Initial Testing Results – P11 Arm Exoskeleton

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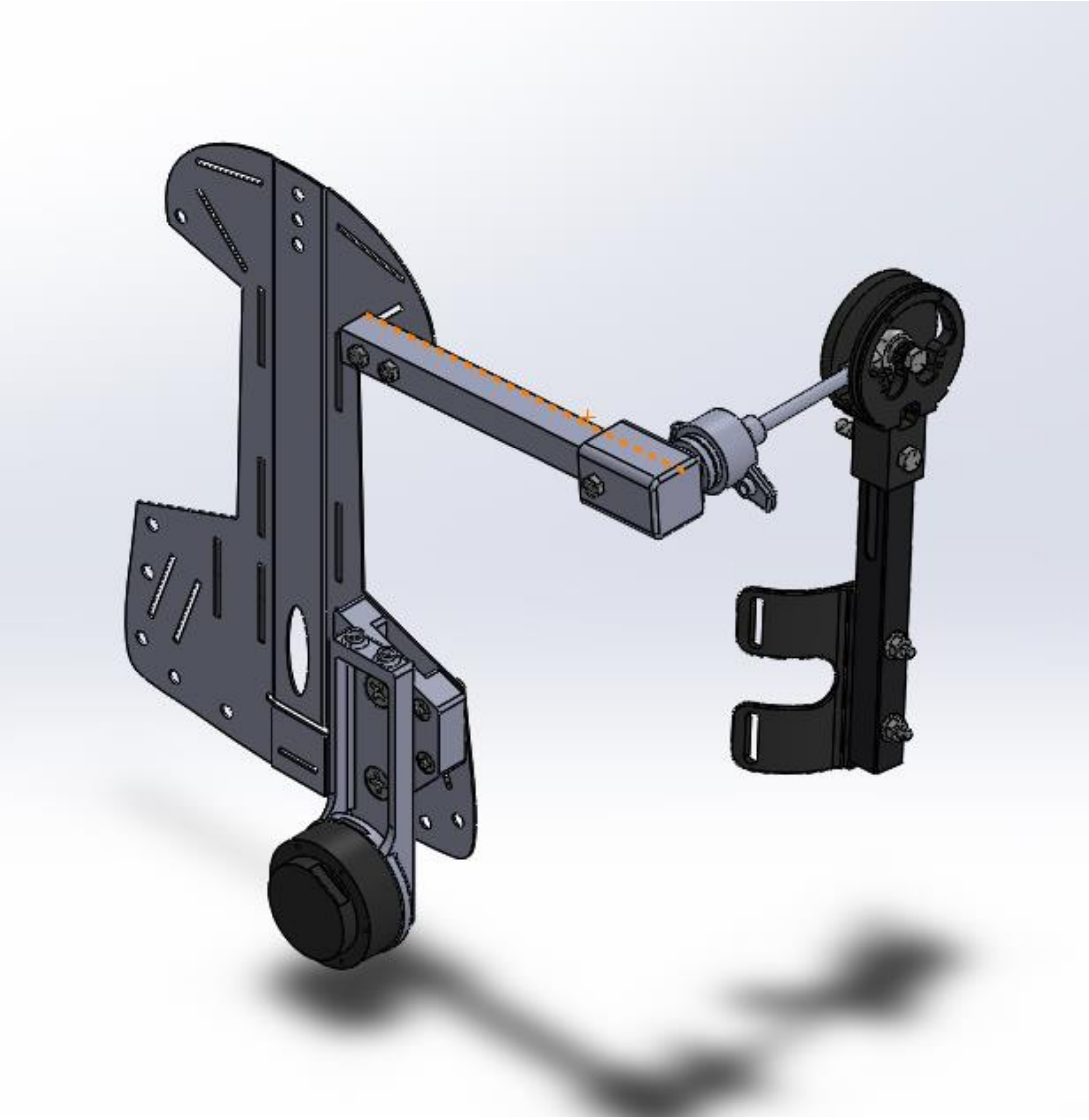


Customer & Engineering Requirements

CUSTOMER REQUIREMENTS	ENGINEERING REQUIREMENTS	INITIAL TESTS	FINAL TESTS
CR1 - Cable Actuated	Bowden Cable Actuation	Is it cable actuated?	N/A
CR2 - Utilize a Pulley	Use Dr. Lerner's Pulley Design	Is a pulley used to create torque?	N/A
CR3 - User Operable	Operate independently of stationary machinery	N/A	Can the user operate the device independently of stationary machines?
CR4 - Lightweight	Weigh < 6 lbs	Does the device weigh less than or more than 6 lbs.?	N/A
CR5 - Low-Profile	Protrude < 10cm (3.94in)	Does the device protrude less than 10cm (3.94in) from the user's body?	N/A
CR6 – Assist Pull-up Motion	15% increase in pull-ups	N/A	Does the device provide a 15% increase in completed pull-ups?
CR7 – Increase User Endurance	15% Increase in time to hold an object	N/A	Does the device improve endurance by reducing arm fatigue?

