

# Below the Knee Exoskeleton

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# ER's and CR's

## CR's

- CR1: Durable
- CR2: High range of motion
- CR3: Comfortable
- CR4: High battery life
- CR5: Adjustable
- CR6: Lightweight
- CR7: Affordability

## ER's

- ER1: Energy efficient
- ER2: Accommodate different shoe size
- ER3: High Torque
- ER4: Supports users of all weight
- ER5: Under 3 kg
- ER6: Temperature of motor
- ER7: Battery Capacity
- ER8: Ingress Protection

# QFD

Design Requirements		Importance (1-5)	Energy efficient	Accommodate different shoe sizes	High torque	Support users of all weights	Under 3 kg	Temperature of motor	Battery Capacity	Ingress Protection	Improvement Direction				
											Customer Competitive Assessment				
											1 Worst	2	3	4	5 Best
Customer Requirements															
Durable		3		3		6	6	6		9		C	AB		
High range of motion		5			9							B	AC		
Comfortable		4		3		3	3	3					A		
High battery life		3	9		6			9	9				B		
Adjustable		3		3		6							C	A	
Lightweight		5			3		9			3			B	AC	
Affordability		5							3	3		C	B		
Technical Importance: Absolute			27	30	78	48	75	57	42	57	A	Caplex Exo			
Technical Importance: Relative			7%	7%	19%	12%	18%	14%	10%	14%	B	Utah Knee			
Design Competitive Assessment	Worst: 1								B	C	C	ETM Motor			
	2					C		B	C	B					
	3	AB			B		C	C							
	4				C	A	B			A					
	Best: 5	C	A	A	A	A	A								
Target Value			90	0.3	1000	90	2	70	1000	54					
USL			60	0.27		120	3	155		68					
LSL			30	0.22	500	30	1.5		500	52					
Units			mins	m	mNm	kg	kg	C	mAh	IP					

# Testing Plan

## 2 Top Level Testing Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed	Other Recourses
Exp1: Weight and COM	ER5: Under 3kg CR6: Lightweight	Scale	Access to device from Lerner's Lab
Exp2: Initial run of device	ER1: Energy Efficient ER3: High Torque ER7: Battery Capacity CR4: High Battery Life	Device, PCB, Battery, Motor	Programmed PCB
Exp3: Ingress Test	ER8: Ingress Protection	Motor and PCB/battery housing, water	Probe, Spray bottle, determined by target IP rating

Exp3: Ingress Test	ER8: Ingress Protection	Motor and PCB/battery housing, water	Probe, Spray bottle, determined by target IP rating
Exp4: Thermal Test	ER6: Temperature of Motor	Arduino, DAQ, motor & housing	Alternate motor housings
Exp5: Final test on human	ER2: Accommodate Different Shoe Size ER4: Supports Users of All Weight ER1: Energy Efficient ER6: Temperature of Motor CR1: Durable CR2: High range of motion CR3: Comfortable CR5: Adjustable CR6: Lightweight	Assembled device, treadmill	Test Lab

# Testing Images

Exp 1: Weight and COM



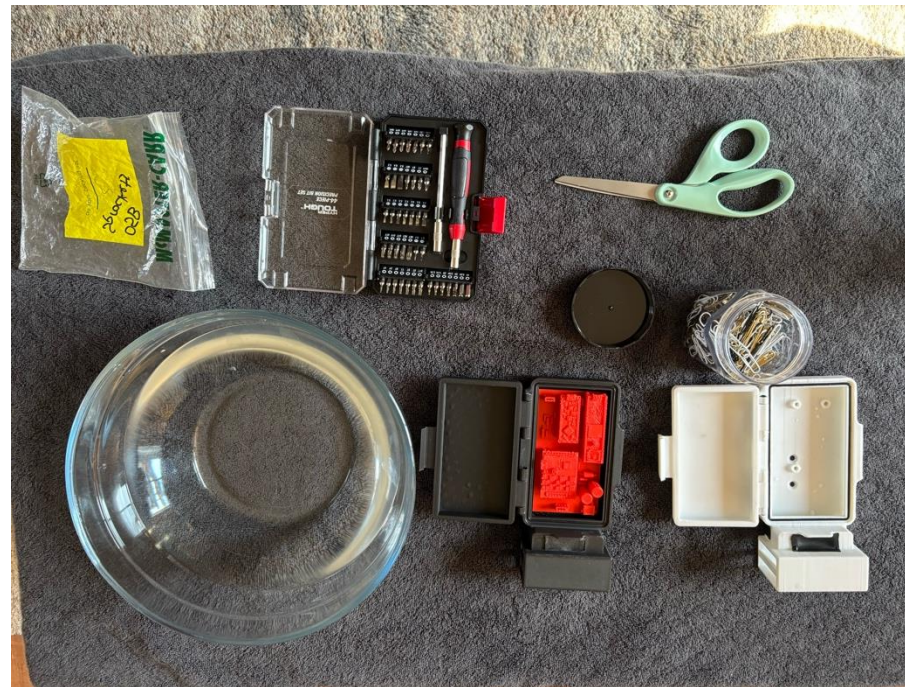
Exp 1:  
Comfortability and  
use.





