Robotic Exoskeleton Assists Shoulder Complex Mobility

- Colin Cipolla
- Dylan Kurz
- Jordan Finger
- Michael George
- Michael Marchica

Introduction

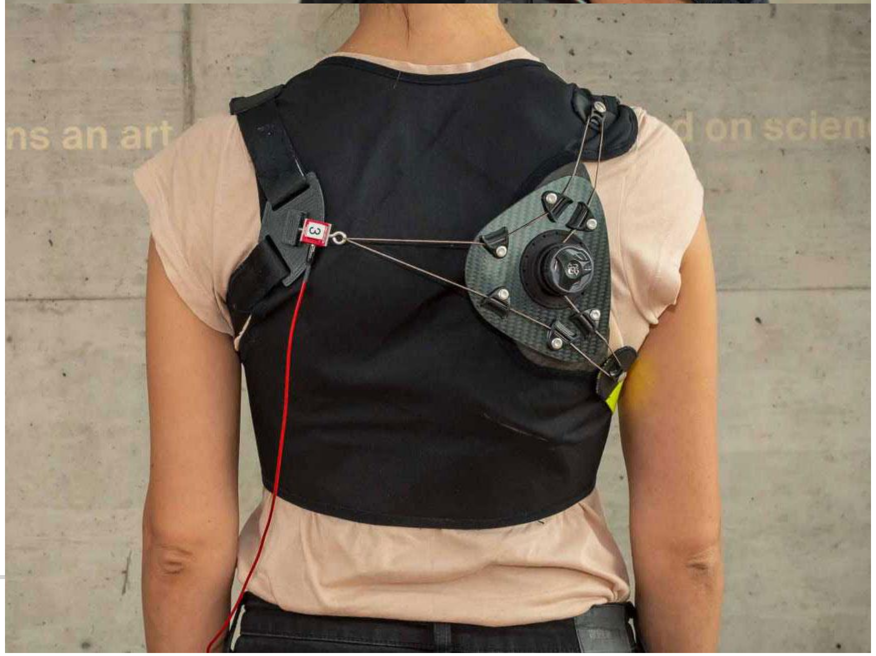
- The research on exoskeletons is limited but currently growing. The main limitations are the prohibitive costs of prototyping these devices
- Our client Dr. Zachary Lerner, lead researcher at the Biomech lab, has spent the last decade researching and developing hip and ankle exoskeletons aimed to assist the gait of a user.
- We have been tasked to create a shoulder exoskeleton with a goal of assisting the user with specific arm motions
- Our project sponsor, W.L. Gore, has allotted us $3,750 to accomplish this task

Project Description

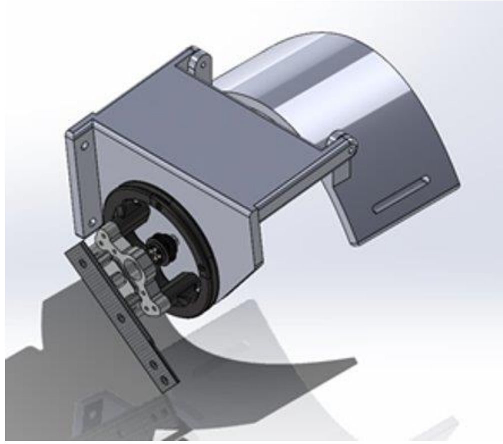
- The team was tasked to design and improve upon the MyoShirt, an exo-suit designed to assist its user with daily activities, with a more specific goal of testing the exoskeleton on its ability to assist the user with arm motions.

Table 1: Design Requirements

Customer Requirement	Engineering Requirement
Cable Actuated	Bowden Cable Actuation
Utilize a Pulley	Revise Dr. Lerner's Pulley Design
User Operable	Operate Independently
Lightweight	Weigh < 6 lbs.
Low-Profile	Protrude < 10 cm (3.94 in.)
Increase Endurance	15% Increase in time to hold an object



