

Human Arm

Equipment: Capstone, Human Arm Model, 45 cm rod, sensor mounting clamp, sensor mounting studs, 2 cord locks, non-elastic cord, elastic cord, two blue passport force sensors, large table clamps, 100g brass mass, angle sensor port, plastic bin

1 Purpose

To investigate the relationship between torque, moment of inertia, and angular acceleration for a human arm. Triceps extension and rotational inertia of the forearm will be observed.

2 Theory

Keep in mind not all aspects of the theory are covered in this experiment, since rotational motion is not an easy concept. **I felt that it was wise to have an elaborate explanation on rotating rigid bodies of torque and angular momentum.**

2.1 Equation of Motion for a Rotating Rigid Body

The equation of motion for a particle moving in a circle may be derived as follows: Consider a point mass m constrained to move on a circle of radius r . Depending on the net force \mathbf{F} acting on it, m may speed up or slow down in its circular motion. The dynamics of this are given by Newton's 2nd Law $\mathbf{F} = m\mathbf{a}$, where \mathbf{a} is the acceleration. (At any instant of time, it is convenient to write the component of this equation, that is in the direction of the velocity or tangential to the circle at the point where the mass is located). Let the component of the force in that direction be F_{tan} , where "tan" stands for tangential and denotes the component of the force that is tangential to the velocity of the mass. For circular motion, we also use the component of the acceleration tangential to the circle $r\alpha$, where r is the radius of the circle on which the particle moves and α is the angular acceleration in rad/s^2 . The relevant component of Newton's 2nd Law becomes $F_{tan} = mr\alpha$. Multiplying both sides of this equation by r gives $rF_{tan} = mr^2\alpha$. **The quantity rF_{tan} is called the torque τ . Torque is present about the axis of rotation of the circle.** (An axis of the circle is a line that runs through the center of the circle and is perpendicular to the plane of the circle.) One could also say that this is the component of the torque along the axis of rotation. The quantity mr^2 is called the moment of inertia I of the mass about the axis of the circle. Inertia is the resistance of the mass to rotate. The equation of motion now has the form $\tau = I\alpha$.

This analysis can easily be extended to a rigid body rotating about an axis fixed in space. Suppose that the rigid body is constructed of point masses m_i each moving in a circle of radius $r_{i\perp}$ and acted upon by a force \mathbf{F}_i whose component in the direction of the velocity is

$F_{i,tan}$. All the point masses will have the same angular acceleration α . Note that the $r_{i\perp}$ do not have a common origin but that each represents the perpendicular distance from the axis of rotation to m_i . The equation of motion for each mass is $r_{i\perp}F_{i,tan} = m_i r_{i\perp}^2 \alpha$. Summing this over all the point masses of the rigid body we have

$$\sum_i r_{i\perp} F_{i,tan} = \sum_i m_i r_{i\perp}^2 \alpha.$$

The forces acting on any mass m_i can be divided into internal and external. Internal forces are those exerted on m_i by the other masses of the rigid body. External forces are all other forces that originate outside of the system of masses. It can be shown that due to Newton's 3rd Law the torques due to the internal forces of the rigid body will cancel. Without changing notation, we assume the torque is due solely to external forces. Extending our definitions of torque and moment of inertia to $\tau = \sum_i r_{i\perp} F_{i,tan}$ and $I = \sum_i m_i r_{i\perp}^2$, the equation of motion for a rigid body rotating about a fixed axis is $\tau = I\alpha$, where τ is the external torque. In other words, for a rigid body rotating about a fixed axis, the sum of the external torques computed about the axis is equal to the moment of inertia computed about the same axis multiplied by the angular acceleration. For the motion of non rigid body particles, the torque is defined about a point. If \mathbf{r} is the vector from that chosen point to the point of application of a force \mathbf{F} , the torque is defined as $\tau = \mathbf{r} \times \mathbf{F}$. Applying this definition to our rigid body rotation, if the chosen point is taken anywhere along the axis of rotation, the torque, as it was defined, is the component of torque along the axis of rotation.

