Design & Fabrication of a Motorized Hip Prosthesis for Total Hip Disarticulation

Aiden Camisa | Team Lead, Controls Integration (LabView)

Victoria Lyon | Operations & Budget Manager, Mechanical Systems

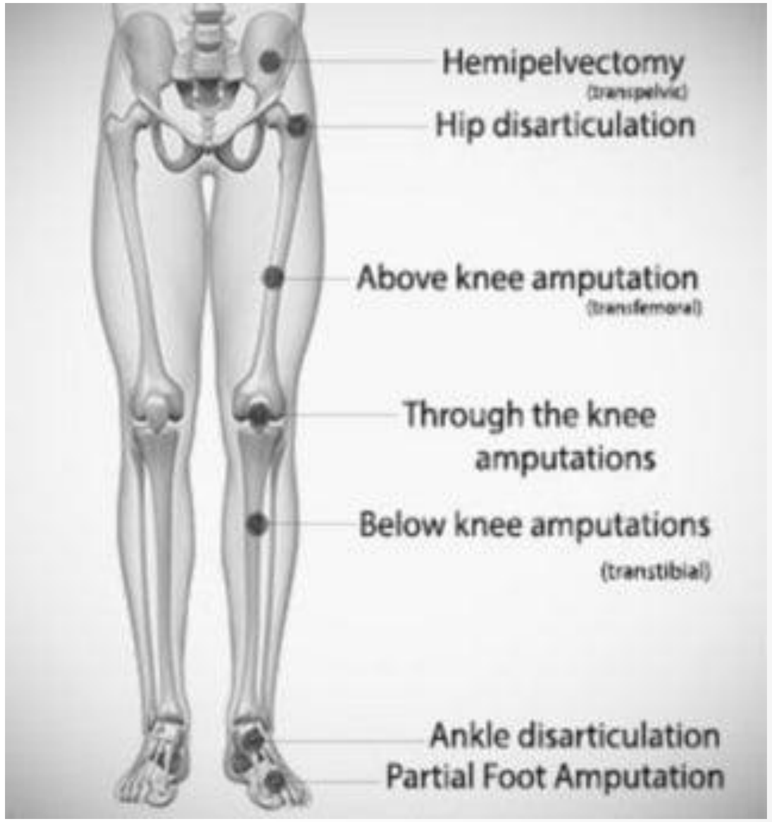
Matthew Martinez | Manufacturing Lead, Biomechanics & Anatomical Design

Quinn O’Neill | Embedded Systems & Motor Control (C++), Website Design Lead

HORIZON HIP

EMPOWERING EVERY STEP

Motivation



What is Hip Disarticulation?

- Removal of the entire lower limb, including the hip
- Makes up 1% of the entire amputee population
- Passive solutions: relying on user movement and mechanical energy to function

How Can We Help?

- Active actuation: utilizes external power to function
- Expand current field of solutions
- Eliminate discrepancies in powered prosthetic research + solutions

Deliverables

Semester 1 | Fall 2025

- Team charter
- Mathematical modeling
    - Individual analyses
- Design & iteration
- Technical reports
- Physical prototyping

Semester 2 | Spring 2026

- Hardware checks (33%, 67%,100%)
- Mathematical modeling
- Technical reports
- Testing checks

National Institutes of Health DEBUT Competition

Summer 2026

Necessity

- Must address a real healthcare need
- Consideration of user safety and regulation

Engineering Application

- Demonstrate innovation
- Provide a working prototype
- Provide abstract & objective statement
- 3-minute descriptive video

DESIGN BY BIOMEDICAL UNDERGRADUATE TEAMS CHALLENGE

Success Metrics

Biomechanical

- Fluid, natural movement during use
- Smooth sagittal-plane motion
- Comfortable fit and weight support
- Lifestyle integration (wearability)
- Minimal disruption to gait

Electrical & Controls

- Reliable sensor feedback
- Accurate motor driver performance
- Power efficiency and battery life
- Timely actuation with low malfunction
- Durable electrical components

Overall

- Active motion in sagittal plane
- Min. 1 hr continuous run time
- Load-bearing up to 90 kg (200lb)
- Lightweight material selection
- Accessible user interface

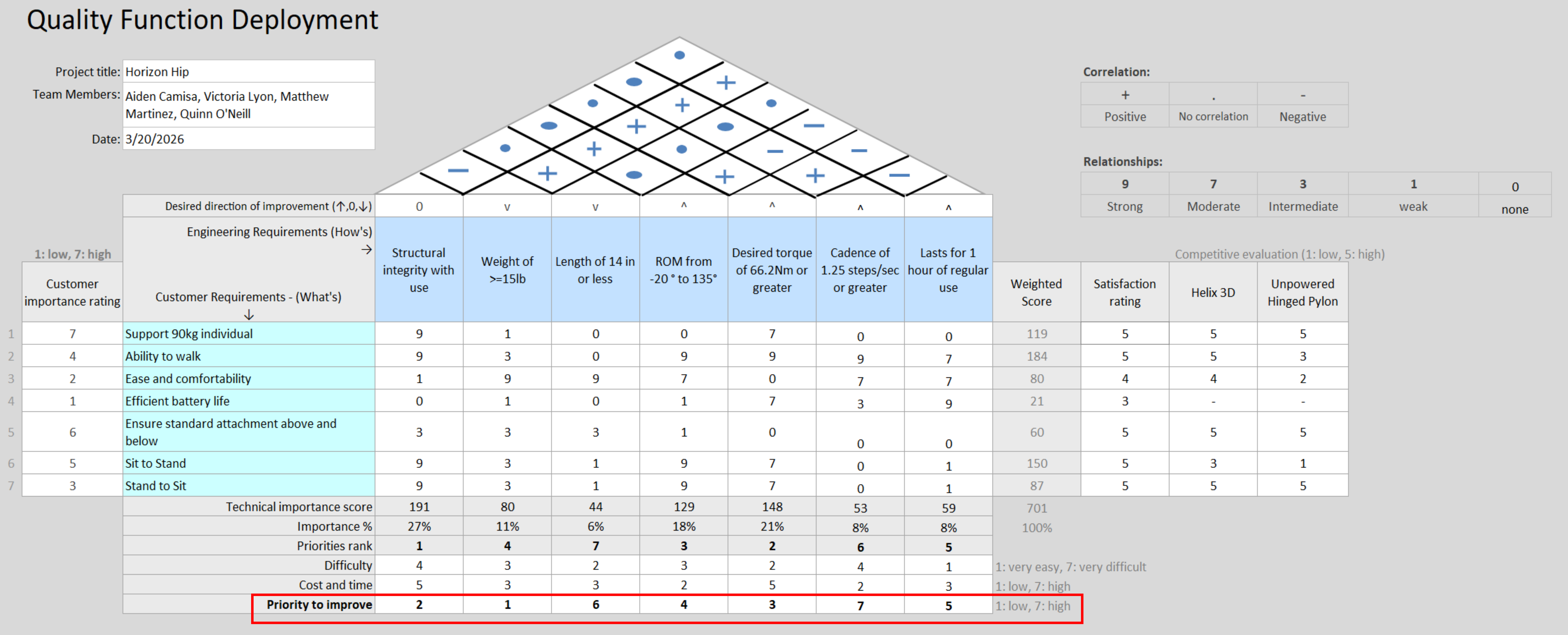
Design Requirements

Customer Requirements
Supports up to 90kg (200lb)
Enables walking ability
Long lasting battery life
Compatible with existing prosthetics & attachments
Assists **sit → stand**
Assists **stand → sit**

Engineering Requirements
Durable: ≥ 18 load test cycles
Lightweight: < 15 lbs
Compact: ≤ 14 in length
Range of Motion: -20° to 135°
Achievable Torque: 66.2 Nm
Desired Cadence: 1.25 steps/sec
Battery life: 1-hour continuous operation

Quality Function Deployment

The Quality Function Deployment (QFD) relates Customer Requirements to Engineering Requirements, creating valuable insight to product prioritization and benchmarking.



Quality Function Deployment

Project title: Horizon Hip
Team Members: Aiden Camisa, Victoria Lyon, Matthew Martinez, Quinn O'Neill
Date: 3/20/2026

Correlation:

+	.	-
Positive	No correlation	Negative

Relationships:

9	7	3	1	0
Strong	Moderate	Intermediate	weak	none

1: low, 7: high

Competitive evaluation (1: low, 5: high)

		Desired direction of improvement (↑,0,↓)	0	v	v	^	^	^	^				
	Customer importance rating	Engineering Requirements (How's) → Customer Requirements - (What's) ↓	Structural integrity with use	Weight of >=15lb	Length of 14 in or less	ROM from -20 ° to 135°	Desired torque of 66.2Nm or greater	Cadence of 1.25 steps/sec or greater	Lasts for 1 hour of regular use	Weighted Score	Satisfaction rating	Helix 3D	Unpowered Hinged Pylon
1	7	Support 90kg individual	9	1	0	0	7	0	0	119	5	5	5
2	4	Ability to walk	9	3	0	9	9	9	7	184	5	5	3
3	2	Ease and comfortability	1	9	9	7	0	7	7	80	4	4	2
4	1	Efficient battery life	0	1	0	1	7	3	9	21	3	-	-
5	6	Ensure standard attachment above and below	3	3	3	1	0	0	0	60	5	5	5
6	5	Sit to Stand	9	3	1	9	7	0	1	150	5	3	1
7	3	Stand to Sit	9	3	1	9	7	0	1	87	5	5	5
		Technical importance score	191	80	44	129	148	53	59	701			
		Importance %	27%	11%	6%	18%	21%	8%	8%	100%			
		Priorities rank	**1**	**4**	**7**	**3**	**2**	**6**	**5**				
		Difficulty	4	3	2	3	2	4	1	1: very easy, 7: very difficult			
		Cost and time	5	3	3	2	5	2	3	1: low, 7: high			
		Priority to improve	**2**	**1**	**6**	**4**	**3**	**7**	**5**	1: low, 7: high			

Design Space Research – Benchmarking

The Helix 3D | Ottobock

- Expansion springs store energy during the stance phase and release it to support swing initiation
- Hydraulic component dampens heel strike and controls pendulum motion
- Approved for a maximum body weight of 100kg (220lb)

The Modular Hip Joint | Ottobock

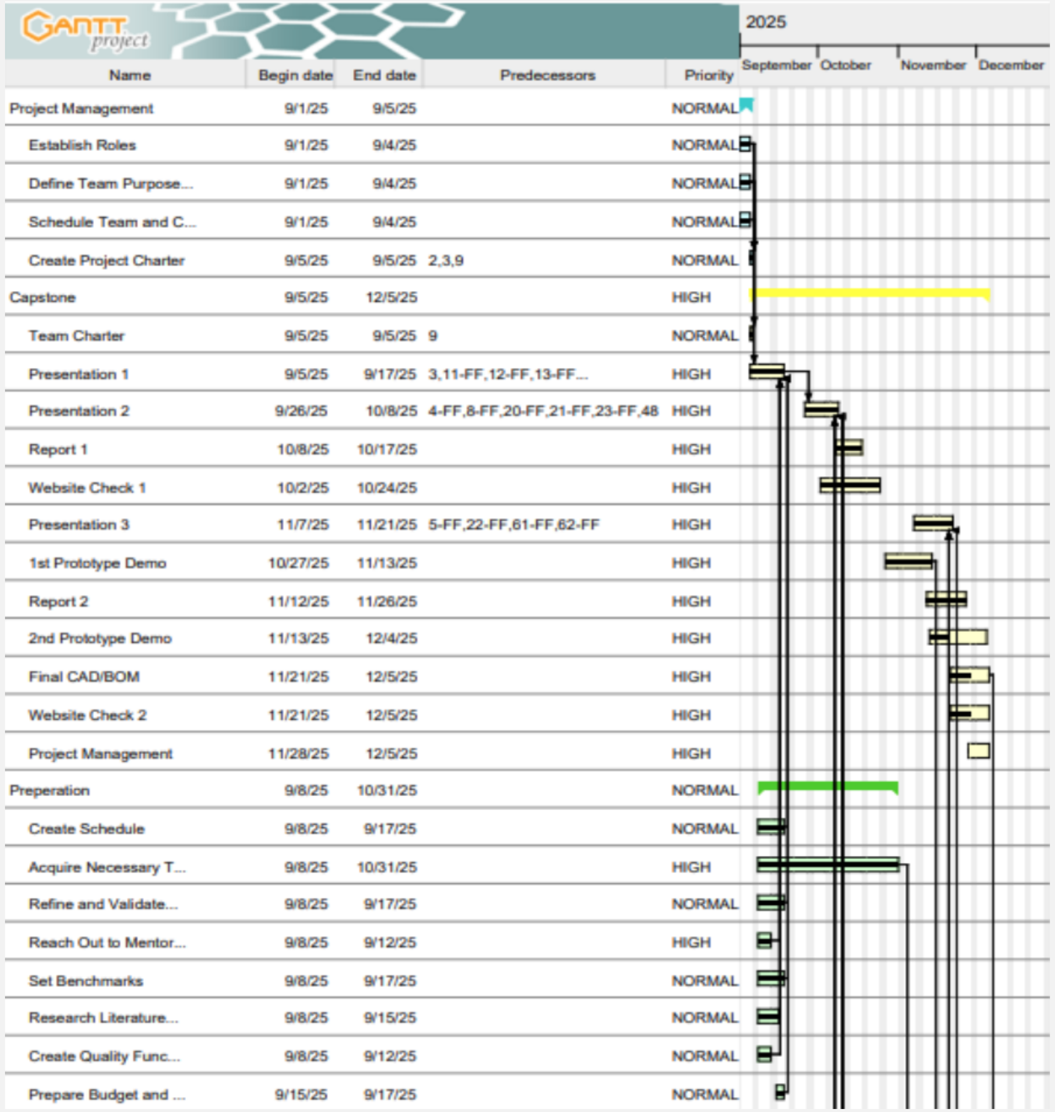
- Adjustable extension assist limits range of motion while walking
- Low structural height helps to minimize pelvic tilt when sitting
- Abduction/adduction, flexion/extension, and rotation are continuously adjustable
- Approved for a maximum body weight of 100kg (220lb)