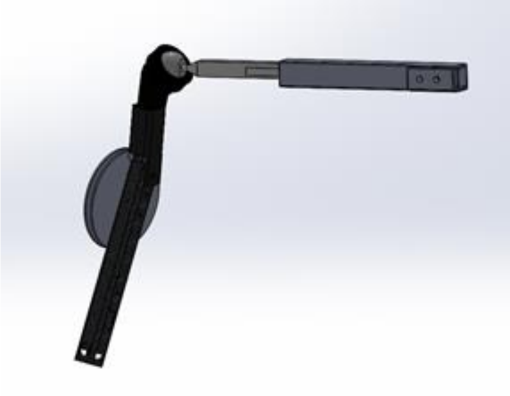
Design Iterations



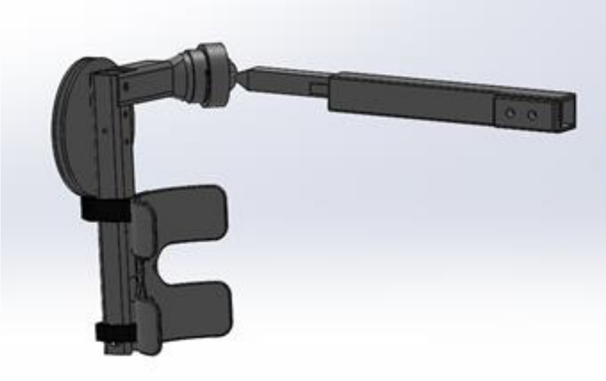
Design 1 – Fall Prototype

Design 2 – Ball & Socket

Design 3 – Revised Ball & Socket

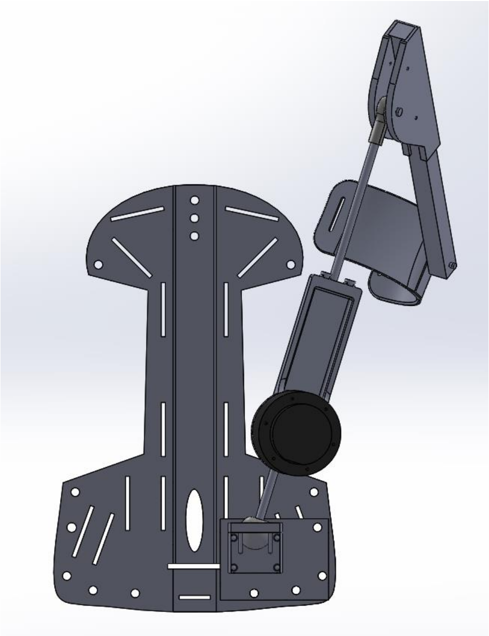


Design 4 – Revolute Joint

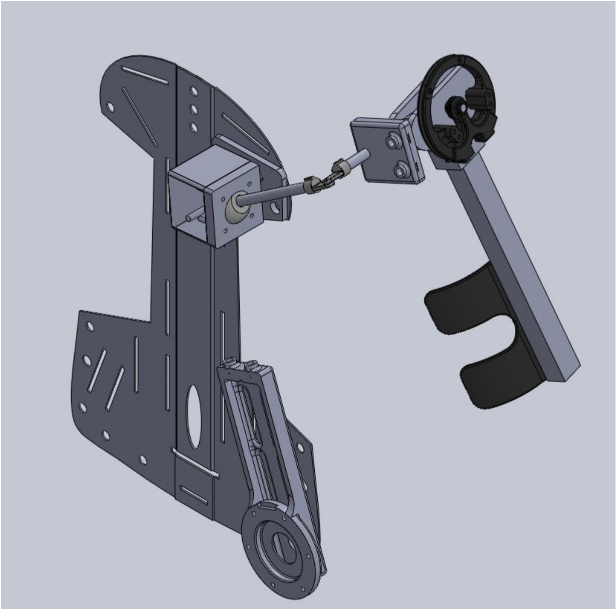


Design 5 – Revised Revolute Joint

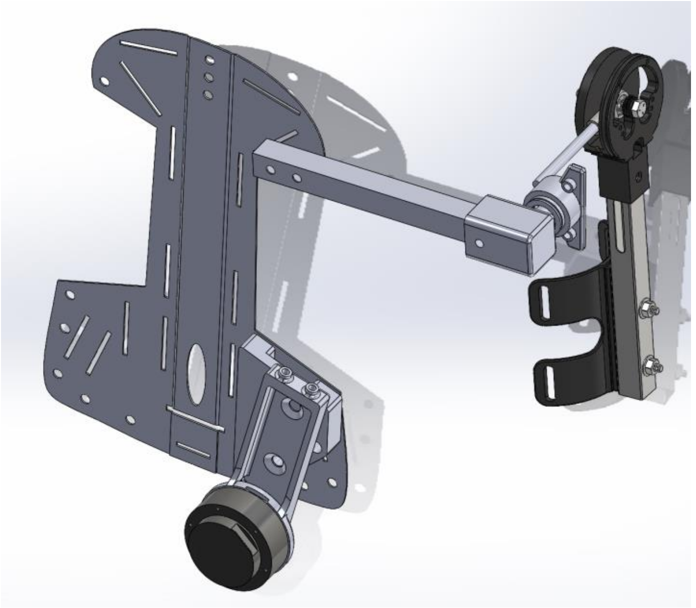
Design Iterations



Design 6 – Spring Prototype – 67% Build



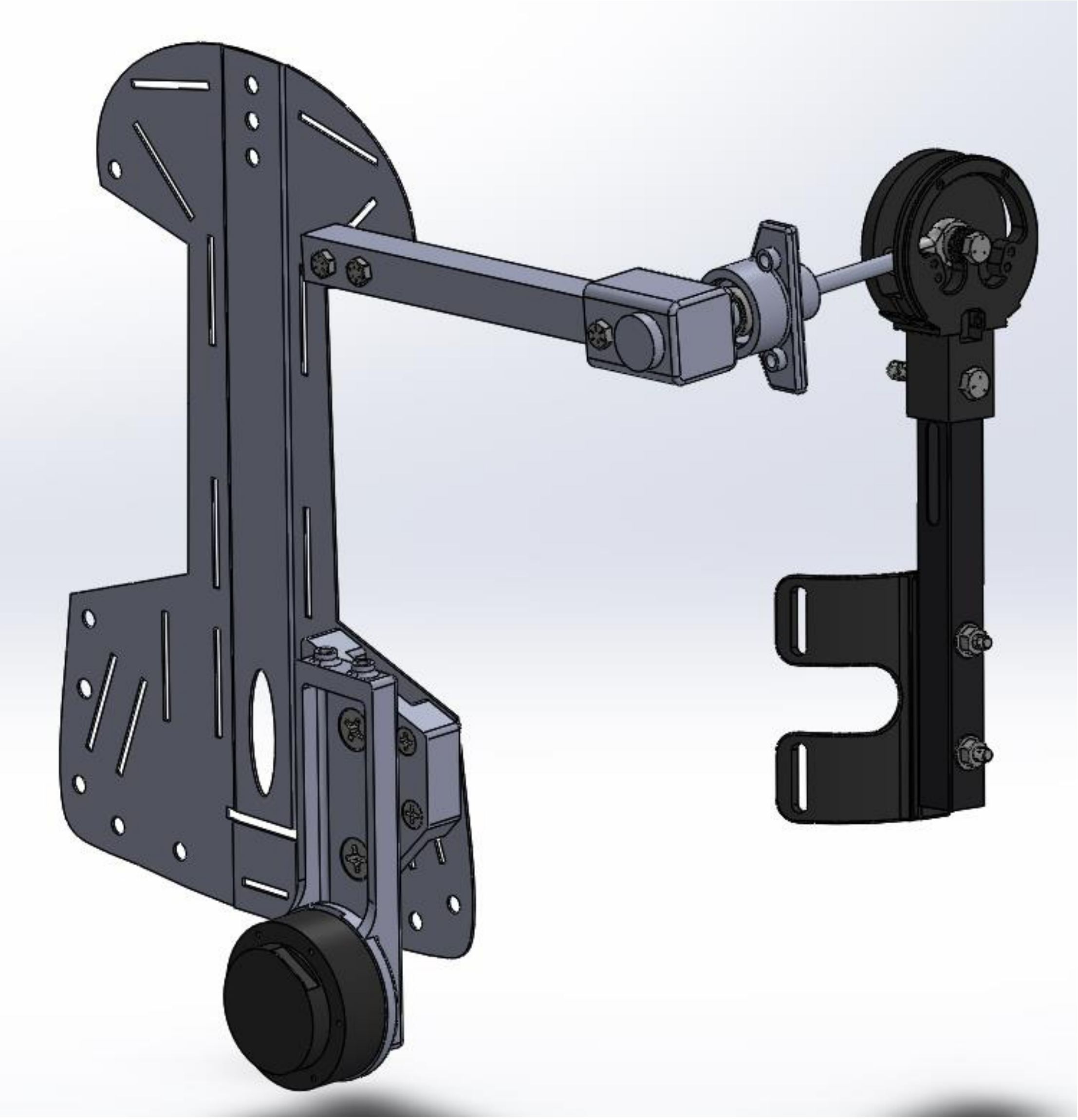
Design 7 – Prototype 4



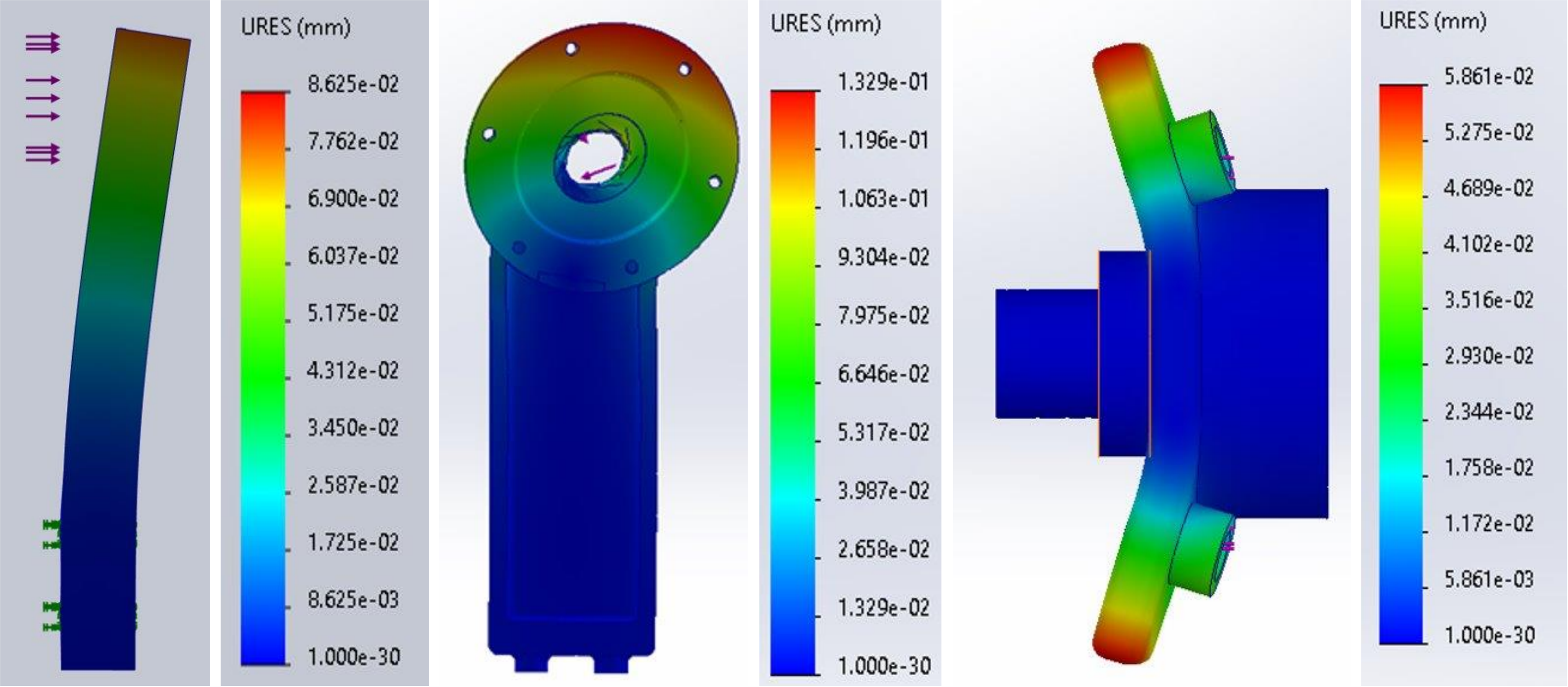
Design 8 – 95% Build

Final Design

- Includes Bowden cable actuation
- Revised pulley design to interface with Carbon Fiber square stock
