagram/Drawings, Data Tables, <u>OR</u> Written Descriptions)
- ☐ 1 point – 2 or more stages/models in the evolution of the design (not including the final design) described using at least one resource (Diagram/Drawings, Data Tables, <u>OR</u> Written Descriptions)
- ☐ 0 points – Not included.

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## III. Potential Energy & Work Calculations: *Using the WhiteboxLearning Background Research and materials provided by Mr. Franklin, calculate the Potential Energy and Work performed by your Prosthetic Arm.*

- ☐ 3 points – The Potential Energies of the Tricep Muscle, Bicep Muscle, Pullback, and Launch as well as Total Work Performed are all correctly shown with calculations clearly visible.
- ☐ 2 points – Most of the above ($PE_{Tricep}$, $PE_{Bicep}$, $PE_{Pullback}$, $PE_{Launch}$, Work) are correctly calculated with most of the work/calculations shown.
- ☐ 1 point – Some of the above ($PE_{Tricep}$, $PE_{Bicep}$, $PE_{Pullback}$, $PE_{Launch}$, Work) are correctly calculated with some of the work shown. (Some may be incorrectly calculated or missing.)
- ☐ 0 points – Multiple calculations are missing altogether.

## IV. Kinetic Energy & Velocity Calculations: *Using the WhiteboxLearning Background Research and materials provided by Mr. Franklin, calculate the Kinetic Energy and Velocity of the projectile.*

- ☐ 3 points – The Kinetic Energy at Pullback and Launch and the Velocity of the Ball are all correctly calculated and work (math) is clearly shown.
- ☐ 2 points – The Kinetic Energy at Pullback and Launch and the Velocity of the Ball are mostly calculated correctly with most of the work (math) shown. (Some mistakes may be evident.)
- ☐ 1 point – Some of the above are correctly calculated with some of the work shown. (Some may be incorrectly calculated or missing.)
- ☐ 0 points – Multiple calculations are missing altogether.

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## V. Schematic Blueprint: *Using the "Engineering Drawing" generated by WhiteboxLearning, identify and label key structural components that mimic the anatomy of the human arm, as well as the functional components of a lever.*

- ☐ 3 points – Print-off is clearly LABELED/ANNOTATED to accurately indicate the location of the Forearm, Upper arm, Elbow Joint, Shoulder Joint, Tricep Tendons (x2), Bicep Tendons (x2), Humerus, Radius, Ulna, Fulcrum, Effort (including direction), and Load (including direction) [Total # Components = 14]
- ☐ 2 points – Print-off is clearly LABELED/ANNOTATED to accurately indicate the location of most (but not all) of the components listed above. (A small number may be somewhat inaccurate or unclear.)
- ☐ 1 point – A large number of components are not labeled, or else they are unclear or significantly inaccurate.
- ☐ 0 points – The print-off is not labeled or annotated. (Or not included.)

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## VI. Prototype Model: *Physical Prototype has been constructed according to instructions and the schematic diagram, matching the virtual design in the Whiteboxlearning Software.*

- ☐ 3 points – Physical Prototype exactly matches virtual model and schematic diagram; Was clearly constructed according to directions with care, neatness, and precision.
- ☐ 2 points – Physical Prototype largely matches virtual model and schematic diagram (some insignificant errors); Was constructed mostly according to directions with care and precision.
- ☐ 1 point – Physical Protoype only somewhat matches virtual model and schematic diagram (some significant differences); Was not constructed according to directions or does not exhbit care or precision.
- ☐ 0 points – Physical Prototype does not match virtual model and/or schematic diagram. Care not taken in its construction. (Or incomplete construction.)