Testing Summary Table

Experiment/Tests	Relevant DR's
Ex 1 – Cable Actuation	ER1
Ex 2 – Pulley Utilization	CR1, ER2
Ex 3 – Weight Tests	CR3 and CR4
Ex 4 – Protrusion Measurements	CR3 and CR5
Ex 5 – Endurance Tests	CR1, CR2, and ER2
Ex 6 – Pull-up Tests	CR1, CR2, CR3, ER1, and ER6

Experiment 1 – Cable Actuation

The first test evaluates the functionality of the device:

- Is the device a cable actuated system?
  - Yes, our device utilizes Bowden cables to transfer a force from the motor around the pulley to the arm bar. The supplied torque moves the arm bar, **but the precision of that motion needs to be refined.**
  - Further testing will allow us to find the allowable speeds that the motor can run without damaging the device or user.

Experiment 2 – Pulley Utilization

Like Experiment 1, this simple test asks the question: Does the device use a pulley to create torque?

- **Yes**, our team altered the pulley Dr. Lerner developed to fit our setup. The pulley is printed out of PLA inlaid with Onyx which provides plenty of strength to the forces that are driven through the pulley.

Experiment 3 – User Operable

Experiment 3 visually measures if the device can be operated independently by the user. This means the user should have the freedom to move, stand, sit, etc. and remain able to operate the device as desired.

- **No**, the power system design for our device was outside of the scope of this project. The current method for the wiring attaches the device to a computer through a 5 ft power cable. As of now the device is not independently operable although it has the opportunity to be.

Experiment 4 – Weight Measurements

The fourth engineering requirement is that the design must weigh less than 6 pounds.

We will measure the weight of the device 2 different ways:

1) **By subtracting the difference of weight while wearing the device vs. not wearing the device, we can calculate the weight of the design.**
2) **By placing the device in its entirety onto a scale and recording the weight**

Our most recent weight experiment measured the device at around 5.2 pounds.

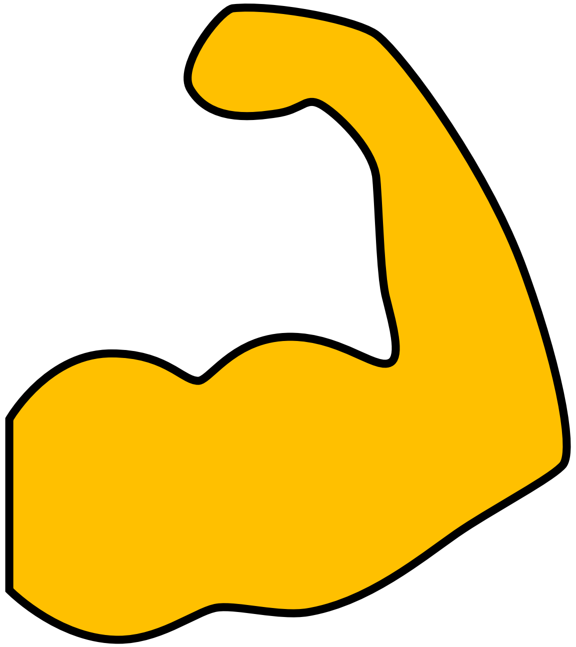
Experiment 5 – Protrusion Measurements

Does the device protrude more than 10cm (3.94in) from the body?

1) Place device onto the test subject
2) Use tape measurer to determine protrusion length
3) Is it more or less than 10cm?
4) Report in table

Component	Protrusion (cm)
Motor	X
Rear CF Bar	X
Pulley	X
Battery	X

Experiment 6 – Endurance Tests



- To measure the endurance limit of the system, we wanted to see how the device performs underneath constant stress.
- For this experiment, we plan on measuring the time the device can sustain a load.
  - Arms must extend at a 90-degree angle in front of the body.
  - 3 different weights will be recorded.
  - Graph will be created in excel showing the difference between unassisted and assisted.