- 2 Carbon Fiber square stock tubes
- 1lbz 3 oz Aluminum Scuba Backplate
- Pulley and block printed in Onyx
- Bowden cable termination house printed in Onyx inlaid with Carbon Fiber
- Aluminum shaft
- Steel all-thread
- PLA printed arm cuff
- 1 AK-60 motor
- Motor house and mount printed in PLA



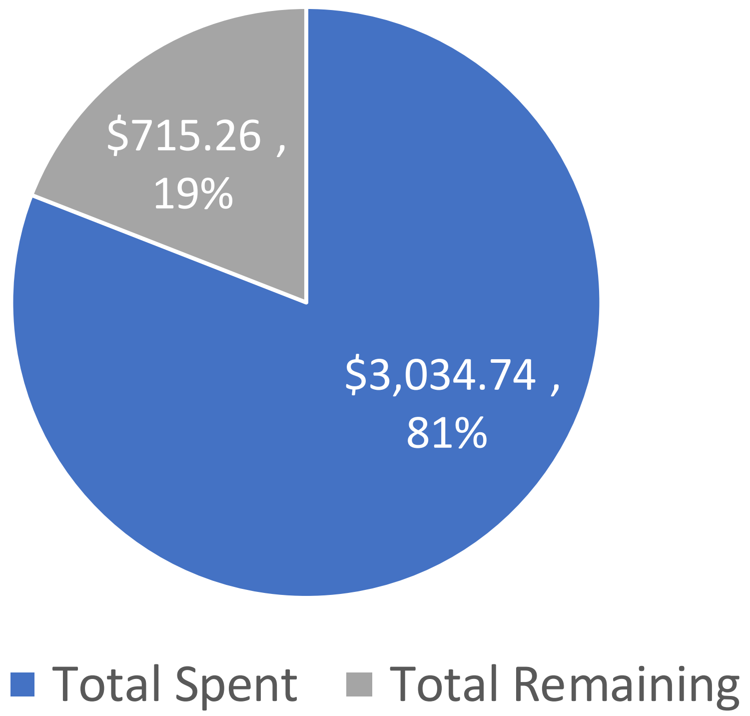
Finite Element Analysis



Budget and Purchasing

Purchasing Plan			
Item	**Quantity**	**Vendor/Manufacturer**	**Total Cost**
AK 60-6 Motor	2	T-Motor	$ 650.00
Onyx Filament 800cc	2	MarkedForge	$ 380.00
CF Filament 150cc	2	MarkedForge	$ 900.00
Roller Chain Sprocket	2	McMaster Carr	$ 26.00
Roller Chain	2	McMaster Carr	$ 36.00
Connecting Link	4	McMaster Carr	$ 7.32
CF Square Stock 32"	1	McMaster Carr	$ 139.99
Adding and Connecting	2	McMaster Carr	$ 6.78
Steel Rod Machinable	1	McMaster Carr	$ 54.17
Onyx Filament 800cc	1	MarkedForge	$ 210.00
CF Filament 50cc	1	MarkedForge	$ 170.00
PLA	1	MarkedForge	$ 56.00
Pirahna Dive Harness	1	Pirahna Dive	$ 90.00
Aluminum Bowden Chain Cable Link	4	ProtoLabs	$ 308.48
		Total Spent	$ 3,034.74
		Total Remaining	$ 715.26
		Total Budget	$ 3,750.00
		Total Utilization	81%

Budget Utilization



Manufacturing Plan

- All 3D printed parts were printed in-house or with the client's printer.
- Parts that were machined or welded were done in the machine shop at NAU by one of the team members.