2.2 Angular Momentum

Angular momentum \mathbf{L} about the point for a particle with linear momentum \mathbf{p} is defined as $\mathbf{L} = \mathbf{r} \times \mathbf{p}$. For a system of particles, if τ represents the sum of the external torques about a point, and \mathbf{L} represents the sum of the angular momenta for the particles about the same point, it is easily shown that an equation of motion is $\tau = \frac{d}{dt}\mathbf{L}$. If any component of τ is zero, that component of the angular momentum is a constant.

2.3 Moments of Inertia

Typically, rigid bodies can be divided into different components. The moment of inertia of each component about the chosen axis can be calculated and then the total moment of inertia obtained by summing the moments of inertia of all components. **Keep in mind the moment of inertia depends on where the rotation of axis is occurring.** We list the moments of inertia of various components of each mass M . Each mass M is assumed uniform.

1. A small mass a distance R from the axis: $I = MR^2$.
2. A thin rod of length L about an axis through the center: $I = \frac{1}{12}ML^2$.
3. A solid cylinder (or disk) of radius R about its axis: $I = \frac{1}{2}MR^2$.
4. A tube of outer radius R_2 and inner radius R_1 about its axis: $I = \frac{1}{2}M(R_1^2 + R_2^2)$.

5. An arm with its elbow at an angle of 90° , and a radius (the distance from the elbow to insertion point which is 0.045 m) about its axis (the elbow): $I = RF/\alpha$.

In this lab, you're only taking into account the moment of inertia of the elbow using two methods.

3 Equipment Description

This section is a reference to equipment you will use and how they may be setup for different parts of the experiment.

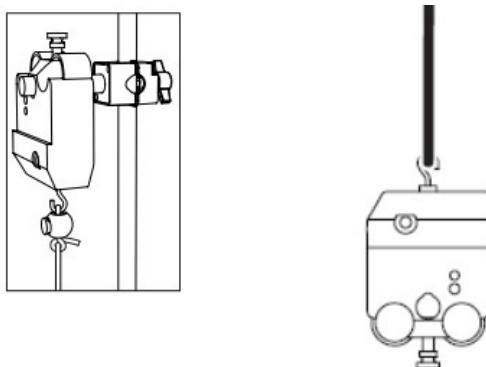
3.1 Force sensor

There is a button on the front that zeros out the sensor. The force sensor has a resolution of 0.03N and can handle a sampling rate of 1000 samples per second. It connects to a blue port of the PASPORT interface, which can record forces within a range of (-50 N to +50 N).