Literature Review

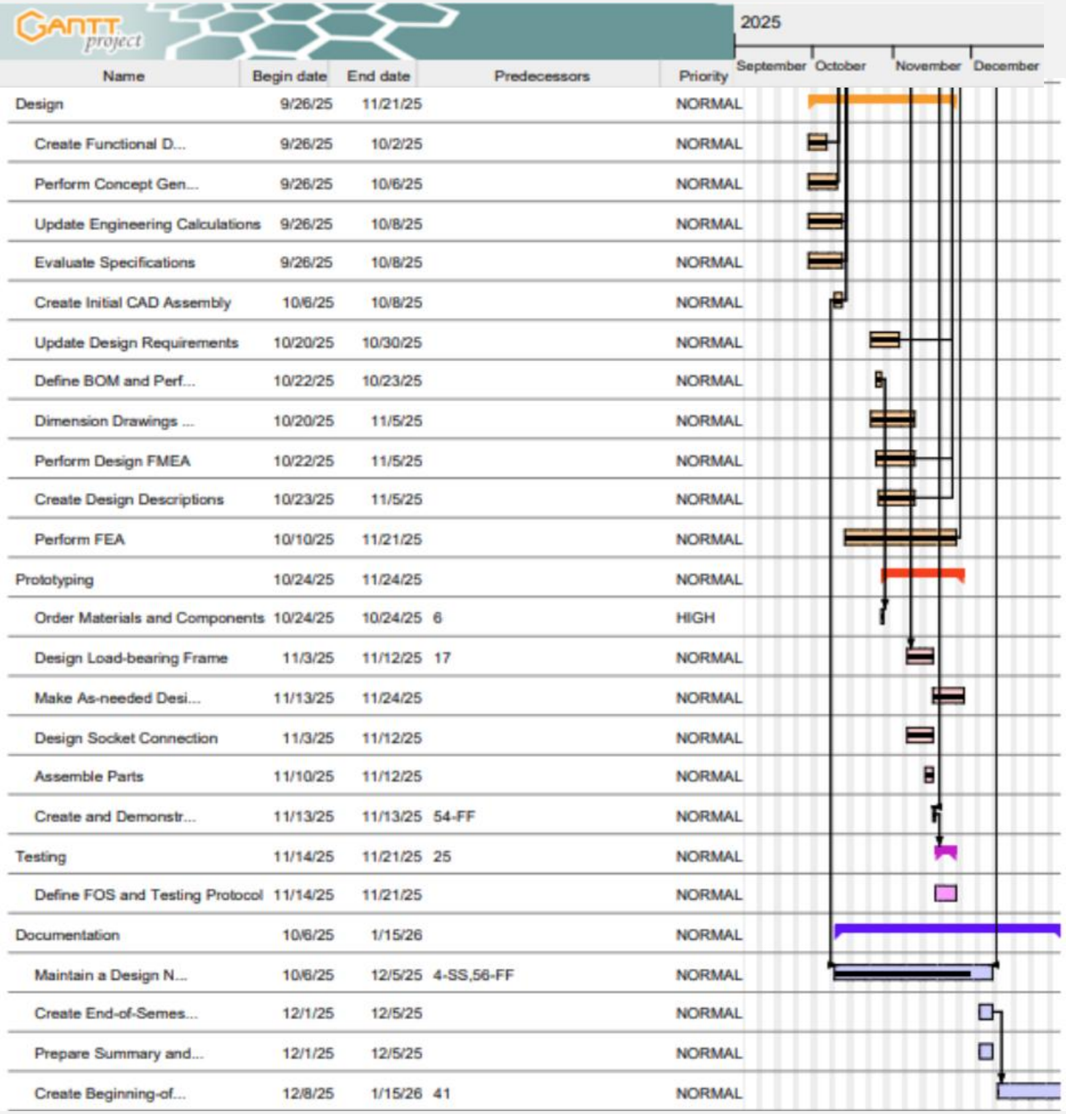
Aiden	Victoria	Matt	Quinn
ISO 7206-8: Endurance performance of stemmed femoral components under cyclic loading. **[3] “Hip biomechanics”** • This is a page that gives degrees of movement of hip for all movement angles.	**[12]“Energy expenditure during walking in amputees after disarticulation of the hip. …”** • Study comparing active knee prosthetics in standing or walking • Useful in considerations for motor type, control algorithms, and overall powered prosthetic necessity. **[10]“Loads in hip disarticulation prostheses during normal daily use”** • Static assessment of a prosthetic leg and hip, helpful in mathematical modeling.	**[15]*“Wearable Robotics: Challenges and Opportunities”*** • Useful for understanding the broader challenges of integrating robotics into wearable devices. • These will help frame design considerations for control systems and user acceptance. [20]**“A multiple-task gait analysis approach: Kinematic, kinetic and EMG reference data for healthy young and adult subjects** • A study that provides a baseline for gait and force data on healthy subjects. • This can be used to compare against prosthetic gait data to evaluate function quality.	**[24] “Ottobock Helix 3D”** • The Helix 3D Ottobock specifications as a basis for our own design. **[26] “Ground reaction forces at different speeds of human walking and running”** • Ground reaction forces at different speeds of human walking and running used as a cross-reference.

Project Management

Schedule (Fall 25)

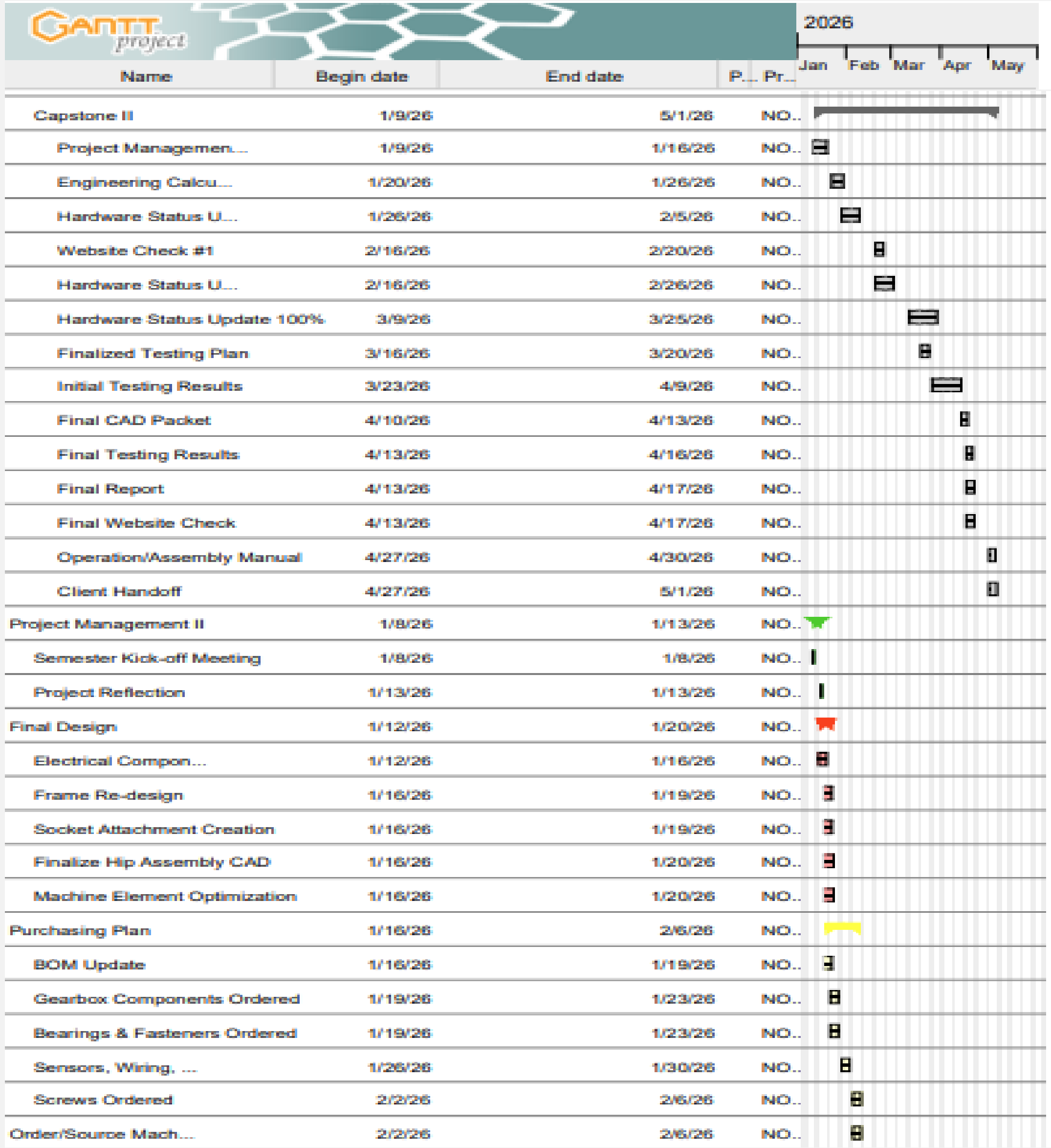


Name	Begin date	End date	Predecessors	Priority
Project Management	9/1/25	9/5/25		NORMAL
Establish Roles	9/1/25	9/4/25		NORMAL
Define Team Purpose...	9/1/25	9/4/25		NORMAL
Schedule Team and C...	9/1/25	9/4/25		NORMAL
Create Project Charter	9/5/25	9/5/25	2,3,9	NORMAL
Capstone	9/5/25	12/5/25		HIGH
Team Charter	9/5/25	9/5/25	9	NORMAL
Presentation 1	9/5/25	9/17/25	3,11-FF,12-FF,13-FF...	HIGH
Presentation 2	9/26/25	10/8/25	4-FF,8-FF,20-FF,21-FF,23-FF,48	HIGH
Report 1	10/8/25	10/17/25		HIGH
Website Check 1	10/2/25	10/24/25		HIGH
Presentation 3	11/7/25	11/21/25	5-FF,22-FF,61-FF,62-FF	HIGH
1st Prototype Demo	10/27/25	11/13/25		HIGH
Report 2	11/12/25	11/26/25		HIGH
2nd Prototype Demo	11/13/25	12/4/25		HIGH
Final CAD/BOM	11/21/25	12/5/25		HIGH
Website Check 2	11/21/25	12/5/25		HIGH
Project Management	11/28/25	12/5/25		HIGH
Preperation	9/8/25	10/31/25		NORMAL
Create Schedule	9/8/25	9/17/25		NORMAL
Acquire Necessary T...	9/8/25	10/31/25		HIGH
Refine and Validate...	9/8/25	9/17/25		NORMAL
Reach Out to Mentor...	9/8/25	9/12/25		HIGH
Set Benchmarks	9/8/25	9/17/25		NORMAL
Research Literature...	9/8/25	9/15/25		NORMAL
Create Quality Func...	9/8/25	9/12/25		NORMAL
Prepare Budget and ...	9/15/25	9/17/25		NORMAL