# Testing Images

## Exp 3: Ingress Protection



## IP (Ingress Protection) Ratings Guide

SOLIDS		WATER	
1	Protected against a solid object greater than 50 mm such as a hand.	1	Protected against vertically falling drops of water. Limited ingress permitted.
2	Protected against a solid object greater than 12.5 mm such as a finger.	2	Protected against vertically falling drops of water with enclosure tilted up to 15 degrees from the vertical. Limited ingress permitted.
3	Protected against a solid object greater than 2.5 mm such as a screwdriver.	3	Protected against sprays of water up to 60 degrees from the vertical. Limited ingress permitted for three minutes.
4	Protected against a solid object greater than 1 mm such as a wire.	4	Protected against water splashed from all directions. Limited ingress permitted.
5	Dust Protected. Limited ingress of dust permitted. Will not interfere with operation of the equipment. Two to eight hours.	5	Protected against jets of water. Limited ingress permitted.
6	Dust tight. No ingress of dust. Two to eight hours.	6	Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities.
Rating Example:		7	Protection against the effects of immersion in water between 15 cm and 1 m for 30 minutes.
IP65		8	Protection against the effects of immersion in water under pressure for long periods.
INGRESS PROTECTION			



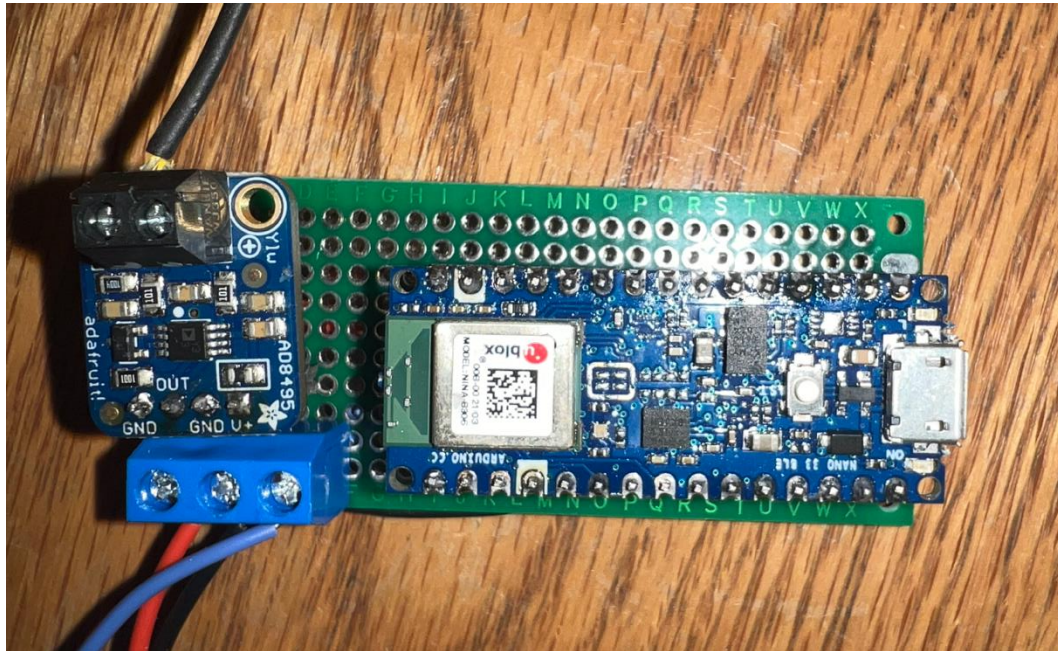
# Testing Images

Exp 2: Initial Run of device



# Testing Images

## Exp 4: Thermal Test





# Testing Images

Exp 5: Final Test on human



# Testing Images

Exp 5: Final Test on human



# Specification Sheet

## 4.1 CR Summary Table

Customer Requirement	CR met? (✓ or ✗)	Client Acceptable? (✓ or ✗)
CR1: Durable	✓	✓
CR2: High Range of Motion	✓	✓
CR3: Comfortable	✓	✓
CR4: High battery life	✓	✓
CR5: Adjustable	✓	✓
CR6: Lightweight	✓	✓
CR7: Affordability	✓	✓

## 4.2 ER Summary Table

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER met? (✓ or ✗)	Client Acceptable? (✓ or ✗)
ER1: Energy efficient	60 mins	± 30 mins	53 mins	✓	✓
ER2: Accommodate shoe size	.27 m	± .05 m	.22m	✓	✓
ER3: High torque	10 N-m	± 5 N-m	12.5 N-m	✓	✓
ER4: Supports users of all weights	90 kg	± 30 kg	90kg	✓	✓
ER5: Under 3 kg	3 kg	± 1 kg	1.168 kg	✓	✓
ER6: Temperature of the motor	>70° C	± 70° C	54.5 ° C	✓	✓
ER7: Battery Capacity	1000 mAh	± 500 mAh	650 <del>mAh</del>	✓	✓
ER8: Ingress Protection	IP45	IP44, IP67	IP45	✓	✓



# Percent Complete

Customer Requirements	Engineering Requirements
100% <ul style="list-style-type: none"><li>- Adjustable</li><li>- Lightweight</li><li>- Affordability</li><li>- High Range of Motion</li><li>- Comfortable</li><li>- High Battery Life</li><li>- Durable</li></ul>	100% <ul style="list-style-type: none"><li>- Accommodate shoe size</li><li>- Supports users of all weight</li><li>- Under 3 kg</li><li>- Ingress Protection</li><li>- Energy Efficient</li><li>- High Torque</li><li>- Temperature of Motor</li><li>- Battery Capacity</li></ul>

# Thank You!