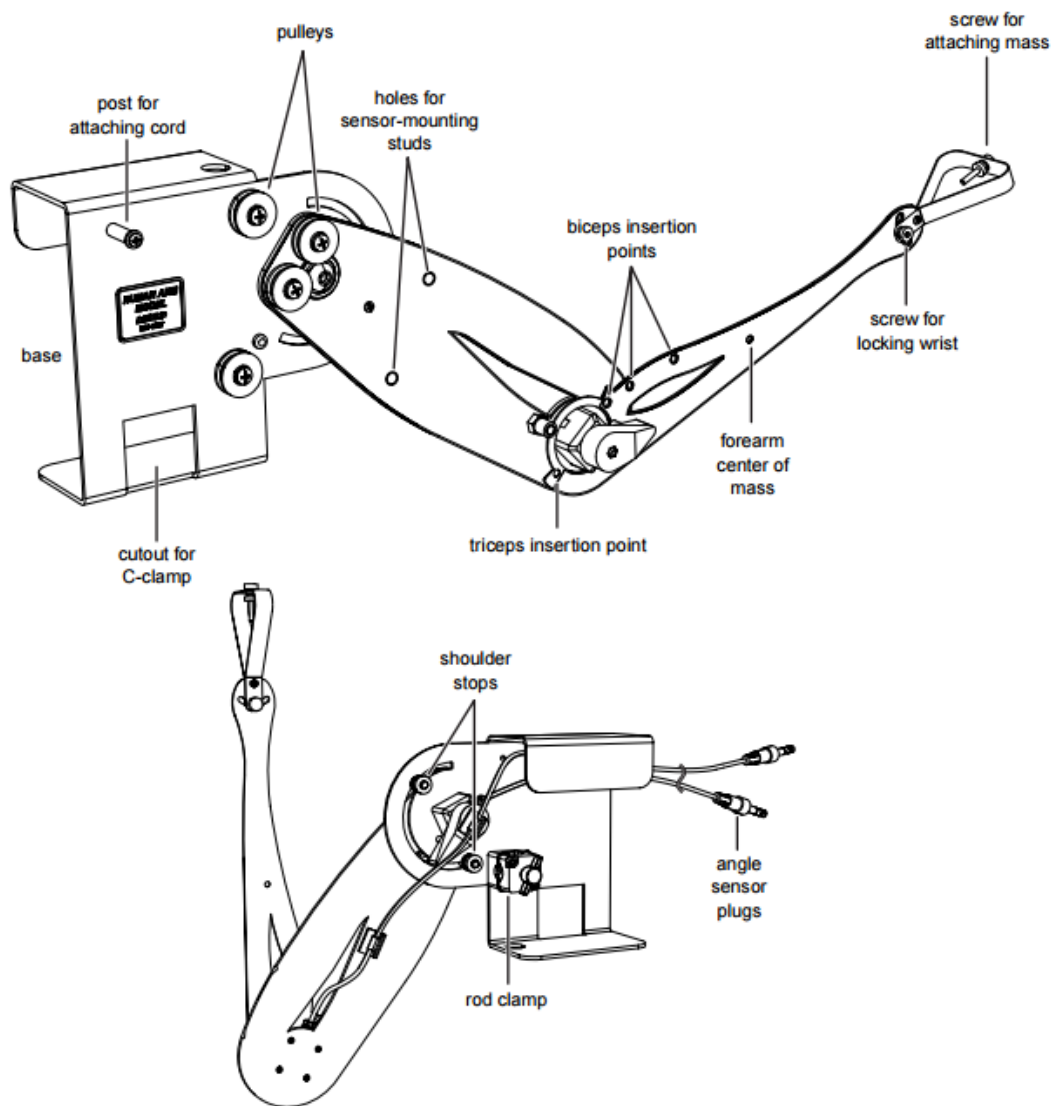
Front view of the Force sensor

You will mount and use the force sensor as illustrated below.



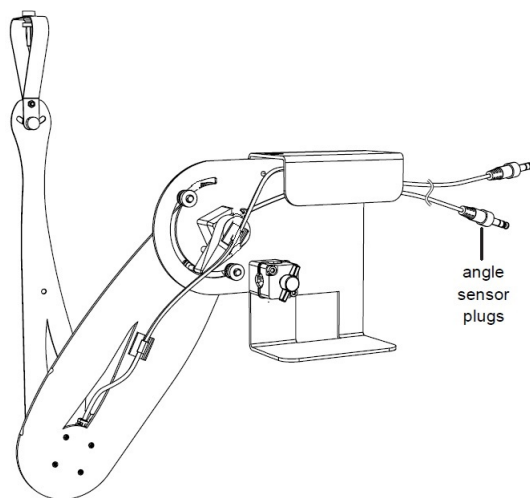
3.2 Human Arm

Throughout this lab, the Human Arm apparatus will be mounted in various orientations. Below is front and back image of the Human Arm. **Be aware of your insertion points**



3.3 Angle sensor

To use the angle sensor, connect the two digital plugs from the Human Arm apparatus to the Pasport angle sensor. **Make sure that you correctly plug in the labeled 1 and 2 angle sensor plugs to the Pasport angle sensor labeled 1 and 2.**



The Pasport angle sensor plugs into one of the lower blue ports of the interface.



4 Programming

Below are general instructions on how to run and setup the software for different parts of the experiment. Use this section as a reference

4.1 Hardware Setup Window

On your desktop screen, double click on the PASCO Capstone software icon. The Capstone software will open up and you should see a tools column, a white screen labeled page, and a displays column.

In the tools column, click on **Hardware Setup**. An image of the interface will pop up.