Experiment 7 - Pullup Tests

During our initial testing, we found that the motor needs to be directly connected to a laptop to run the code and actuate the device.

- The current cord length for our connection is too short for the team to complete a pull up.

We have setup a meeting with Dr. Lerner to see how he wants to complete the pull up test.

Experiment 7 - Pullup Tests Cont.

Procedure:

1) Have the user perform pull-ups unassisted
2) Record number
3) Rest 5 minutes
4) Have the user perform pull-ups while assisted by the device
5) Record number
6) Calculate percent difference

$$I = \frac{N_A - N_{UA}}{N_{UA}} \times 100$$

$$I = \frac{10 - 6}{6} \times 100 = 66.7\%$$

Specification Sheet

Requirement	CR/ER Met?	Target for ER's	Tolerance for ER's	Client Acceptable?
CR 1 – Cable Actuated	Yes	Bowden Cable Actuation	N/A	TBD
CR 2 – Utilizes a Pulley	Yes	Utilizes Dr. Lerner's Pulley Design	N/A	TBD
CR 3 – User Operable	No	Yes	N/A	TBD
CR 4 - Lightweight	Yes	6lb	+ 4lb	TBD
CR 5 – Low Profile	TBD	10cm	N/A	TBD
ER 1 - Pullups	TBD	15% increase in pull-ups	+/- 2.5%	TBD
ER 2 - Endurance	TBD	15% increase in endurance	+/- 2.5%	TBD