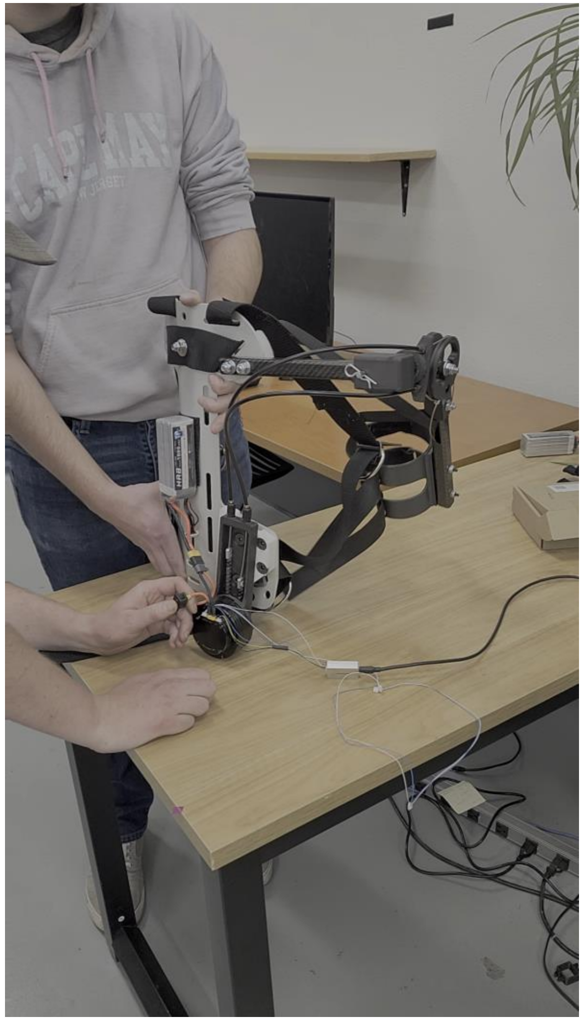
Manufacturing Plan				
Item	Quantity	Vendor/Manufacturer		Total Cost
Shoulder Plate	1	Team	3D Print	$0.00
Hinge Plate	1	Team	3D Print	$0.00
Large Pulley	1	Team	3D Print	$0.00
Large Pulley Bridge	1	Team	3D Print	$0.00
Pulley Flat Anchor	1	Team	3D Print	$0.00
Tube Spacer	1	Team	3D Print	$0.00
Bicep Cuff	2	Team	3D Print	$0.00
Bicep Mount Upper	1	Team	3D Print	$0.00
Bicep Mount Lower	1	Team	3D Print	$0.00
Ball Joint Bar	2	Team	3D Print	$0.00
Ball Joint	1	Team	3D Print	$0.00
Pivot Point	1	Team	3D Print	$0.00
Socket Mounting Plate	1	Team	3D Print	$0.00
Corner Hinge	1	Team	3D Print	$0.00
Motor Mount Plate	1	Team	3D Print	$0.00
Motor Mount	3	Team	3D Print	$0.00
Onyx Pulley	1	Team	3D Print	$0.00
Onyx Corner Hinge	1	Team	3D Print	$0.00
Aluminum Shaft	1	Team	Machine Shop	$0.00
Sprocket Shaft Weld	1	Team	Machine Shop	$0.00