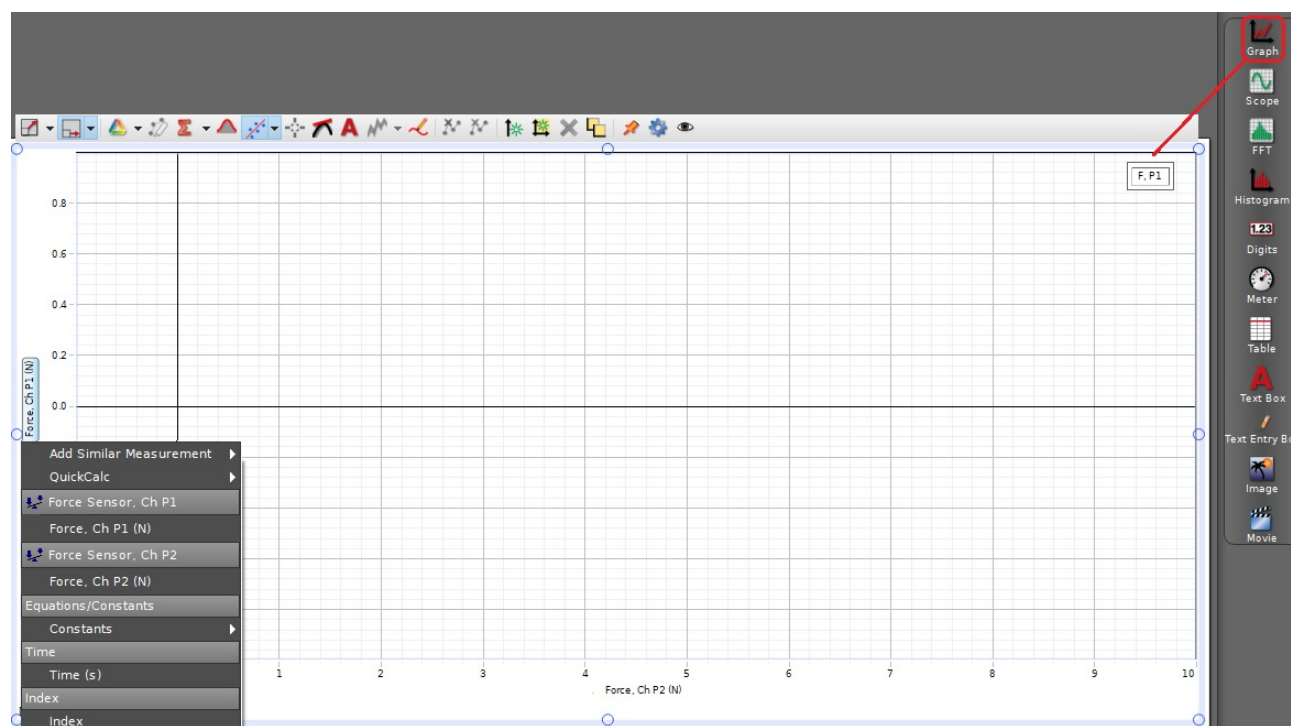


Click on the tack located on the top right corner of the hardware setup window to prevent windows from overlapping.



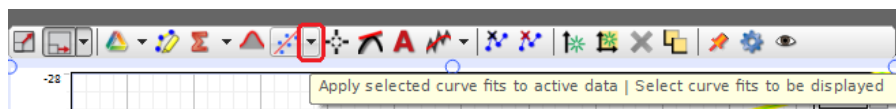
4.2 Setting up graph displays

In the displays column, find the graph icon. Drag and drop the graph icon onto the white screen. A graph will pop up. On the vertical and horizontal axes, there is a **select measurements** button, used to label the axes. For the first parts of the experiment, you will create a plot of two forces. One force will be plotted on the x-axis and the other on the y-axis.

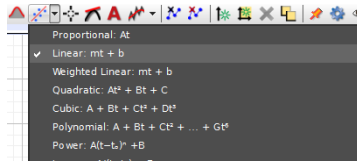


4.2.1 Plotting a Linear fit line

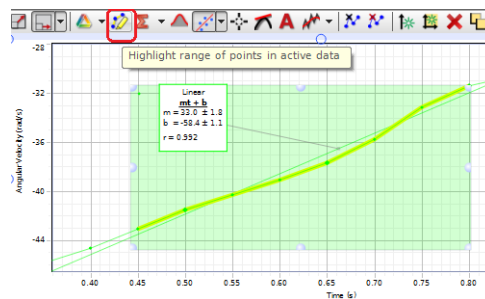
Go to the top of the graph display window. Click on the down arrow next to the diagonal red line with blue dots.



A drop down menu will pop open. Select Linear.