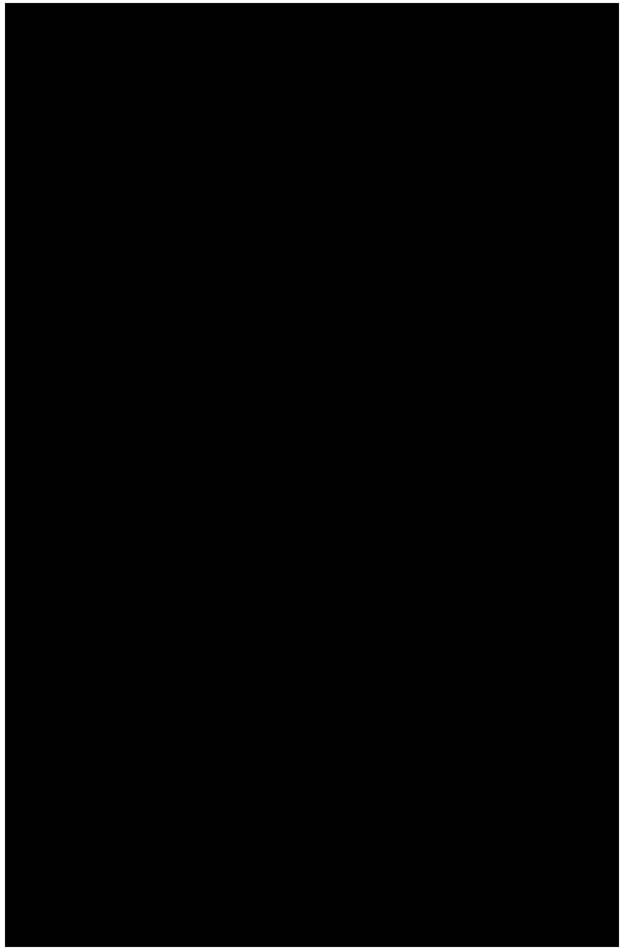
QFD

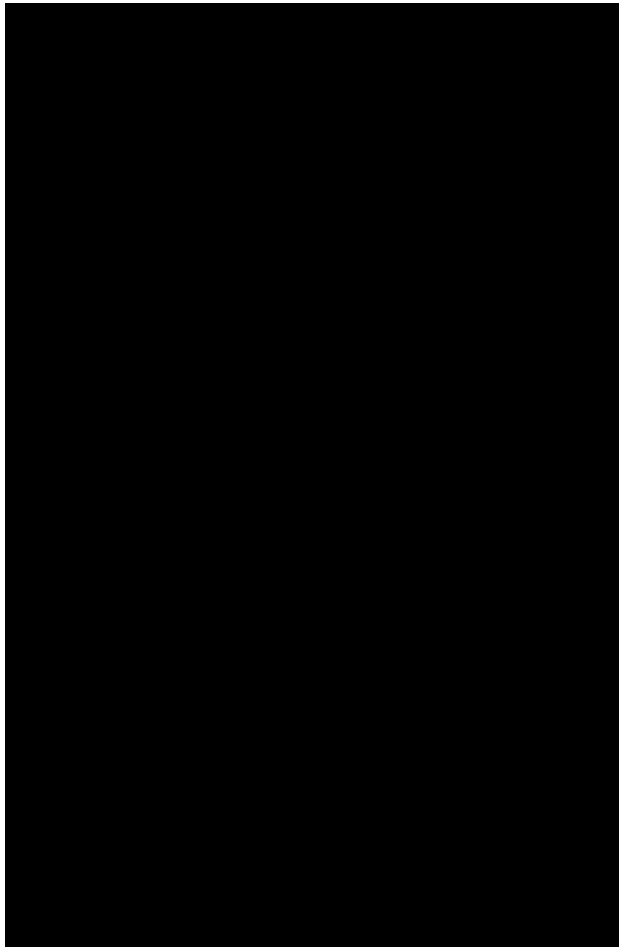
	Increase mobility	Decrease total load on arm and shoulder muscle	DC Motor actuation	Increase shoulder and back stability	Implement a failsafe mechanism	Increase everyday quality of life
Increase mobility						
Decrease total load on arm and shoulder muscle	-3					
DC Motor actuation		3				
Increase shoulder and back stability	-9	3				
Implement a failsafe mechanism			9			
Increase everyday quality of life	3	3		1	1	
Cable driven system		9	9	-1	1	

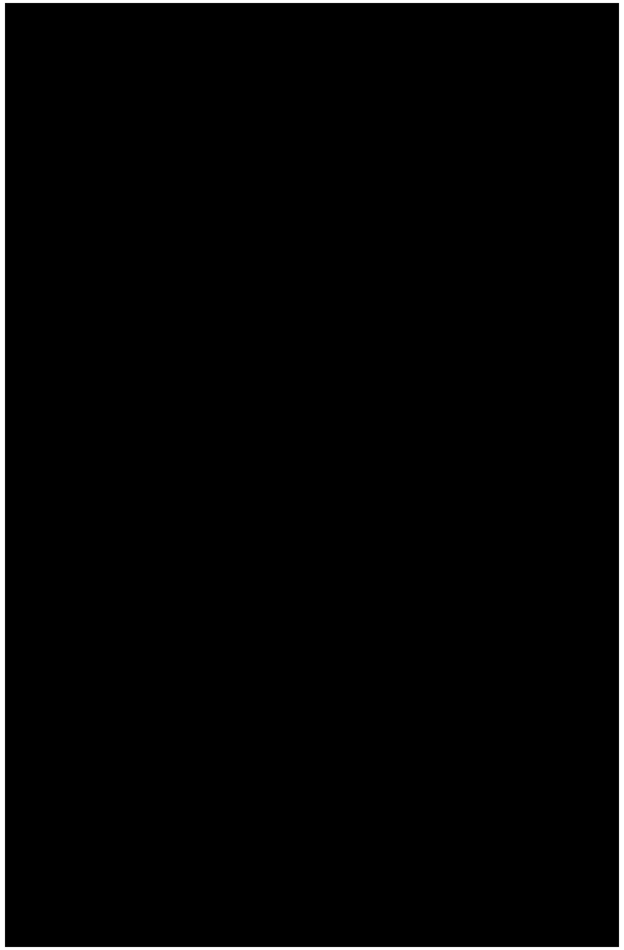
Legend	
A	Myoshirt
B	HPHT
C	MAXFAS

		Technical Requirements							Customer Opinion Survey				
Customer Needs	Customer Weights	Increase mobility	Decrease total load on arm and shoulder muscle	DC Motor actuation	Increase shoulder and back stability	Implement a failsafe mechanism	Increase everyday quality of life	Cable driven system	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
Lightweight	5	9	3	1			9	3	B	C	A		
Portable	3	3					9	3	AB		C		
Low Profile	5	9		3	1	1	3	9	B	A	C		
Comfort	3	1			1		9				AB	C	
Safety	4			3		9	3	3				A	BC
Stability	4		3	1	9		1	3					ABC
Technical Requirement Units		ROM	N	N/A	N	N/A	N/A	N/A					
Technical Requirement Targets		N/A	N/A	N/A	100	N/A	N/A	N/A					
Absolute Technical Importance		102	27	36	44	41	130	93					
Relative Technical Importance		2	7	6	4	5	1	3					