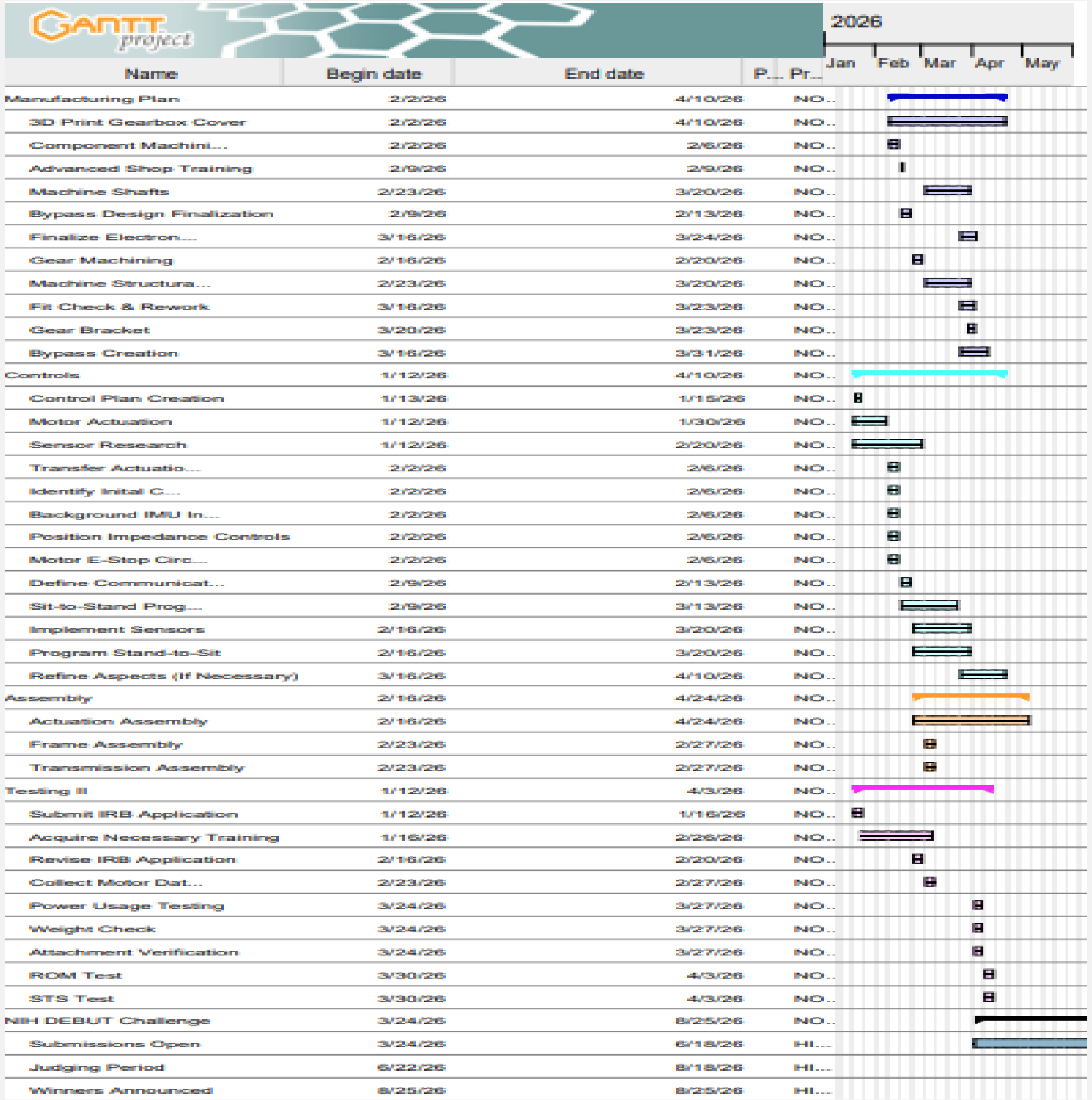


Name	Begin date	End date	Predecessors	Priority
Design	9/26/25	11/21/25		NORMAL
Create Functional D...	9/26/25	10/2/25		NORMAL
Perform Concept Gen...	9/26/25	10/6/25		NORMAL
Update Engineering Calculations	9/26/25	10/8/25		NORMAL
Evaluate Specifications	9/26/25	10/8/25		NORMAL
Create Initial CAD Assembly	10/6/25	10/8/25		NORMAL
Update Design Requirements	10/20/25	10/30/25		NORMAL
Define BOM and Perf...	10/22/25	10/23/25		NORMAL
Dimension Drawings ...	10/20/25	11/5/25		NORMAL
Perform Design FMEA	10/22/25	11/5/25		NORMAL
Create Design Descriptions	10/23/25	11/5/25		NORMAL
Perform FEA	10/10/25	11/21/25		NORMAL
Prototyping	10/24/25	11/24/25		NORMAL
Order Materials and Components	10/24/25	10/24/25	6	HIGH
Design Load-bearing Frame	11/3/25	11/12/25	17	NORMAL
Make As-needed Desi...	11/13/25	11/24/25		NORMAL
Design Socket Connection	11/3/25	11/12/25		NORMAL
Assemble Parts	11/10/25	11/12/25		NORMAL
Create and Demonstr...	11/13/25	11/13/25	54-FF	NORMAL
Testing	11/14/25	11/21/25	25	NORMAL
Define FOS and Testing Protocol	11/14/25	11/21/25		NORMAL
Documentation	10/6/25	1/15/26		NORMAL
Maintain a Design N...	10/6/25	12/5/25	4-SS,56-FF	NORMAL
Create End-of-Semes...	12/1/25	12/5/25		NORMAL
Prepare Summary and...	12/1/25	12/5/25		NORMAL
Create Beginning-of...	12/8/25	1/15/26	41	NORMAL

Schedule (Spring 26)



Name	Begin date	End date	P...	Pr...
Capstone II	1/9/26	5/1/26		NO..
Project Managemen...	1/9/26	1/16/26		NO..
Engineering Calcu...	1/20/26	1/26/26		NO..
Hardware Status U...	1/26/26	2/5/26		NO..
Website Check #1	2/16/26	2/20/26		NO..
Hardware Status U...	2/16/26	2/26/26		NO..
Hardware Status Update 100%	3/9/26	3/25/26		NO..
Finalized Testing Plan	3/16/26	3/20/26		NO..
Initial Testing Results	3/23/26	4/9/26		NO..
Final CAD Packet	4/10/26	4/13/26		NO..
Final Testing Results	4/13/26	4/16/26		NO..
Final Report	4/13/26	4/17/26		NO..
Final Website Check	4/13/26	4/17/26		NO..
Operation/Assembly Manual	4/27/26	4/30/26		NO..
Client Handoff	4/27/26	5/1/26		NO..
Project Management II	1/8/26	1/13/26		NO..
Semester Kick-off Meeting	1/8/26	1/8/26		NO..
Project Reflection	1/13/26	1/13/26		NO..
Final Design	1/12/26	1/20/26		NO..
Electrical Compon...	1/12/26	1/16/26		NO..
Frame Re-design	1/16/26	1/19/26		NO..
Socket Attachment Creation	1/16/26	1/19/26		NO..
Finalize Hip Assembly CAD	1/16/26	1/20/26		NO..
Machine Element Optimization	1/16/26	1/20/26		NO..
Purchasing Plan	1/16/26	2/6/26		NO..
BOM Update	1/16/26	1/19/26		NO..
Gearbox Components Ordered	1/19/26	1/23/26		NO..
Bearings & Fasteners Ordered	1/19/26	1/23/26		NO..
Sensors, Wiring, ...	1/26/26	1/30/26		NO..
Screws Ordered	2/2/26	2/6/26		NO..
Order/Source Mach...	2/2/26	2/6/26		NO..

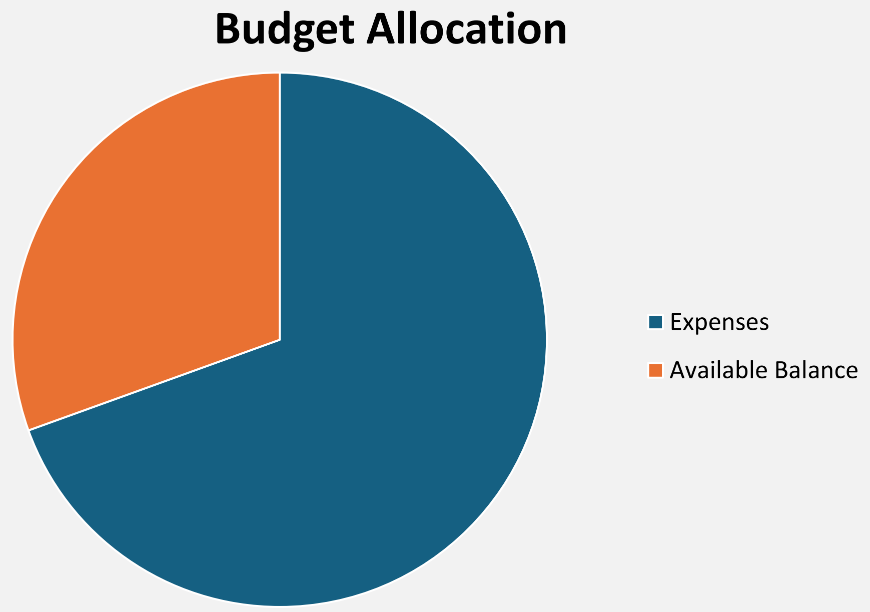


Name	Begin date	End date	P...	Pr...
Manufacturing Plan	2/2/26	4/10/26		NO..
3D Print Gearbox Cover	2/2/26	4/10/26		NO..
Component Machini...	2/2/26	2/6/26		NO..
Advanced Shop Training	2/9/26	2/9/26		NO..
Machine Shafts	2/23/26	3/20/26		NO..
Bypass Design Finalization	2/9/26	2/13/26		NO..
Finalize Electron...	3/16/26	3/24/26		NO..
Gear Machining	2/16/26	2/20/26		NO..
Machine Structura...	2/23/26	3/20/26		NO..
Fit Check & Rework	3/16/26	3/23/26		NO..
Gear Bracket	3/20/26	3/23/26		NO..
Bypass Creation	3/16/26	3/31/26		NO..
Controls	1/12/26	4/10/26		NO..
Control Plan Creation	1/13/26	1/15/26		NO..
Motor Actuation	1/12/26	1/30/26		NO..
Sensor Research	1/12/26	2/20/26		NO..
Transfer Actuatio...	2/2/26	2/6/26		NO..
Identify Inital C...	2/2/26	2/6/26		NO..
Background IMU In...	2/2/26	2/6/26		NO..
Position Impedance Controls	2/2/26	2/6/26		NO..
Motor E-Stop Circ...	2/2/26	2/6/26		NO..
Define Communicat...	2/9/26	2/13/26		NO..
Sit-to-Stand Prog...	2/9/26	3/13/26		NO..
Implement Sensors	2/16/26	3/20/26		NO..
Program Stand-to-Sit	2/16/26	3/20/26		NO..
Refine Aspects (If Necessary)	3/16/26	4/10/26		NO..
Assembly	2/16/26	4/24/26		NO..
Actuation Assembly	2/16/26	4/24/26		NO..
Frame Assembly	2/23/26	2/27/26		NO..
Transmission Assembly	2/23/26	2/27/26		NO..
Testing II	1/12/26	4/3/26		NO..
Submit IRB Application	1/12/26	1/16/26		NO..
Acquire Necessary Training	1/16/26	2/26/26		NO..
Revise IRB Application	2/16/26	2/20/26		NO..
Collect Motor Dat...	2/23/26	2/27/26		NO..
Power Usage Testing	3/24/26	3/27/26		NO..
Weight Check	3/24/26	3/27/26		NO..
Attachment Verification	3/24/26	3/27/26		NO..
ROM Test	3/30/26	4/3/26		NO..
STS Test	3/30/26	4/3/26		NO..
NIH DEBUT Challenge	3/24/26	8/25/26		NO..
Submissions Open	3/24/26	6/18/26		HI...
Judging Period	6/22/26	8/18/26		HI...
Winners Announced	8/25/26	8/25/26		HI...

Budget

Budget Overview	
Budget	$ 4,500.00
Fundraising	$ 1,750.00
Expenses	$ 3,127.06
Available Balance	$ 1,372.94

All fundraising was in-kind, big thank you to NextStep Prosthetics & Professor David Willy!