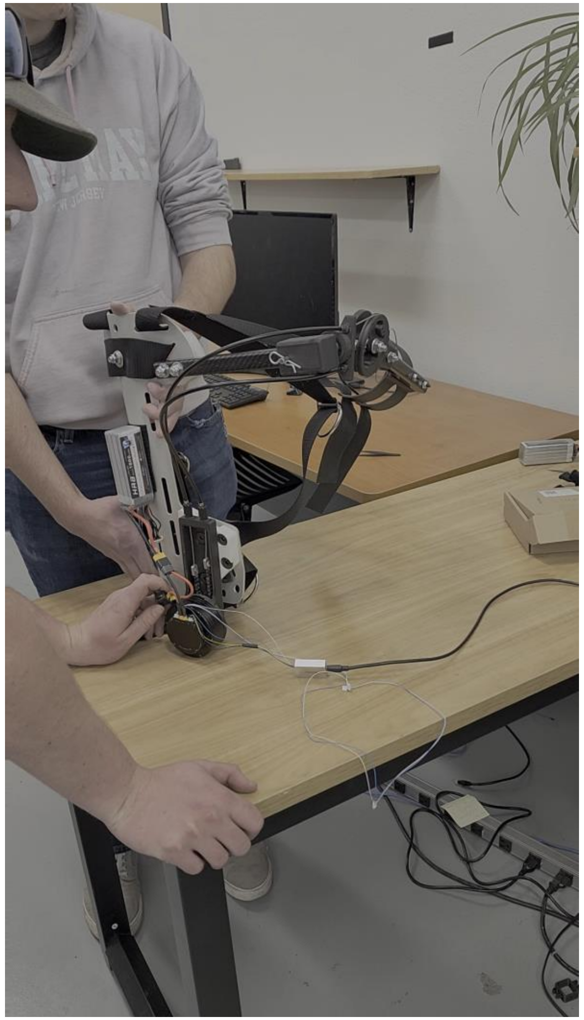
Testing Plan

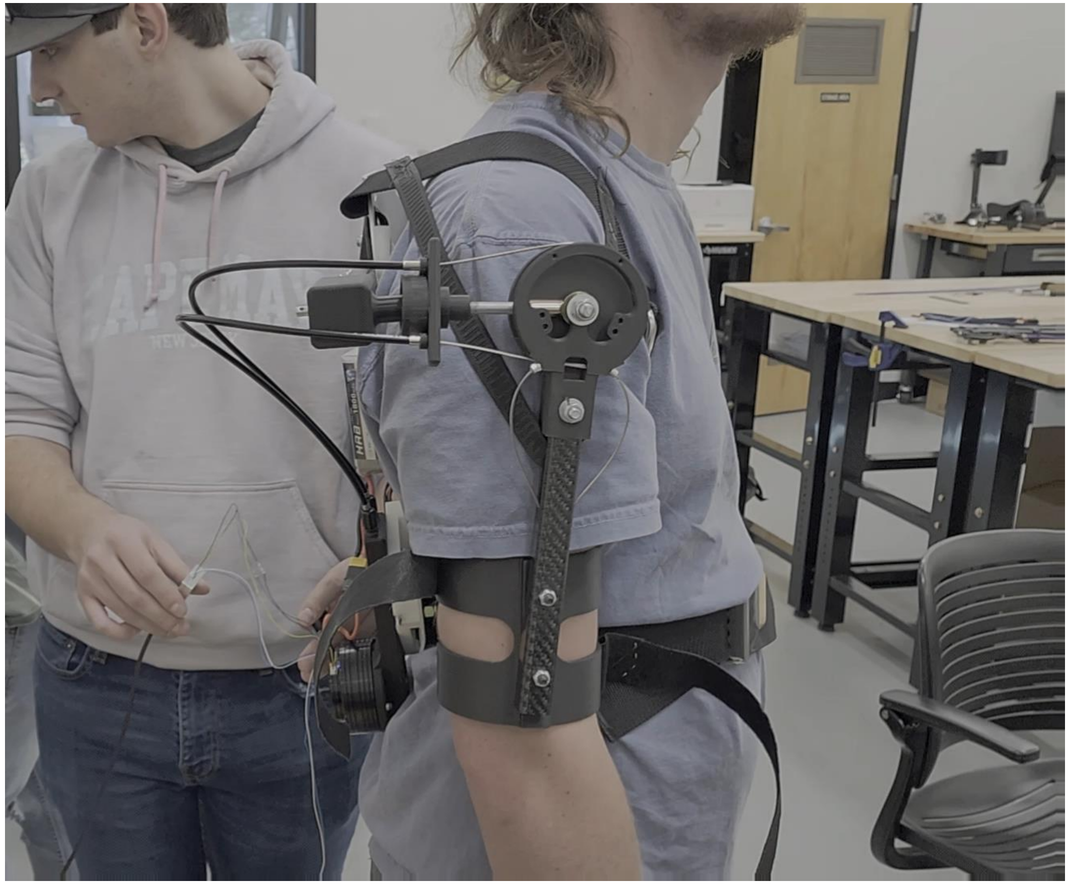
Table 2: Testing Plan

CUSTOMER REQUIREMENTS	INITIAL TESTS	FINAL TESTS
Cable Actuated	Is it cable actuated?	N/A
Utilize a Pulley	Is a pulley used to create torque?	N/A
User Operable	N/A	Can the user operate the device independently of stationary machines?
Lightweight	Does the device weigh less than or more than 6 lbs.?	N/A
Low-Profile	Does the device protrude less than 10cm (3.94in) from the user's body?	N/A
Assist Shoulder Endurance	N/A	15% Increase in time to hold an object unassisted versus assisted