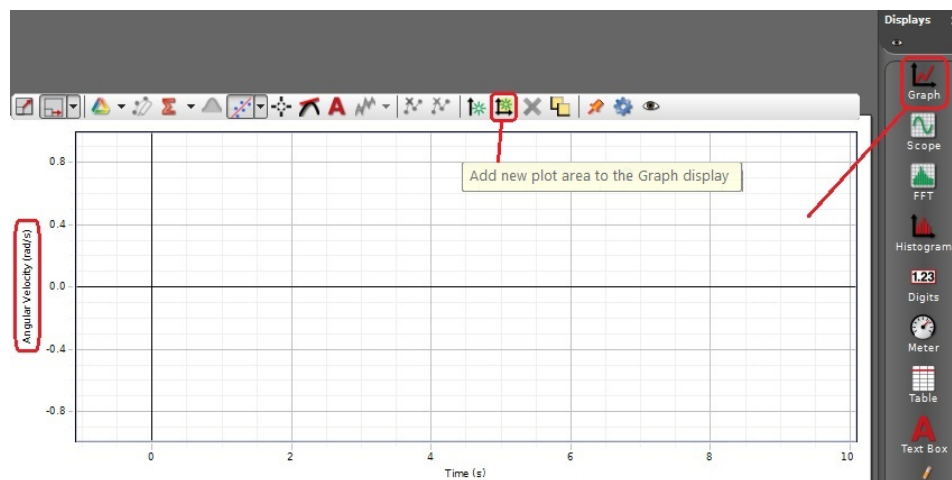


The software has a highlight button located on top of the graph. Use this button to select the best parts of the graph.



4.2.2 Graphs of multiple plots and angular acceleration

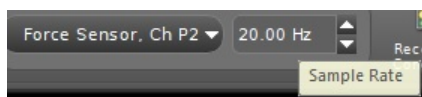
To add additional axes to the graph, click the **Add new plot area to the Graph display** button, shown below.



Note: In section 5.2.6, you are going to need a graph with three vertical axes (one for elbow angle, one for angular velocity, and one for bicep force) and a horizontal axis (time). The slope of the angular velocity vs. time line is the angular acceleration α . **To determine the slope, i.e. angular acceleration α , you have to fit a linear fit curve to an appropriate portion of the angular velocity graph.** (See section 4.2.1). Use this slope to do preliminary analysis of your data while you are still in the lab.

4.3 Adjusting sample rate

Located on the bottom part of the screen.



4.4 Changing units

Click on the units to change from radians to degrees.



5 Experiments

5.1 Extension of Triceps in horizontal orientation

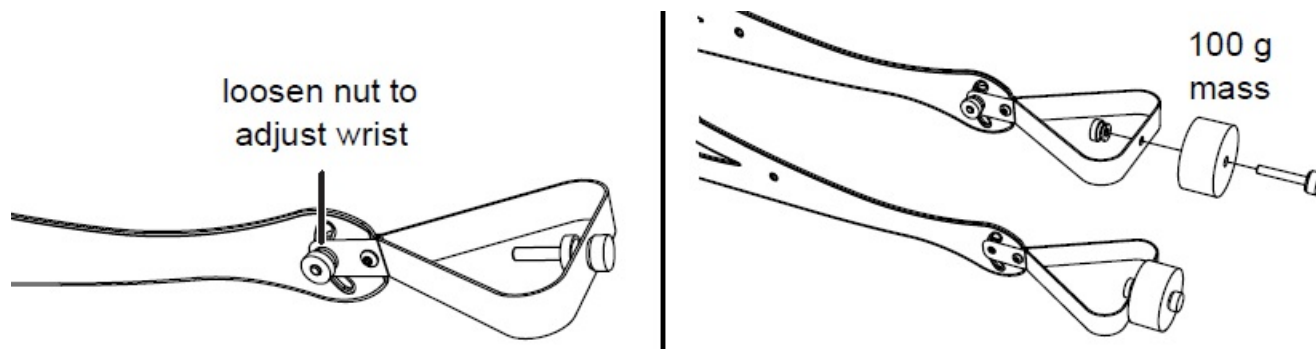
5.1.1 Introduction

In this part the upper arm is in the horizontal position.