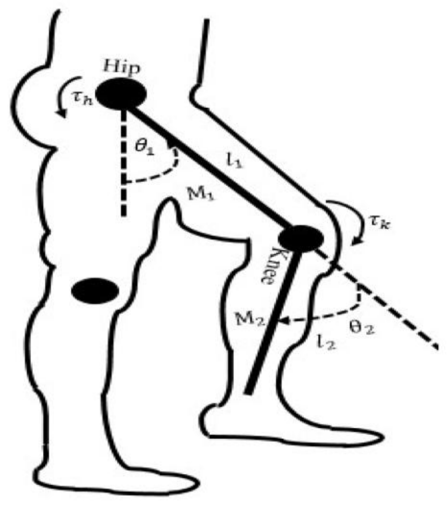


30.5% of budget remaining

Bill of Materials

Category	Item No.	Description	Primary Vendor	Unit Price	Quantity	Make/Buy	Manufacturer	Lead Time	Part Status
Main Assembly	1	AK80-64 KV80 Motor	CubeMars	$ 911.77	1	Buy	CubeMars		In-Hand
Main Assembly	2	Angular Contact Bearing	BearingsDirect	$ 13.54	3	Buy	NTN Bearings	3-4 Weeks	In-Hand
Main Assembly	3	1030L Gear	Zoro	$ 200.00	1	Buy	Boston Gears	2-3 Weeks	In-Hand
Main Assembly	4	1030R Gear	Zoro	$ 195.00	1	Buy	Boston Gears	2-3 Weeks	In-Hand
Main Assembly	5	Upper Shaft	NAU Machine Shop	$ 7.21	1	Make	Quinn	2 days	In-Hand
Main Assembly	6	Lower Shaft	NAU Machine Shop	$ 7.21	1	Make	Victoria	4 days	In-Hand
Main Assembly	7	Retaining Ring	DSR	$ -	2	Buy	Hillman	1 Week	In-Hand
Main Assembly	8	Shaft Key	Amazon	$ 3.25	2	Buy	dmiotech	3-4 Weeks	In-Hand
Main Assembly	9	Frame (Motor Side)	McMaster-Carr	$ 146.01	1	Buy	Red Rock Manufacturing	3-4 Weeks	In-Hand
Main Assembly	10	Frame (Bearing Side)	McMaster-Carr	$ 131.55	1	Buy	Red Rock Manufacturing	3-4 Weeks	In-Hand
Main Assembly	11	Lamination Plate	NextStep Prosthetics	$ -	1	Buy	Ottobock	5 days	In-Hand
Main Assembly	12	Base Plate	McMaster-Carr	$ 16.02	1	Make	Aiden	3-4 Weeks	In-Hand
Main Assembly	13	Male Pyramid Adapter	Ebay	$ 25.00	1	Buy	Trulife	N/A	In-Hand
Main Assembly	14	Structure Enforcing Bar	NAU Machine Shop	$ 10.17	1	Make	Victoria	3-4 Weeks	In-Hand
Hardware	15	M6-1x25 Socketcap Head Screw	Amazon	$ 19.99	4	Buy	Everbilt	1 Week	In-Hand
Hardware	16	M6-1x15 Socketcap Head Screw	Amazon	$ -	2	Buy	Fgruh	10 days	In-Hand
Hardware	17	M3x12 Socket Cap Head Screw	Amazon	$ -	8	Buy	Fgruh	10 days	In-Hand
Hardware	18	M4x10 Socket Cap Head Screw	Amazon	$ -	6	Buy	Fgruh	10 days	In-Hand
Hardware	19	M8x20mm Countersunk Screw	HomeDepot	$ 2.67	2	Buy	Everbilt		In-Hand
Hardware	20	M6x35 Countersunk Screw	Ebay	$ -	4	Buy	Trulife	10 days	In-Hand
Electronics	21	Adafruit CAN Controller	Adafruit	$ 19.95	1	Buy	Adafruit	2-3 Weeks	In-Hand
Electronics	22	MicroSD Card	Adafruit	$ 13.69	2	Buy	Adafruit	2-3 Weeks	In-Hand
Electronics	23	Buck Converter	Amazon	$ 15.99	1	Buy	YABOANG	1 Week	In-Hand
Electronics	24	Breadboard Jumper Wire	Amazon	$ 10.99	1	Buy	TODOELEC	5 days	In-Hand
Electronics	25	IMU Sensor	Adafruit	$ 6.99	2	Buy	HiLetgo	5 days	In-Hand
Electronics	26	RUBIK Link V2.0	CubeMars	$ 40.00	1	Make	CubeMars		In-Hand
Electronics	27	CAN Bus HAT	Waveshare	$ 39.99	1	Buy	Waveshare		In-Hand
Electronics	28	36V Battery	Amazon	$ 32.83	1	Buy	Amazon		In-Hand
Electronics	29	Battery Adapter	Amazon	$ 5.82	1	Buy	Amazon		In-Hand

Mathematical Modeling



Hip Joint Torque

What is the torque at the hip joint required for flexion?

Torque Equation:

$$\tau = rFsin\theta$$

Static torque at hip joint:

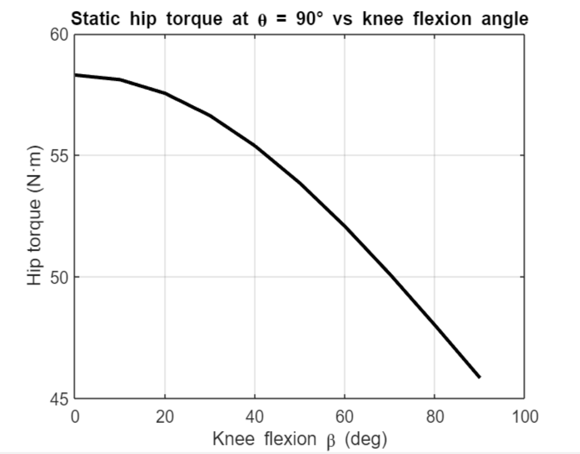
$$\tau_{hip}(\theta,\beta) = m_{thigh}gr_{thigh}sin\theta + m_{shank}g(L_1 sin\theta + r_{shank}\sin(\theta-\beta)) + m_{foot}g(L_1 sin\theta + L_2\sin(\theta-\beta))$$

$$Knee\ angle = \beta$$

$\beta = 0 \qquad \tau = 58.3Nm$

$\beta = 60 \qquad \tau = 52.1Nm$

$\beta = 90 \qquad \tau = 45.8Nm$



Important because it gives us a base minimum requirement of constant torque, which can help determine motor and power

Power

What battery size is best for an active hip prosthetic?

Equations Used

Angle Vs. Time (1)

$$\theta(t) = \theta_0 + A\sin\left(\frac{2\pi t}{T}\right)$$

Angular Velocity (2)

$$\omega(t) = \frac{d\theta}{dt} = A \cdot \frac{2\pi}{T}\cos\left(\frac{2\pi t}{T}\right) \quad (\mathrm{rad/s})$$

Mechanical Power (3)

$$P_{\mathrm{mech}}(t) = \tau\big(\theta(t)\big)\,\omega(t)$$

Electrical Energy per Step (4)

$$E_{\mathrm{step}} = \int_0^T \frac{\max\left(P_{\mathrm{mech}}(t), 0\right)}{\eta_{\mathrm{motor}}}\,dt \;+\; P_{\mathrm{anc}}T$$

Conversions (5)

$$\mathrm{Wh/step} = \frac{E_{\mathrm{step}}}{3600}, \qquad \mathrm{Wh/min} = \mathrm{Wh/step} \times 60, \qquad \mathrm{Runtime\ (min)} = \frac{\mathrm{Battery\ (Wh)}}{\mathrm{Wh/min}}$$

or

$$\mathrm{Battery\ Wh} = \mathrm{Runtime\ (min)} \times \mathrm{Wh/min}$$

Assumptions

Knee Torque Data
- From static torque's (58.3, 52.1, and 45.8 Nm)
- θ range 0<θ<90

Step Cadence
- T = s (60s/min)

Motor efficiency
- η_motor = 7%

Ancillary Power (Other electronic power)
- 10 W

This allows us to find the Wh needed for the time we desire.

Time (Min)	Battery required (Wh)
10	21.73
20	43.46
30	65.19
45	97.79
60	130.38
90	195.57

Ground Reaction Forces

What are the max forces and moments on a leg during a normal walking gait?

Assumptions

- The reaction force is approximately 1.5 times that of body weight during heel strike and toe off, and just body weight at mid stance based on a study
- Mass of 90kg
- Foot length of 24.16cm
- Shank length of 39cm
- Foot at 90° to the Shank at all stages
- Heel at 20° to ground during heel strike
- Toes at 20° to ground during toe off

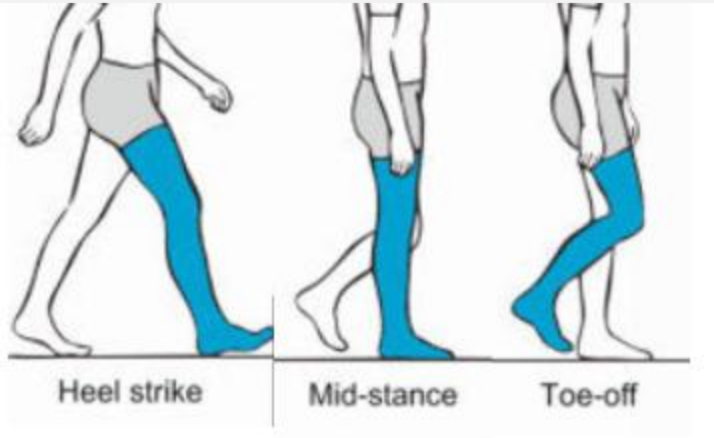
Equations

$$R_1 = 1.5mg \; R_2 = mg$$
$$\sum F = 0 \sum M_k = 0$$
$$F_t = F_k \sin\theta \;\; F_a = F_k \cos\theta$$

The maximum force is 1.324kN during the heel strike and toe of sections of the walking gate.
1.244kN if which is in axial and .453kN in transverse

The maximum moment is 176.65kN during the heel strike phase

These calculations give us an idea of the force that the upper leg prosthetic will be undergoing at the knee due to a normal waling cycle



Stress & Strain

What magnitudes of stress and strain are placed on a prosthetic leg in everyday wear?

$$\sigma_{axial} = \frac{F}{A}, \sigma_{bending} = \frac{Mc}{I}, \ \varepsilon = \frac{\sigma_{max}}{E}$$

Assumptions

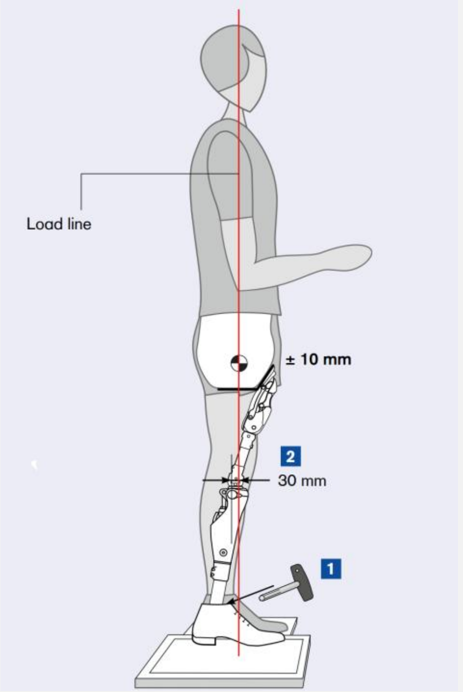
- 90kg individual
- Area of Upper Leg Tube
  - 30mm Outer Diameter, 2mm thick
- Aluminum