## VII. Refinement of Model: *Show evidence of how you modified and/or revised your Prototype Model based off the results of real-world trials. Data Tables, Written Descriptions, and Diagrams/Sketches showing progressive changes to the model are all appropriate. Modifications may include Arm Angle, Pullback Angle, Launch Angle, Number of Rubber Bands (Bicep and Tricep), Type of Rubber Bands (Bicep and Tricep), Configuration of Rubber Bands, etc.*

- ☐ 3 points – 3 or more modifications in the refinement of the model (not including the final model) described using all available resources (Diagram/Drawings, Data Tables, <u>AND</u> Written Descriptions)
- ☐ 2 points – 3 or more modifications in the refinement of the model (not including the final model) described using <u>multiple</u> resources (Diagram/Drawings, Data Tables, <u>OR</u> Written Descriptions)
- ☐ 1 point – 2 or more modifications in the refinement of the model (not including the final model) described using at least one resource (Diagram/Drawings, Data Tables, <u>OR</u> Written Descriptions)
- ☐ 0 points – Not included.

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## VIII. Ballistics Predictions: *Using the "Predictive Model" component of the Background Research on WhiteboxLearning, combined with multiple repeated trials of the real-world prototype, predict with accuracy and precision the trajectory of the projectile. (Determined by calculating average of 3 launches, following 1 practice launch)*

- ☐ 3 points – Distance from launch is accurately predicted within +/- 0.25 meters.
- ☐ 2 points – Distance from launch is accurately predicted within +/- 0.5 meters.
- ☐ 1 point – Distance from launch is accurately predicted within +/- 1.0 meters.
- ☐ 0 points – Distance from launch is not predicted with any accuracy. (Distance is highly variable, with distances exhibiting differences of > 1.0 meters)

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## IX. Actual Trajectory: *Through use of WhiteboxLearning design software, real-world trials, and modifications to physical prototype, student is able to launch projectile on a trajectory that goes precisely 7.50 meters.*

- ☐ 3 points – Actual distance from launch is accurate within +/- 0.5 meters.
- ☐ 2 points – Actual distance from launch is accurate within +/- 1.0 meters.
- ☐ 1 point – Actual distance from launch is accurate within +/- 1.5 meters.
- ☐ 0 points – Actual distance from launch is > 1.5 meters.

## X. Post-Analysis & Reflection: *Minimum 300-word discussion of difficulties and obstacles faced during execution of this project along with the methods and strategies employed to overcome those obstacles. Description of what could account for the physical prototype not matching the virtual design identically. What concepts or lessons could be taken from this project and applied elsewhere?*

- ☐ 3 points – Thoughtful typed response that addresses all 3 aspects of the prompt above with proper spelling, grammar, and syntax.
- ☐ 2 points – Response that mostly addresses the prompt above but may contain minor errors or omissions that still do not drastically diminish the students' original thought.
- ☐ 1 point – Response that addresses only one aspect of the prompt above, or may be off-topic, or does not clearly express students' thought.
- ☐ 0 points – Not included, or else response does not address the prompt in any meaningful way.

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## XI. Concept Drawing: *Your opportunity to be an artist. Create an illustration of what a fully-formed prosthetic arm based on your prototype might look like. Be sure to label the most important components.*

- ☐ 3 points – Illustrated diagram that shows care and attention in depicting a visual representation of the model
- ☐ 2 points – Illustrated diagram that show limited care and attention is depicting a model
- ☐ 1 point – Illustrated diagram that shows little care or attention at accurately depicting a possible model
- ☐ 0 points – Not includeded, or else very little care taken in illustration; confusing or messy

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## XII. Lever Identification: *Identify what type(s) of simple machines are at work in the Prosthetic Prototype and justify your answer in relation to the Virtual Design, Engineer Drawing, or Model Prototype.*

- ☐ 3 points – Class of lever accurately identified and defined with reference to specific structural characteristics
- ☐ 2 points – Class of lever accurately identified, but may not contain clear reasoning or evidence
- ☐ 1 point – Class of lever incorrectly identfied (but nevertheless provided supporting evidence);
  -OR- Class of lever correctly identified, but no reasoning or justification provided
- ☐ 0 points – Not includeded, or incorrectly identified with no supporting evidence to back up claim

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:

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

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.

$$PE_{launc\ h} = PE_t - PE_b = 0.0 - 0.0 = 0.0\ Joules$$

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

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

# 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 =***

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.

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

$$v = 4.78\ m/s$$

# **<u>Kinetic Energy & Velocity</u>**

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.

*<u>Be sure to show your math.</u>*

***Velocity =***