Initial Testing

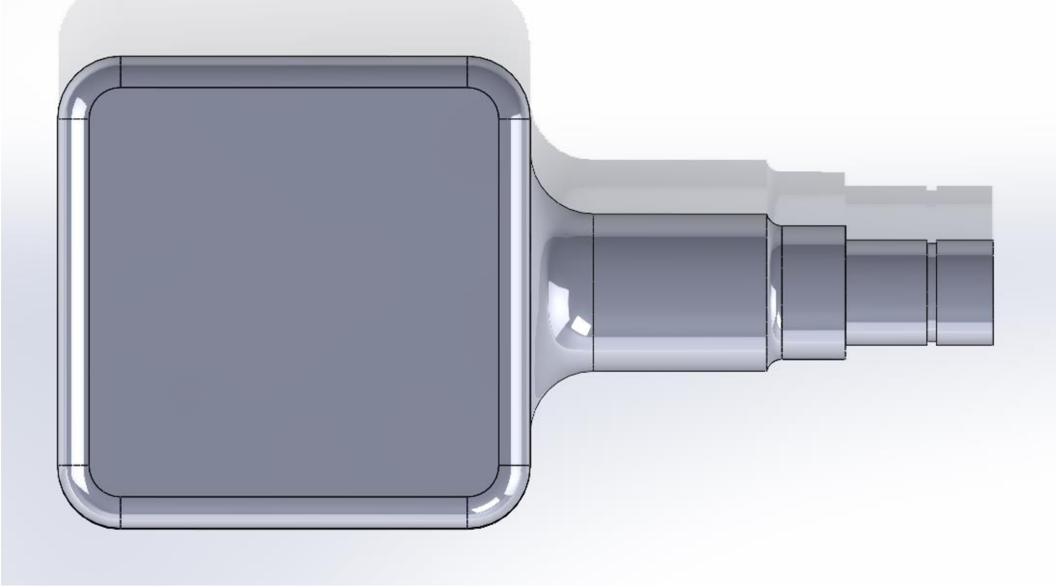


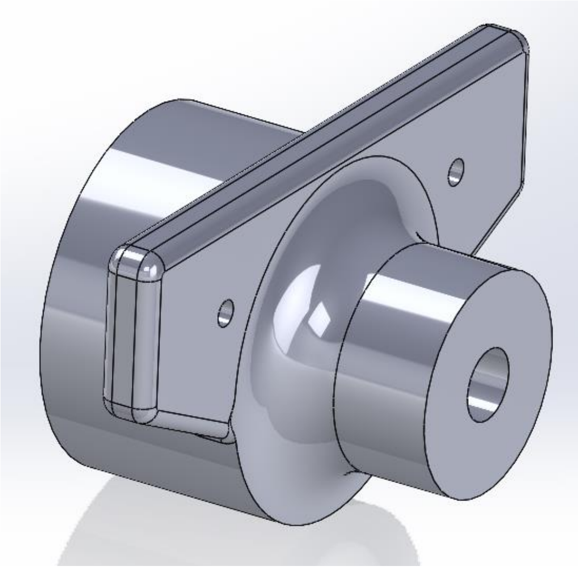




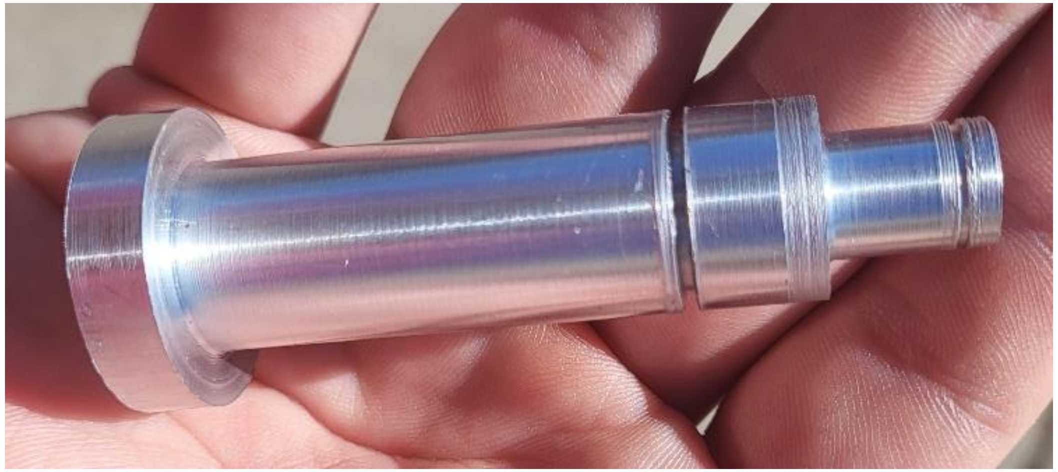
Testing Iterations

- Originally printed out of PLA. Inadequate printing pattern that allowed for shearing shown in Figure X.
- New design, Figure X, adds a fillet to the base of the all-thread interface for minimized stress concentration. Printed out of Onyx inlaid with Carbon Fiber. Printed perpendicular to the force direction.