Case 1: Standing

$$\sigma_{axial} = 5.0185\,MPa$$
$$\varepsilon = 7.169 * 10^{-5}$$

Case 2: Walking

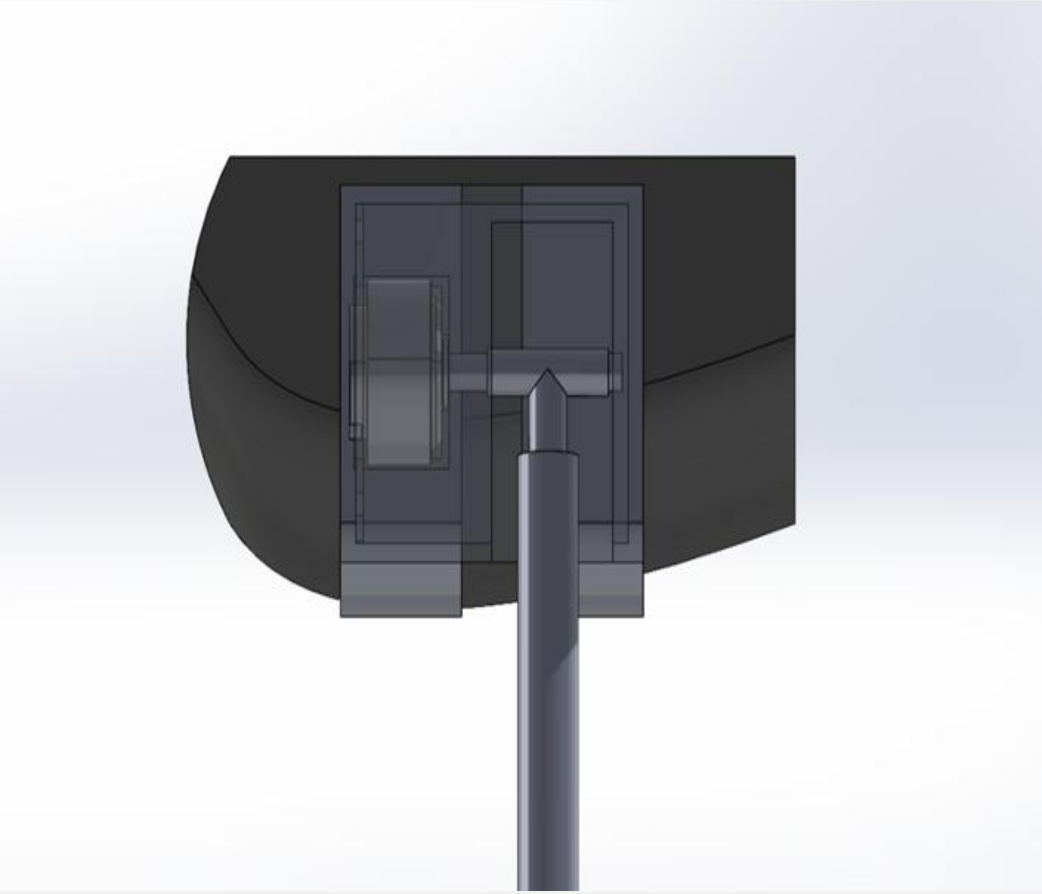
$$\sigma_{axial} = 7.528\,MPa$$
$$\sigma_{bending} = 57.317\text{ Mpa}$$
$$\sigma_{max} = 64.845\,MPa$$
$$\varepsilon = .0009262$$



This computation allows for lifecycle analysis, durability, and material selection throughout the design process.

Design Process

First Design



Composition:

- Exterior cube housing
- Shaft coupling

Cons:

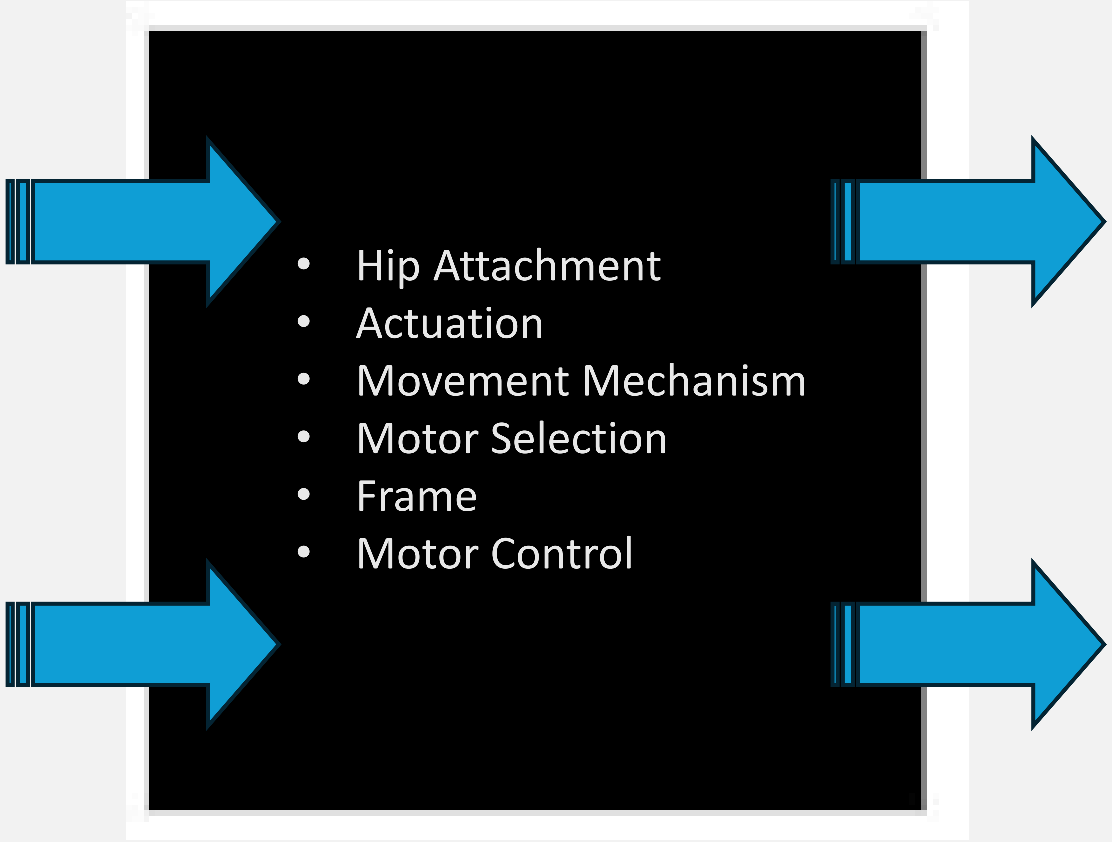
- Does not use gears
- Awkward shape and protrusion
- Difficult manufacturing and assembly

Functional Decomposition

Black Box Model

Inputs

- Attached to a standard lower leg
- Movement from stand to sit and sit to stand
- Easy to use
- Movement for walking.

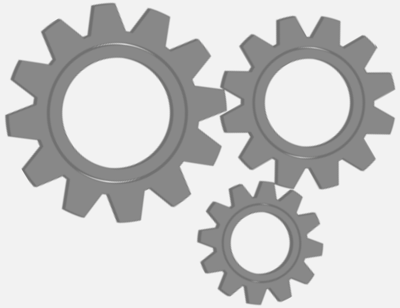


- Hip Attachment
- Actuation
- Movement Mechanism
- Motor Selection
- Frame
- Motor Control

Outputs

- Standard fittings for Lower leg prosthetics by way of a pyramid adapter
- DOF should be a -20 to 135°
- Total weight should be less than sound leg
- System should provide torque to the body to assist it in lifting.

Concept Generation



Morphological Matrix

Component	**1**	**2**	**3**	**4**
Actuation	Linear actuator	Series Elastic Actuators	Rotary Actuator	Variable Stiffness Actuator
Power Transmission	Gear system	Cable	Electrostatic clutch	Belt
Mechanisms	Stewart platform with 2 Links	Ball Joint	Universal Joint	Rigid Links
Hip Attachment Pattern	Dual attachment [2 components bolted to socket]	Lateral [side socket attachment]	Singular front bolt [typical use]	Angled alignment [lower corner attachment]

Selection Criteria

Structural Safety

- Uniformity, minimal protrusions
- Withstand expected load of 90kg

Manufacturability

- Feasible to prototype and produce
- Practical material and accessibility

Reliability

- Prevents failure in critical or varied conditions
- Simple user interface

Power Efficiency

- Ensuring Practicality
- “All day” use

Adaptability

- Standardized attachments
- Interface with existing sockets

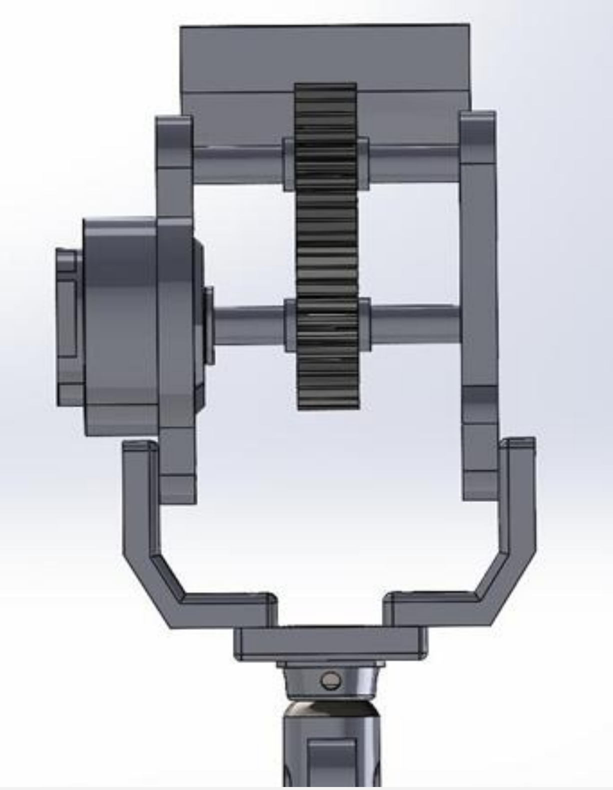
Assisted actions

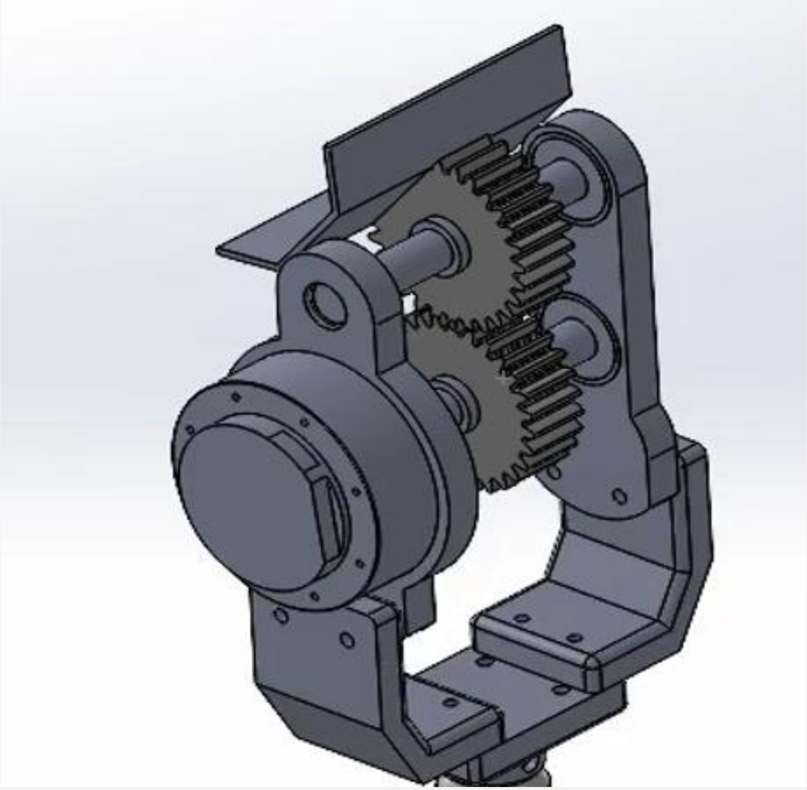
- Stand-to-Sit
- Sit-to-Stand

Final Selection

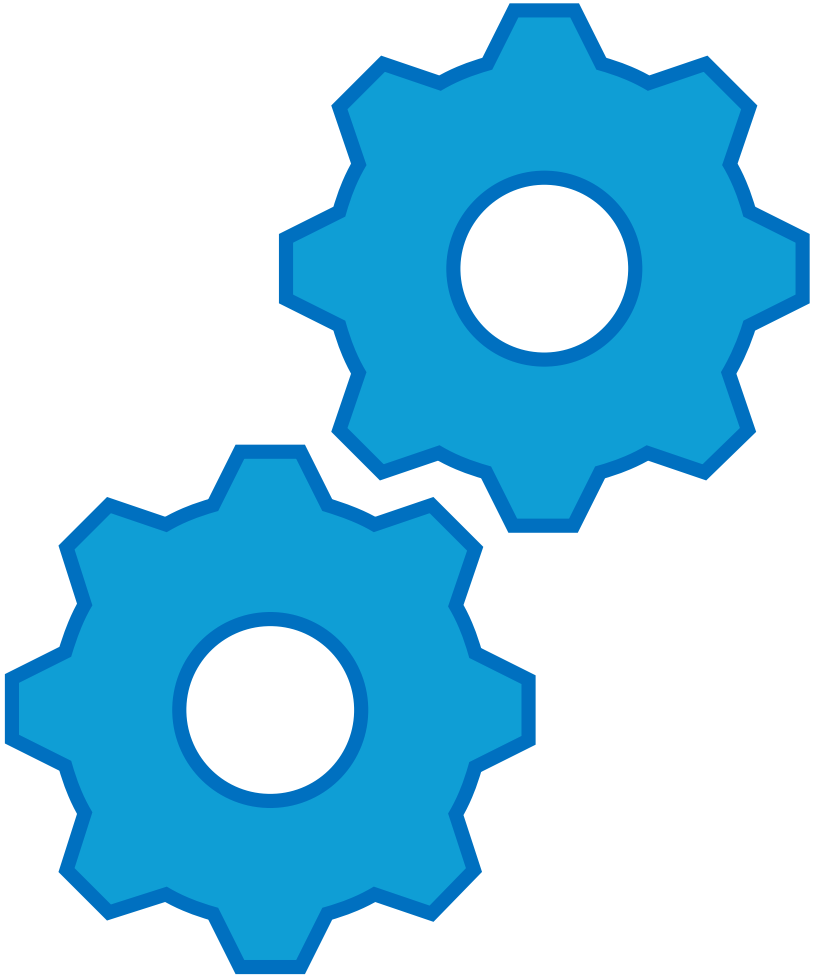
Actuation	Power Transmission	Attachment
Brushless DC Motor	Gears	Standardized to Helix 3D

