NORTHERN ARIZONA UNIVERSITY

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ME 476C-5

To: Dr. Sarah Oman
From: *Active Prosthetic Team 18F12*
Date: *October 12, 2018*
Re: *Analytical Memo*

In order to design an active prosthetic for below elbow amputees, four analytical calculations were agreed upon by the team. An analysis of the material type and how it affects the strength and thermoformability of the arm will be done by Antoinette Goss. Arduino code for the sensing and motorized motion of the hand will be written by Felicity Escarzaga. Different percent infill calculations will be conducted by Allison Cutler to determine the allowable range the arm can be designed within. Different shapes and the mechanical forces applied to each will be evaluated by Jannell Broderick to determine the most efficient form of the arm.

<u>Strength and Thermoforming Material Type- Antoinette Goss</u>

Antoinette Goss will be analyzing the different materials that could potentially be used for the arm. Potential materials could include PLA, ABS, PET, and HIPS. The materials will be tested on their strength and thermoforming ability to ultimately find the best material to create the base and cast of the arm. It is also important to test these properties in order to find which material will be the easiest to mold while still able to handle a reasonable load. To test each material against thermoforming and strength, some specific calculations will need to be used. The strain rate ductility will be tested against increased heat to understand its ability to be deformed and manipulated. It is important to note that the material cannot be too hot to touch, or else it will not be able to be properly molded. Antoinette will begin with the Eyring-influenced strain rate equation shown below. This equation correlates the yield behavior to a thermal activation. This is modeled in a strain equation:

$$\varepsilon = \varepsilon *\cdot sin(h)^n(\frac{(\sigma_y-\sigma_i)V}{2kT}) \quad (1)$$

Where (n) is the material parameter, (v) is activation volume, (k) is the Boltzmann constant, and (σ_y) is the yield stress. Internal stress (σ_i) and the strain rate can then be derived into the following equations:

$$\sigma_i(T) = \sigma_i(0) - mT \quad (2)$$

$$\varepsilon \cdot T = \varepsilon_0 exp\,(-\frac{H_\beta}{KT}) \quad (3)$$

Where (m) is the material parameter, (H) is the activation energy of loss peak (β), and (T) is absolute temperature at a given point. These values will be calculated and plotted in a stress vs strain curve in MatLab to determine the most malleable and durable material at different temperatures.

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Arduino Code for Sensing- Felicity Escarzaga

Felicity will be writing a code and finding the hardware to sense an object within close range. Once the object is in close range, the user will be signaled using motor actuation. This code simulates the motor actuation and sensing capability that will be applied to the prosthetic hand. The microcontroller used will be chosen by analyzing different Arduino boards and their properties. Factors that may influence the type of board include number of attach interrupt pins, PWM pins, IO pins and pins total, flash memory, clock speed, cost, and more. Each factor will depend on the number of sensors and motors, and the type of sensors and motors needed. Other hardware such as the motors, motor driver, sensors, and sensor shield, will be analyzed based on their necessary output, resolution, compatibility, and cost.
The code will be dependent on the resolution of the sensors and motors, making hardware selection an important part in this analysis. Since compatibility between hardware will be the most challenging aspect, iterations of hardware types will be compared to select the best combination of hardware to test the code. The resources that will be used are: Arduino software, the Arduino online guide, Arduino libraries provided in the software, tutorials, schematics, and specification sheets provided with hardware.

Percent Infill Effects- Allison Cutler

Allison will be determining the range of percent infill that allows the arm can have without fracturing. This analysis will be done by taking the material properties of Polylactic Acid and determining the stress (σ) and strain (ε). Strain will be calculated using Hooke's Law, equation 4, and stress will be found from equation 5. The stress and strain will be graphed in order to determine the yield strength (σ_y) of the material.

$$\sigma = E\varepsilon \tag{4}$$

$$\sigma = \frac{F}{A} \tag{5}$$

Where the force will be an arbitrary changing load and the area will be the assumed cross-sectional area of the arm, both of which are inputs that can easily be changed. Weight will be calculated using equation 6, which depends upon mass (m) and gravity (g). Mass is calculated using equation 7. Volume (V) depends on the length (l_i), width (w_i), and height (h_i) of the space within the shell multiplied by the percent infill (p_{infill}), as well as the outer shell length (l_o), the outer shell width (w_o), and outer shell height (h_o). The volume changes as the percent infill changes.

$$W = mg \tag{6}$$

$$m = V\rho \tag{7}$$

$$V = l_o w_o h_o - l_i w_i h_i (1 - p_{infill}) \tag{8}$$

Weight will then be compared with the yield strength (σ_y) of the material to determine the range of percent infill that can be used in the design. A matlab code will be written for the calculations so that the material properties and dimensions can easily change.

Shape and Mechanical Forces - Jannell Broderick

This analysis involves calculating the forces on differently shaped prosthetics. Jannell will create Free Body Diagrams and MatLab code to display the effects that different forearm design shapes will have on force distribution. She will also factor in the location of forces. These forces can be distributed loads or point loads. Jannell will be treating the forearm as a cantilever beam because the top of the forearm will be fixed to the patient's limb much like a cantilever is fixed in one location. From this analysis she will find the necessary strength of material and the location of stress concentration. In addition, she will learn how to use finite element analysis within Solidworks. This will allow her to show the stress concentration on each type of forearm design. By knowing the maximum forces and location of the forces, it will allow the team to know best shape to optimize the strength of the forearm. It will also tell the team which locations on the arm may need reinforcements to withstand the forces applied. If time allows she will compute a similar analysis for different design shapes for the fingers and palm of the hand.
For this analysis there are a few equations to consider. She will calculate the forces and moments on the arm. Assumptions will be made based on common forces on arms. This includes picking up items, pushing objects, pulling objects, rotational forces, and gravitational forces on the arm. Force (F) depends on mass (m) and acceleration (a). Moment depends on the force (F) and the distance (L) from the fixed location. The base equation for moment and force are as follows:

$$F = ma \tag{9}$$

$$M = FL \tag{10}$$

These will be implemented into the Free Body Diagrams. The reaction forces and moments will also be found. This will be done by using the Sum of Forces and Moments along the forearm will be computed.

$$\Sigma F = 0 \tag{11}$$

$$\Sigma M = 0 \tag{12}$$

For a cantilever beam she will also need the deflection equations for cantilever beam. There are different deflections based on the type and location of the loads. The deflection (δ) depends on Modulus of elasticity (E), the Moment of Inertia (I), the force (F), the full length of the beam (l), Moment (m), distributed load (ω), and distance to the load (L). The equations are as follows:

Load at free end:

$$\delta = \frac{Fl^3}{3EI} \tag{13}$$

Load at any point: $$\delta = \frac{FL^2}{3EI}(3l - L) \quad (14)$$

Distributed load: $$\delta = \frac{\omega l^4}{8EI} \quad (15)$$

Couple Moment: $$\delta = \frac{Ml^2}{2EI} \quad (16)$$

Note: the moment of inertia depends on the shape of the forearm. Jannell will research the moment of inertia for the different cross-sectional areas.

These equations are just a brief overview of the needed equations that will be used. A MatLab code will be developed to accommodate the different forearm shapes and force locations.