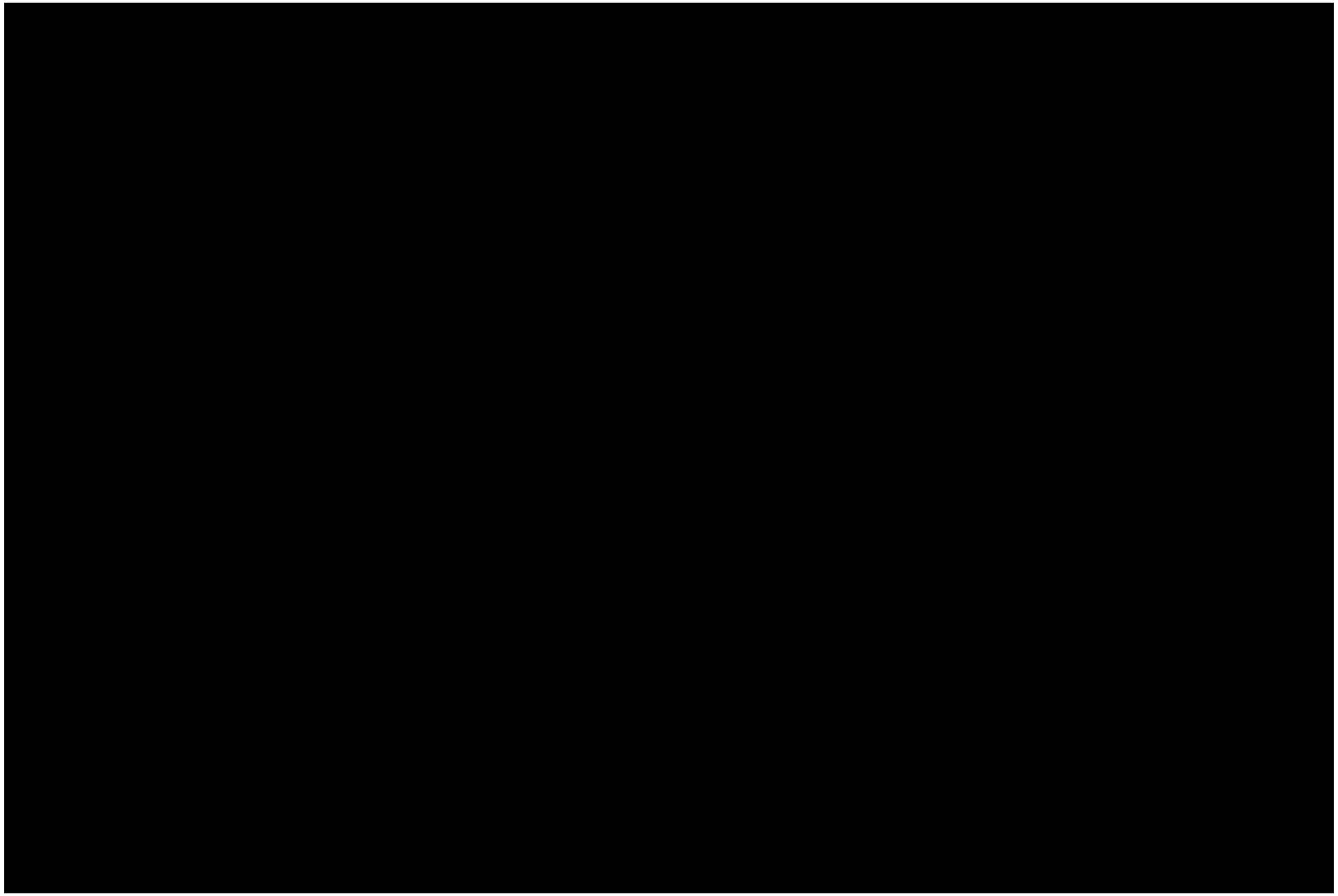
Initial Tests







Initial Tests - Shaft Failure



Future Plans - New Shaft

- Same design as before, now the shaft holding the bearing will be aluminum instead of PLA/Oynx.
- With this change we will be adding weight, current design weighs in at 5.5lbs, with this new shaft we shouldn't exceed 7lbs.
- This is okay with this client as stated in meeting if we are less than 10lbs we are good, but less than 6 is preferable.