Iteration 1



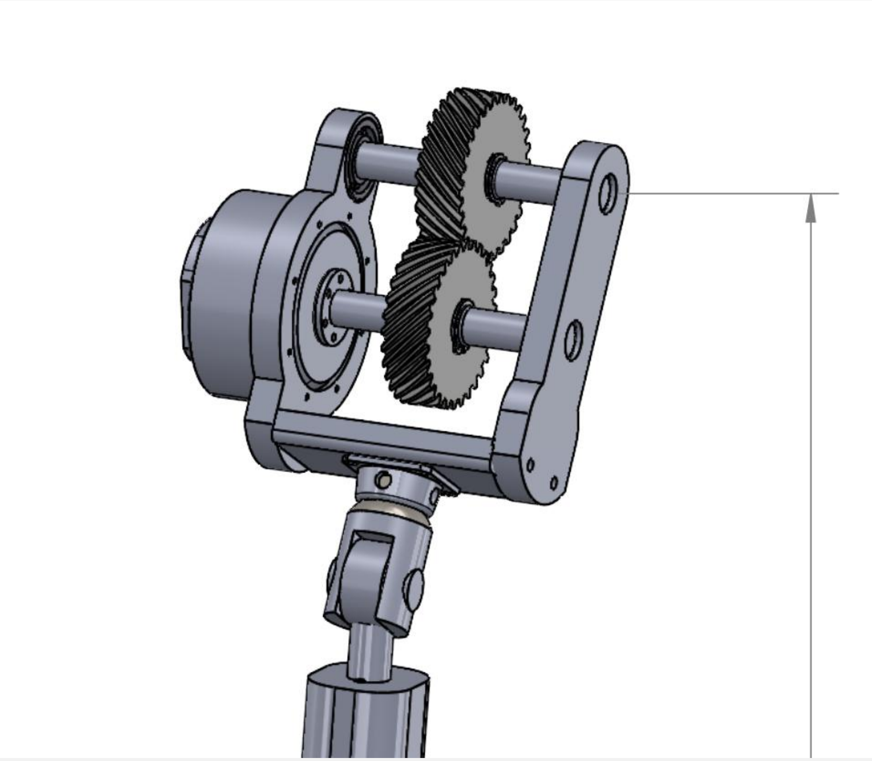


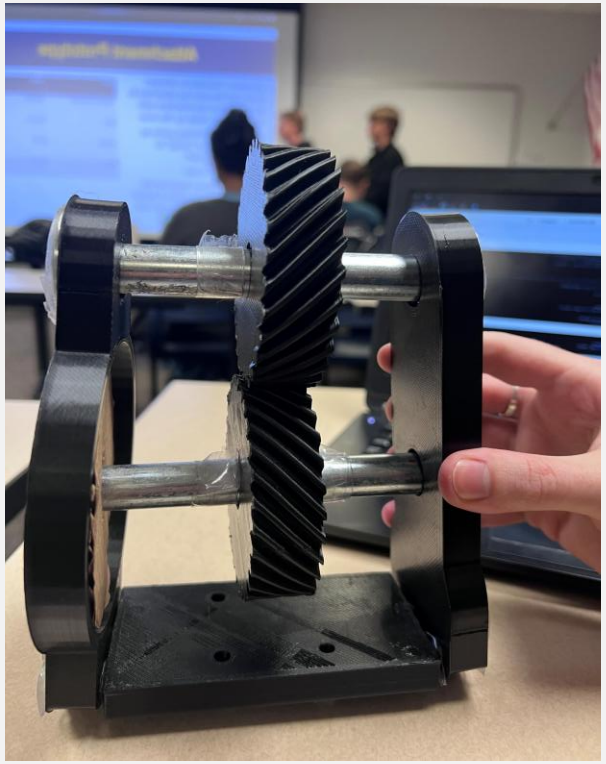
- Spur gears
- New frame and shape for less protrusion
- Excess height
- Width



Prototyping

Iteration 2





- Removed extra side brackets
- Helical gears
- Improved shape
- Excess width
- No means of attachment

Failure Modes and Effects Analysis (FMEA)

1. Identify				2. Classify									3. Take action	4. Action results			
Item (component, part, assembly)	Function	Requirements	Failure mode	Effect(s) of potential failure	Severity	Classification	Potential causes of failure	Current design controls (prevention)	Occurrence likelihood	Current design controls (detection)	Effectiveness of best method of detection control	RPN (Risk priority no.)	Recommended action(s)	Severity	Occurrence	Detection	RPN (Risk priority no.)
Motor	Providing torque to the shaft	Motor must provide enough torque, smooth, accurate torque/positioning	Control instability or sustained vibration during gait	User discomfort, reduced balance, risk of fall, joint wear	9	Safety	Poor control tuning, insufficient damping	Torque limits, firmware control	3	Manual Testing, Encoder	3	81	Implement rate limits, use high-rate inner current/torque loop	9	2	2	36
Motor	Providing torque to the shaft	Motor must provide enough torque	Motor can not meet required torque to lift leg	Leg stops moving	4	Product failure	Motor is defunct	Product testing, inspection	1	Torque monitor, current sensing	1	4	Maintenance schedule	5	4	3	60
Motor Shaft	Power Transmission	Transmit movement	Detaches from motor	Hinders rotation	10	Safety	Fastener failure, vibration	Motor casing, using standard bolts	3	Gait stability	4	120	Include repair kit, include fasteners or clamps with design.	10	2	2	40
Motor Shaft	Power Transmission	Handles load	Shaft breaks	Joint & leg detaches	10	Safety	Material failure	Material Selection, mathematical modeling	2	Gait stability	4	80	Replace shaft, bring to prosthetist	5	3	3	45

Failure Modes and Effects Analysis (FMEA)

1. Identify				2. Classify									3. Take Action	4. Action Results			
Item (component, part, assembly)	Function	Requirements	Failure mode	Effect(s) of potential failure	Severity	Classification	Potential causes of failure	Current design controls (prevention)	Occurrence likelihood	Current design controls (detection)	Effectiveness of best method of detection control	RPN (Risk priority no.)	Recommended action(s)	Severity	Occurrence	Detection	RPN (Risk priority no.)
Battery	Provide Power to the motor	Provides enough power for the motor to allow it to produce the required torque	Does not reach required power	The motor doesn't power the leg, and the leg is not able to reach the required gate	4	Product failure	Dysfunctional battery. Low power battery.	Mathematically determines the amout of power required for the motor	1	Low voltage alarm in testing	1	4	Use battery with 20-30% capacity margin	5	4	3	60
Battery	Provide Power to the motor	Provides enough power for the motor to allow it to produce the required torque	Wires break / detatch from motor	Leg stops moving with power. potential danger with loose wires	6	Safety	wires not secured tightly	Clips built into motor, and no major movement of motor or battery, and sealing of the wires to the mold	3	Motor stops working, look at wire	2	36	secure wires closely to the mold to prevent damage and movement	7	3	2	36
Rasberry Pi Controllor (Electrical system)	Acts as a computer to provide control	Simple and easy Interface	No Control of leg	Locks in place or becomes frozen in place. Possible triping and injury	4	Product failure	Code is wrong or something is unplugedx	Rasberry pie with a CANbus attachment to the motor.	4	Testing the code and wiring before using it on a individual	5	80	Implement a test sequence to make sure everything works.	4	4	1	16
Attachment Plate	Suspend system on socket	Securely hold system without movement	Detaches from socket	System detaches	10	Safety	Extreme wear, unforseen force	Secure standard fasteners	2	Stability, inspection	3	60	Safety test, user manual	5	4	3	60

Critical Failure Points

Failure Point and Risk Trade offs

I. Motor not providing sustained torque.
    I. Unstable Motion - Falling

II. Misalignment or failure of Shaft under load.
    I. System damage or motion failure

III. Attachment loosening or detaching from socket.
    I. Loss of support

Solution and Mitigation

I. Motor analysis on biomechanic datasets, implemented closed loop control and rate limits (high-rate inner current/torque loop

II. Mathematical modeling, material selection, shaft keys in place as additional fail-safe, structural bar and retaining rings for alignment

III. Maintenance checks before testing and keeping a secure connection under repeated use

Design Validation and Prototyping – Questions and Answers

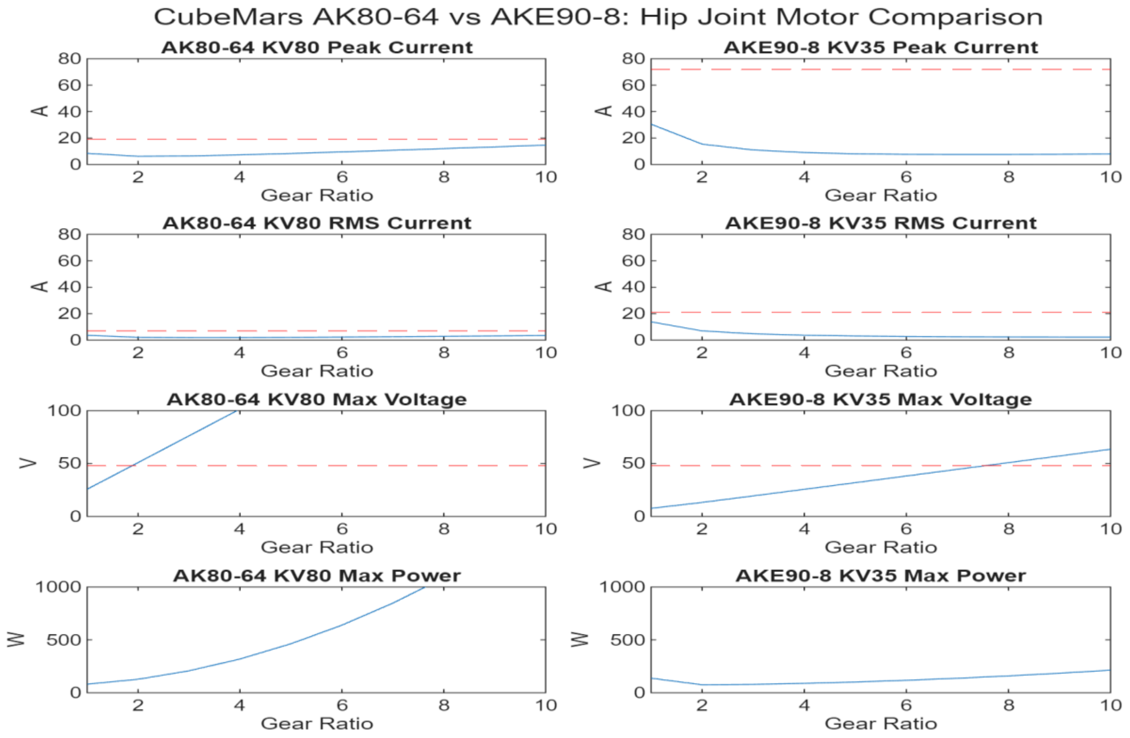
Question	Answer
Does the general shape of our system allow for adequate rotation about the center of rotation?	Yes. The system rotated full around the top gear as we hoped for
Does our system feel like the sleek replacement for the upper leg that we were hoping for?	No. we found the system far too wide and thought it would be awkward to use.