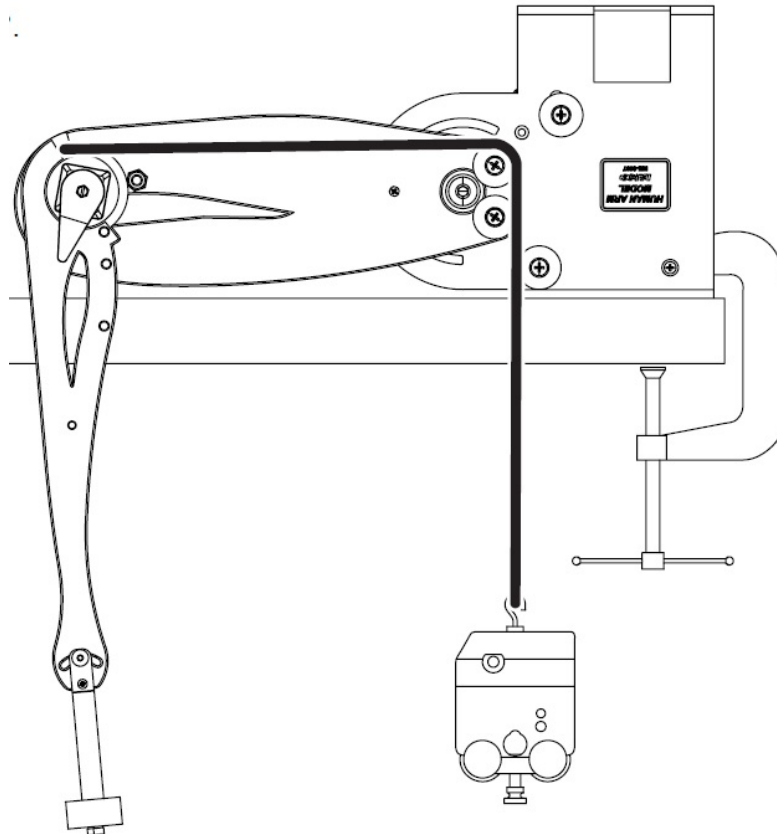
Hold a mass in your hand then lean forward and rotate your shoulder back so that your upper arm is horizontal. Bend your elbow at 90° so that your forearm hangs straight down. While keeping your upper arm horizontal, lift the mass by extending your elbow. This is the motion you will be observing in this section.

5.1.2 Setup

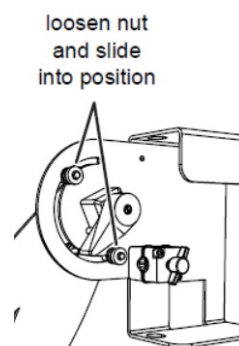
1. Mount a 100 gram mass on the hand of the Human Arm



2. Use the large table clamp and mount the base of the Human Arm in the vertical orientation with the label upside down on the outer edge of the table. (Look at the following image)

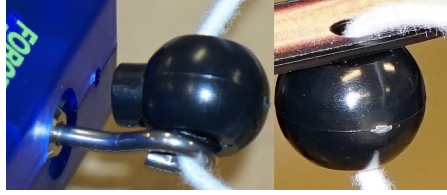


3. Lock the shoulder at around 90° angle. You need to adjust the two shoulder stops. Below is location of the shoulder stops.



4. Attach the **non-elastic** cord from the **force sensor** to **tricep insertion point** as illustrated above. If you're unaware of where tricep insertion point is look in section 3.2.

On the next page is an illustration of using cord lock at the force sensor and insertion point.

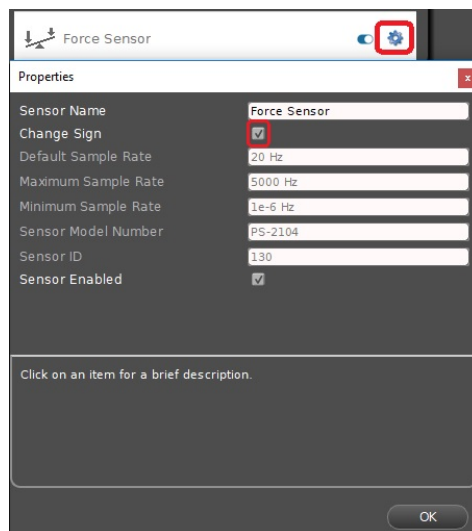


5. Connect the model arm angle sensor plugs to the Pasport angle sensor, and connect the angle sensor to the blue port of the interface. Make sure you correctly plug in the labeled plugs into the correct labeled angle sensor ports. Look at section 3.3. Next, plug the force sensor into your interface.