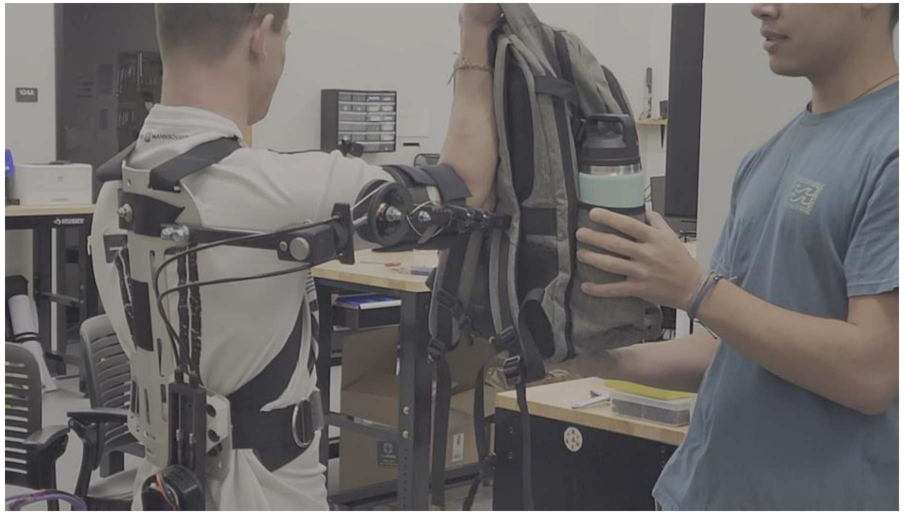


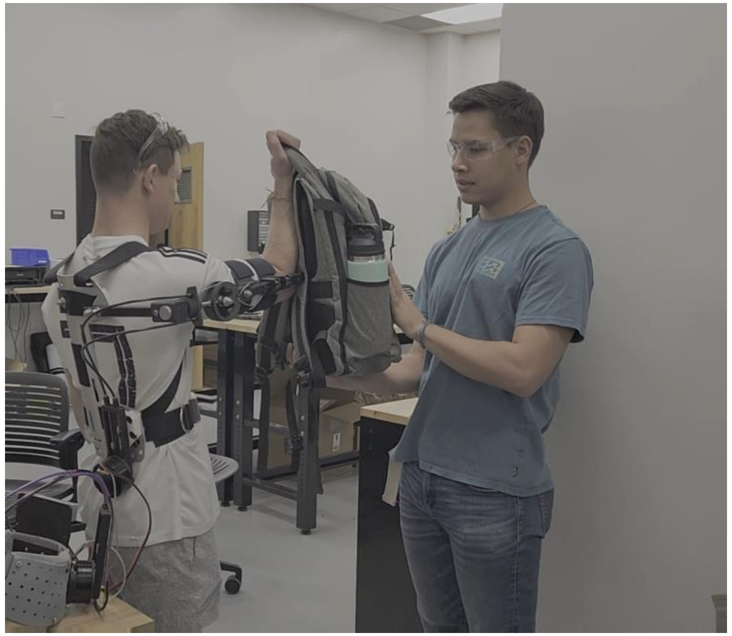


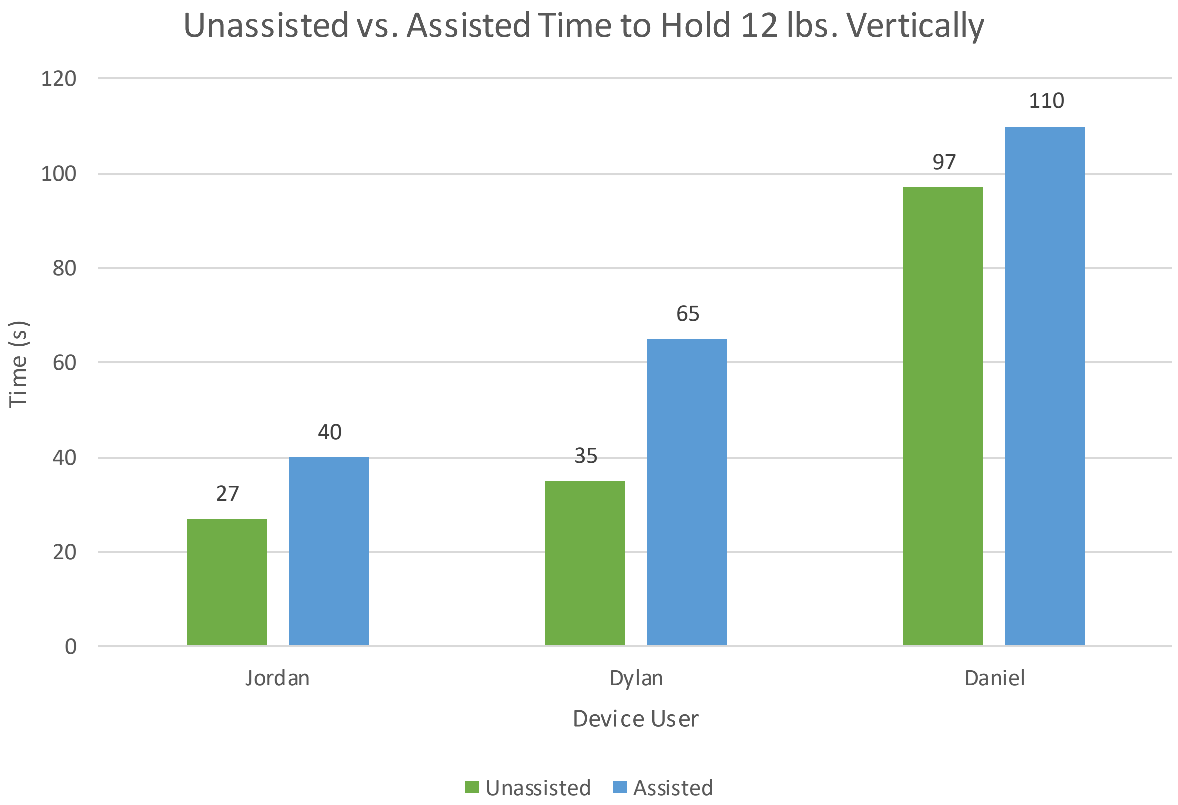
- Shaft originally printed out of PLA. Designed as one piece. Inadequate design allowed for extruding shaft to shear.
- New shaft, Figure X, machined out of an aluminum bar. More structurally sound and secure.



Final Testing







During this test, the motor was outputting 7 N-m of torque which was roughly 20 N-m of torque at the shoulder.

Specification Sheet

Table 3: ER Summary

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER Met? (Yes or No)	Client Acceptable? (Yes or No)
Bowden Cable Actuation	N/A	N/A	N/A	Yes	Yes
Revise Dr. Lerner's Pulley Design	N/A	N/A	N/A	Yes	Yes
Lightweight	< 6 lbs.	+ 4 lbs.	5.5 lbs.	Yes	Yes
Low-Profile	< 10 cm (3.94 in.)	Maximum 10 cm	3.97 in	No	Yes
Independently Operable	Independently Controlled	N/A	N/A	No	Yes
Increase in time to hold an object	15% Increase	Minimum 12.5%	Average of 49% Increase	Yes	Yes

Future Work

2 Arm System: This will help stabilize the device and produce results for the initial, but discontinued, pull-up test.

Fail Safes: Although the output power from the motor is easily controlled it would be reassuring to have immediate stops that disable the device past a certain limit.

Increased Mobility: Currently, the rear Carbon Fiber bar makes the device to rigid to raise the arm laterally or move fluidly. Increasing the range of motion while applying torque in the correct direction will broaden the opportunities for this project.

Thank You

Questions?