Mathematical Modeling P2

Motor Analysis

CubeMars AK80-64 (KV80)

- Provides required hip torque with lower electrical demand
- Stays within limits
- More efficient – smaller battery use
- Lighter weight



Motor	Gear Ratio	Peak Current (A)	RMS Current (A)	Max Voltage (V)	Max Power (W)
AK80-64 KV80	1	8.44	3.63	25.75	81.28
AKE908 KV35	1	30.47	13.84	7.66	137.56

Shafts

Parameters:

- $d = 20mm$
- $T_m = 48\ N * m$
- $M_a = 176\ kN * m$
- $S_e(AL) = 270\ MPa \mid S_{ut}(AL) = 110\ MPa$
- $S_e(Ti) = 480\ MPa \mid S_{ut}(Ti) = 550\ MPa$
- $T_a = M_m = 0$

Von Mises Stress:

$$\sigma'_a = \sqrt{\left(\frac{\mathbf{32}\boldsymbol{K_f M_a}}{\boldsymbol{\pi d^3}}\right)^2 + 3\left(\frac{\mathbf{32}\boldsymbol{K_{fs} T_a}}{\boldsymbol{\pi d^3}}\right)^2}$$

$$\sigma'_m = \sqrt{\left(\frac{\mathbf{32}\boldsymbol{K_f M_m}}{\boldsymbol{\pi d^3}}\right)^2 + 3\left(\frac{\mathbf{32}\boldsymbol{K_{fs} T_m}}{\boldsymbol{\pi d^3}}\right)^2}$$

Results	Aluminum (6061)	Titanium (Grade 4)
σ'_a	336.25 MPa	340.71 MPa
σ'_m	.0382 MPa	.0425 MPa
σ'_{max}	336.29 MPa	340.75 MPa

Based on these results, **Grade 4 Titanium would be the best material solution**.

Further adjustments could include shoulder design / filet grooves on shaft to improve stress distribution.

Frame Analysis

<u>Goal</u>: Is Iteration 1 or Iteration 2 better at resisting naturally accruing forces?

Assumptions

- Body force = 882.9N
- Reaction force = 1324N
- Torsional load = 120 N*m
- Yield Str = 275 MPA

$$\sigma = \frac{M}{I}$$

$$M = F \cdot L$$

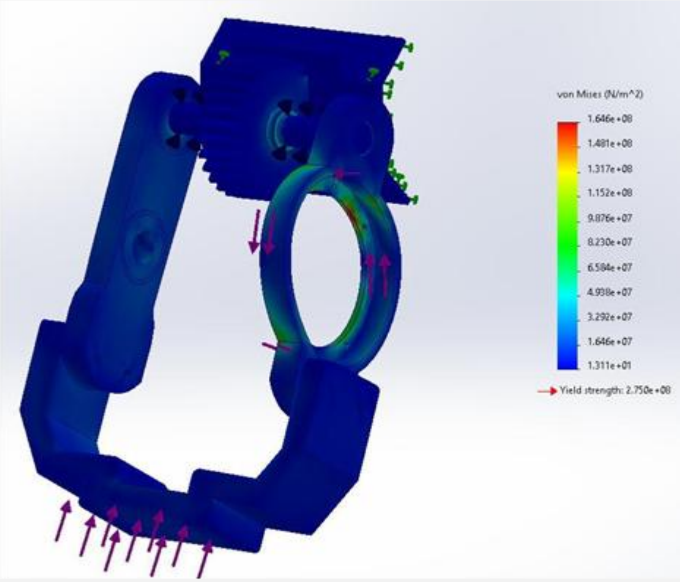
$$I_{lower\ frame} = \frac{bt^3}{12}$$

$$I_D = \frac{\pi(D_0 - D_i)}{64}$$

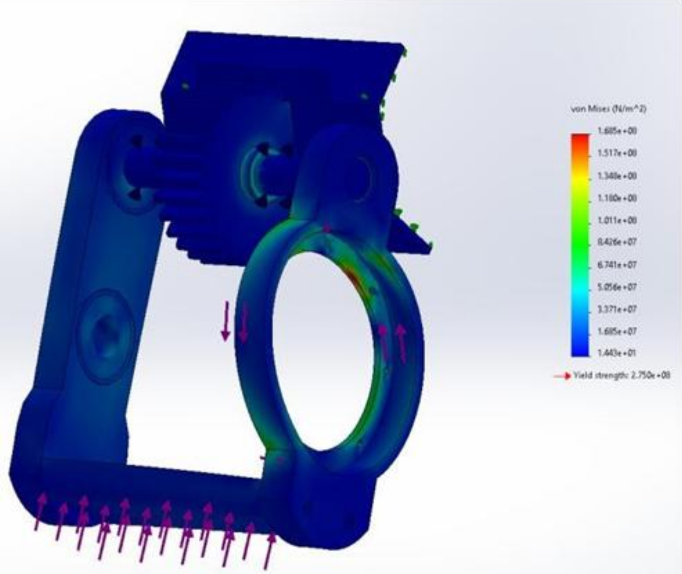
$$FOS = \frac{\sigma_y}{\sigma}$$

Results

- Iteration 1 has slightly higher peak stress at **150-160 MPa.**
- Iteration 2 has a peak stress of **140-150 MPa.**
- Both below yield str but Iteration 2 is better



Iteration 1



Iteration 2

Bearing Analysis

Assumptions:

S_f = 2
F_r=1324N
D_i= 20mm
The bearing loaded at the end of shaft, reaction force located ¾ along the shaft

Reaction Force:

$$\sum M = 0 \sum F = 0$$

$$F_D = 1986\ N$$

Allowed force of 6550N via online research

Bearing Life:

Bearing listings give all the information we need to test if our bearing is suitable.

$$L_R = 10^6 \qquad C_{10} = 6550N$$

To find bearing life we use 2 formulas:

$C_{10} = F_D(\frac{L_D}{L_R})^{\frac{1}{3}}$ and $L_D = l_D n_D 60$

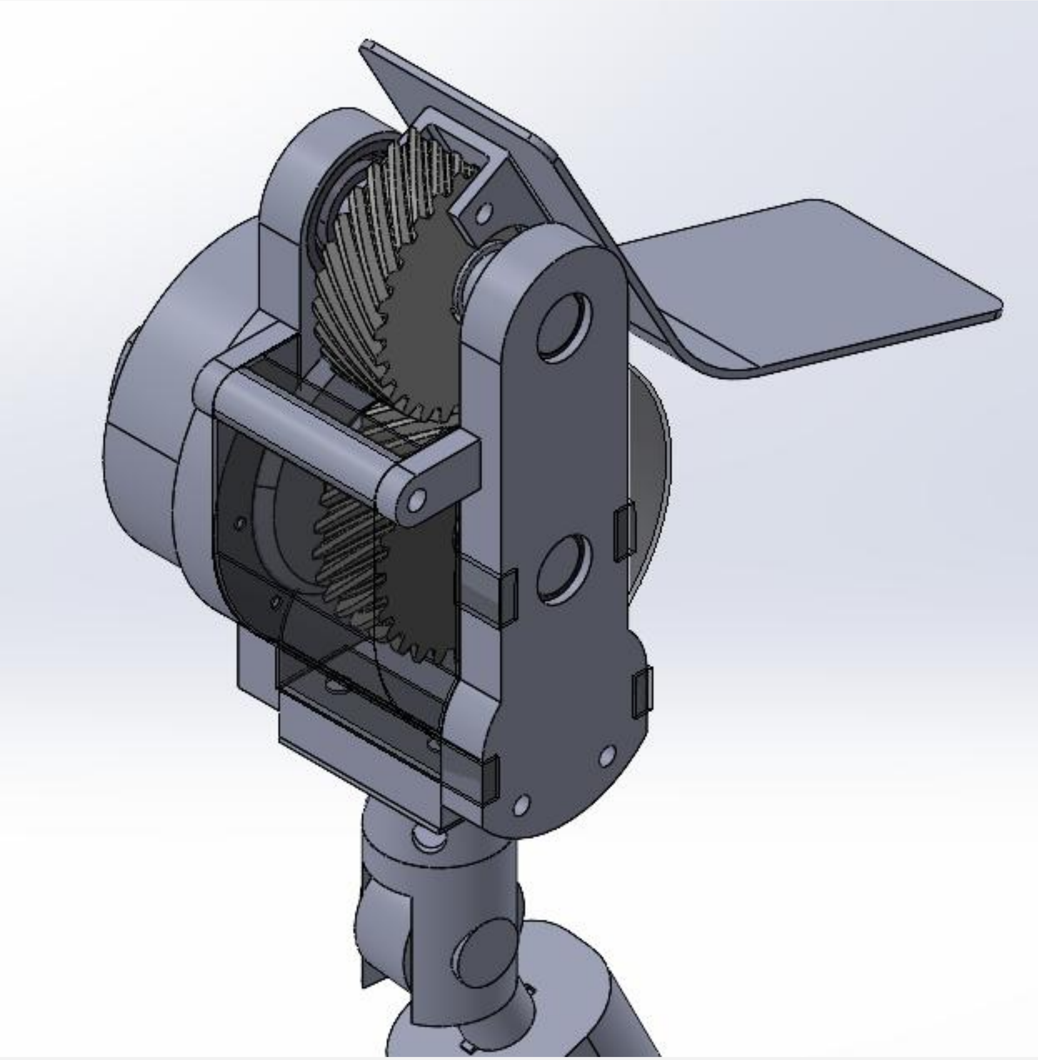
Combined to get

$$l_D = \frac{1}{60n_D} L_R(\frac{C_{10}}{F_D})^3$$

Giving us a lifetime rating of 9965 **hours** of operation.

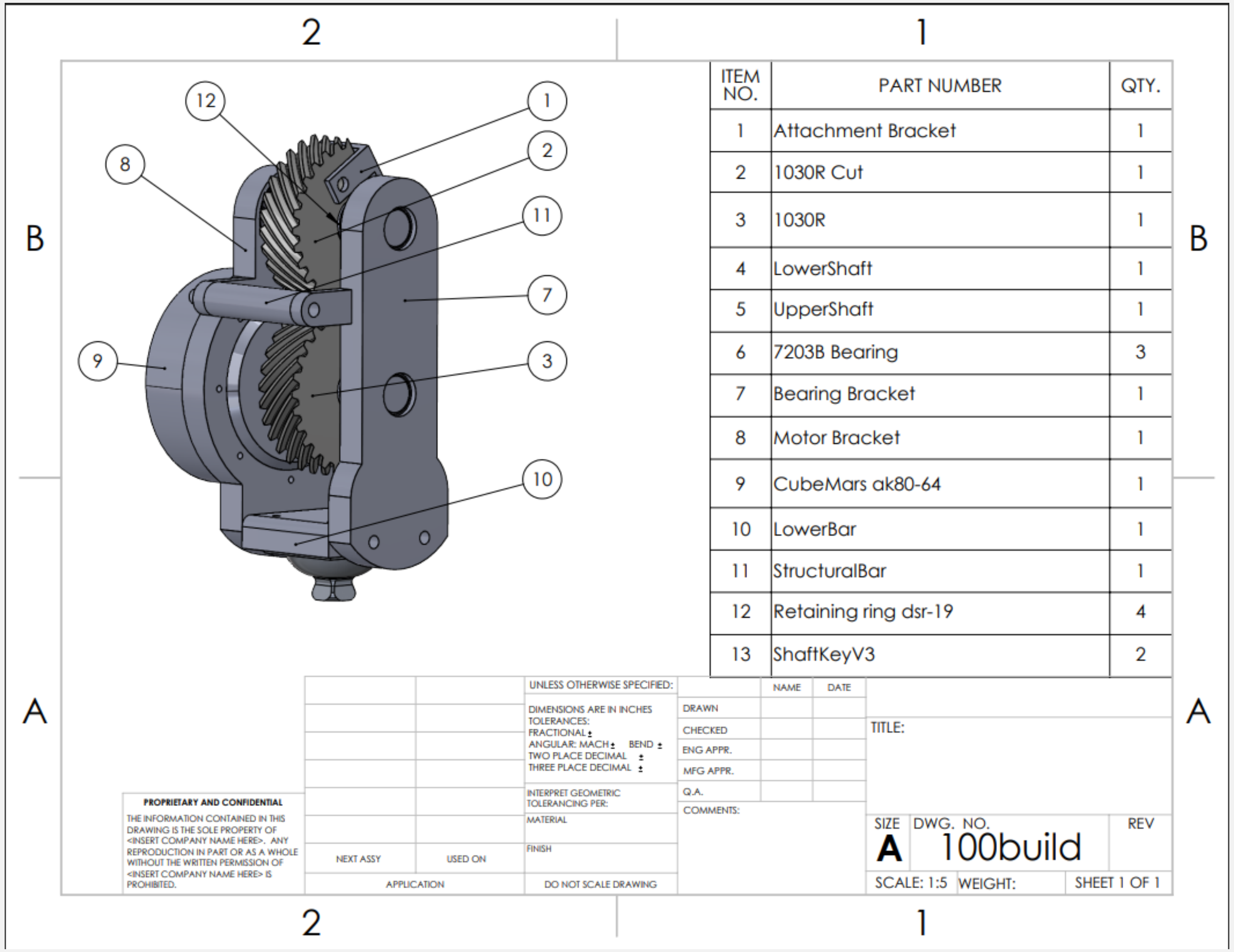
Complete Assembly

Final Design



- Condensed width
- Cut gear for closer rotation to body
- Attachment plate
- Structural bar for alignment and stability