Note: You will hold the force sensor in your hand and pull to make the model's forearm extend.

5.1.3 Programming and running the experiment

- Make sure the two digital plugs of the Human Arm apparatus are plugged into the Pasport angle sensor and that the angle sensor is plugged into the Pasport port. **Also, make sure you only have one force sensor connected to the interface.**
- Start Capstone and set the sampling rate of the force sensor to 20 Hz. Look at section 4.3
- Create a graph of **Tricep force vs. Elbow angle**. For Elbow angle on the graph you will use **Angle 1**. Look at section 4.2 to setup a graph.
- Hold the forearm in place horizontally by pulling with the force sensor. You might need to change how the force sensor perceives the direction of + or - negative.



- Click Record and pull along the force sensor so that you slowly extend the elbow from the initial angle of 90° to 15° . Have your partner click Stop when you reach 15° .

5.1.4 Analysis and questions

As the arm lifts the mass, does elbow angle increase or decrease? Does the triceps force increase or decrease? Why or why not? If you repeated the experiment with a mass of 200 grams what would happen to the curves of the graphs?

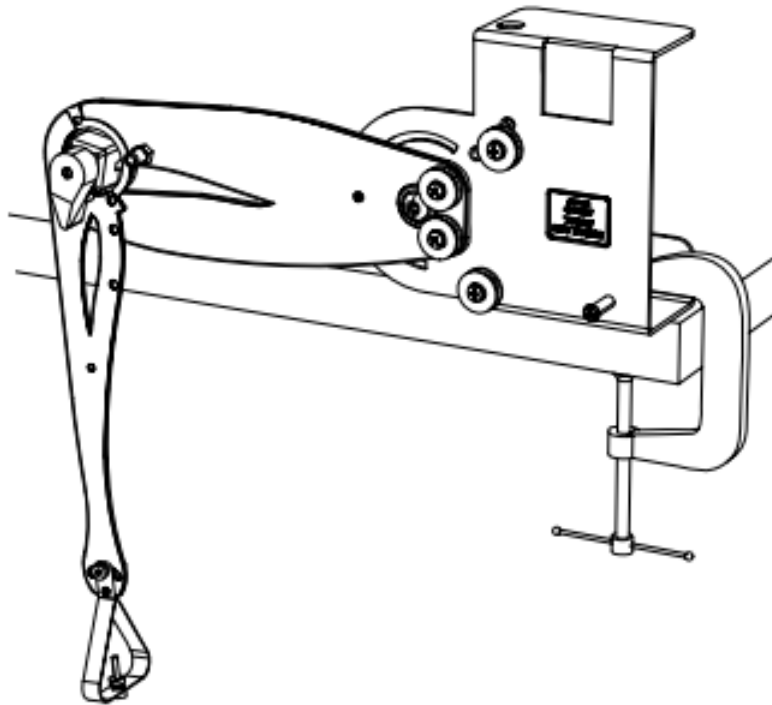
5.2 Rotational Inertia of a Forearm

5.2.1 Introduction

For this last experiment there are two methods you will use to determine the rotational inertia of the forearm when the axis of rotation occurs at the elbow. **Part A**, you will determine the period of oscillation of the elbow. **Part B**, you're applying a known force to the elbow and measure the resulting angular acceleration.

5.2.2 Part A Set-up

1. Keep the Human Arm mounted in the same orientation as in the previous section and make sure that the shoulder is still locked in place at 90° .



2. Remove the force sensor, cord, and the added mass from the hand.
3. The angle sensor should be already plugged in from the previous experiment.

5.2.3 Part A Procedure

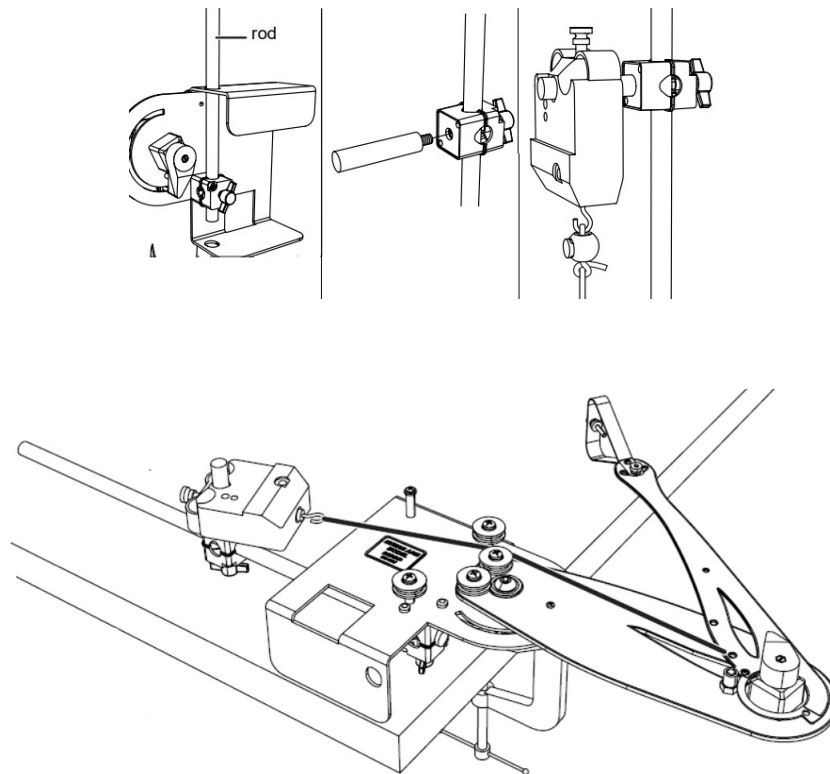
- Restart the Capstone software and set the sampling rate of the angle sensor to 200 Hz.
- Set-up a graph for a plot of elbow angle vs. time.
- Displace the forearm with a small amplitude and release it so that it oscillates freely.
- Click Record.
- As soon as the forearm stops its oscillation click Stop.

5.2.4 Part A Analysis

The rotational inertia around the axis of the elbow is given by $I = T^2 Mgd / (4\pi^2)$. T is the period of oscillation with a small amplitude. The period is similar to a pendulum. $M = 0.10$ kg which is the mass of the forearm and hand, $g = 9.8 \text{ m/s}^2$, and $d = 0.14$ m is the distance from the elbow to the center of mass which is marked with a hole. Determine T from the graph of elbow angle versus time. Use this value of T to determine the rotational inertia.

5.2.5 Part B Set-up

1. Remove the table clamp and reposition the Human Arm apparatus along the surface of the table.
2. Mount the Human Arm along the surface of the table, and the force sensor onto the rod as illustrated below.



3. Install and connect the **elastic cord** from the **standard bicep insertion point** to the **force sensor** and adjust the length so that the cord has a slight tension when the **elbow is fully flexed**. Again look at the previous illustration.
4. Connect the force sensor to the interface and restart the software.

5.2.6 Part B Procedure

- In Capstone, adjust the sampling rate of the force sensor to 200Hz.
- Create a graph with three plots. (Look in section 4.2.2 for the location to add additional plots button.) One for the elbow angle, angular velocity which have units of rad/s, and bicep force vs. time.
- Make sure you can clearly read the angles of your data when you record the data.
- Have your partner click Record and start to pull the forearm and hold it at approximately 75° .
- Then release the forearm and allow it move freely as the elastic cord contracts and then click Stop.

5.2.7 Part B Analysis

Take a close look at the angular acceleration when the elbow angle is about 90° . The rotational inertia is (approximately) $I = rF/\alpha$, where $r = 0.045$ m is the distance from the elbow to the insertion point, F is the bicep force, and α is the rotational acceleration.

- On the graph of angle versus time, **identify the time span during which the elbow rotates from 80° to 100° . Explain whats occurring for that part of the graph.** You need to adjust the scale of the graph!
- Across the same time span, find the average force, F . **This means you need to select the force curve across that time span to obtain the mean value!** Use the mean value function located in the graph tool bar next to the Σ button.
- Across the same time span, fit a line to the angular velocity vs. time plot. Use a linear fit curve from section 4.2.1 to determine the slope of the curve. The slope of this line is α .
- Use these values of F and α to determine the rotational inertia.

6 Finishing Up

Be considerate and leave the equipment in proper order for your fellow mates. If not your instructor will take off points your next lab report.