Final Hardware



ITEM NO.	PART NUMBER	QTY.
1	Attachment Bracket	1
2	1030R Cut	1
3	1030R	1
4	LowerShaft	1
5	UpperShaft	1
6	7203B Bearing	3
7	Bearing Bracket	1
8	Motor Bracket	1
9	CubeMars ak80-64	1
10	LowerBar	1
11	StructuralBar	1
12	Retaining ring dsr-19	4
13	ShaftKeyV3	2

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

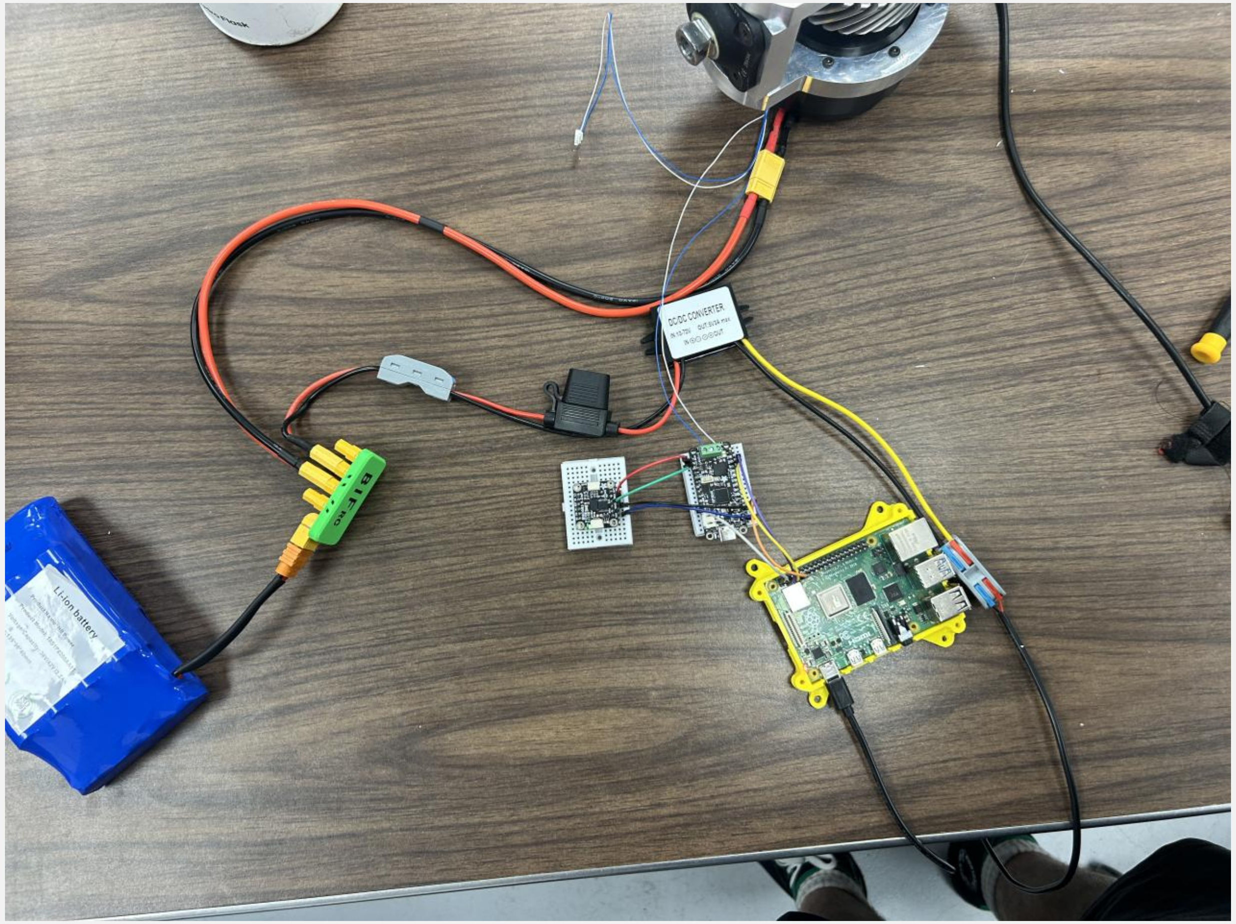
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

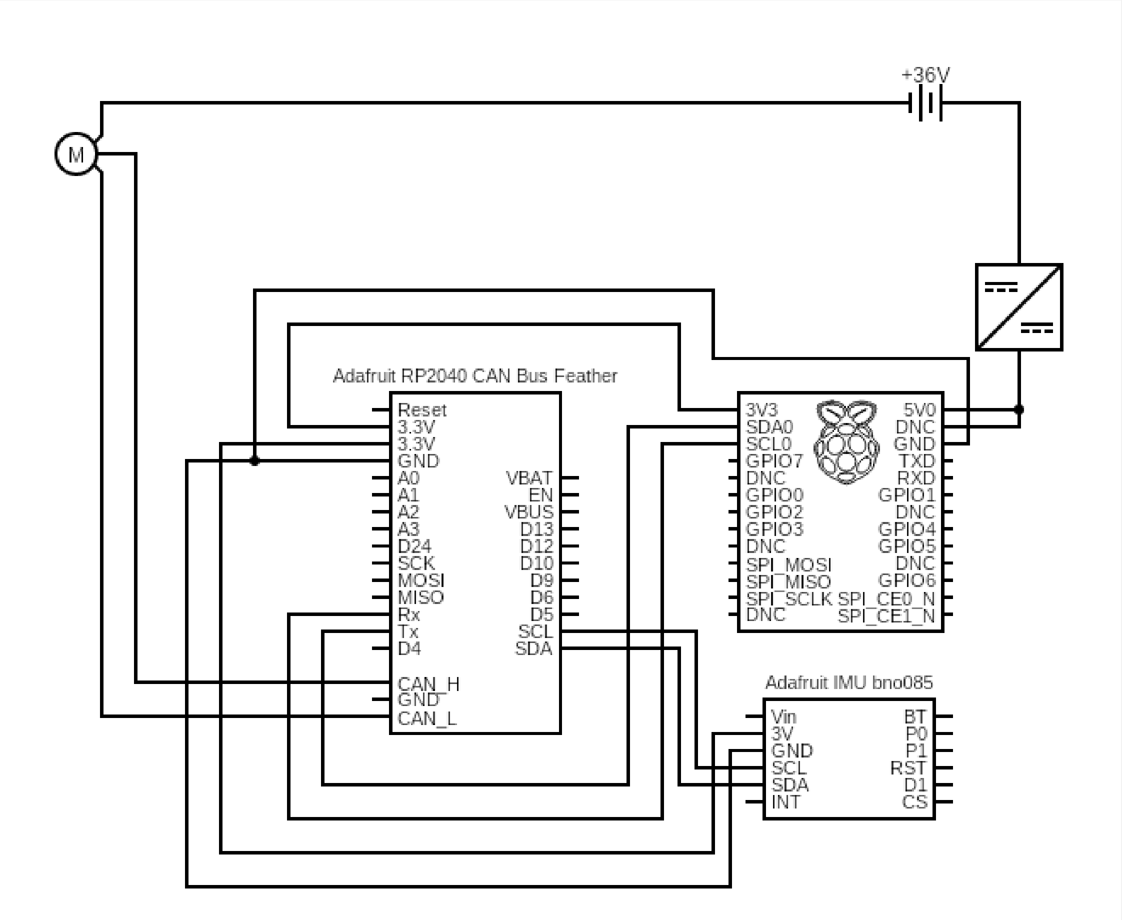
COMMENTS:

TITLE:

SIZE A
DWG. NO. 100build
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

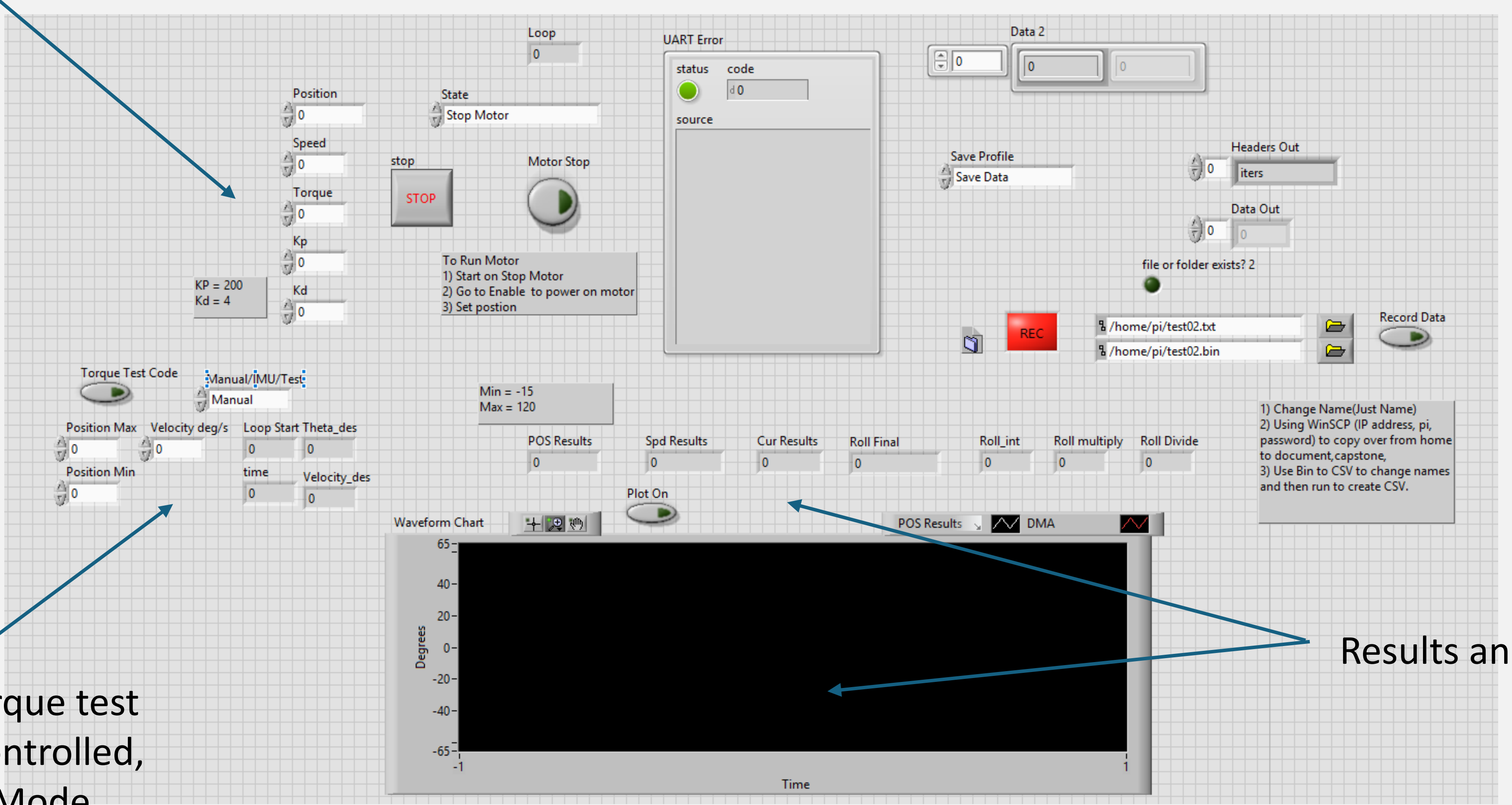
Final Electrical Assembly





Code Outline - Labview

Input variables



Loop 0
Position 0
Speed 0
Torque 0
Kp 0
Kd 0
State Stop Motor

KP = 200
Kd = 4

To Run Motor
1) Start on Stop Motor
2) Go to Enable to power on motor
3) Set postion

UART Error
status
code 0
source

Data 2 0 0 0
Save Profile Save Data
Headers Out 0 iters
Data Out 0 0
file or folder exists? 2
/home/pi/test02.txt
/home/pi/test02.bin

Torque Test Code
Manual/IMU/Test Manual
Position Max 0
Velocity deg/s 0
Loop Start Theta_des 0 0
Position Min 0
time 0
Velocity_des 0

Min = -15
Max = 120

POS Results 0
Spd Results 0
Cur Results 0
Roll Final 0
Roll_int 0
Roll multiply 0
Roll Divide 0

1) Change Name(Just Name)
2) Using WinSCP (IP address, pi, password) to copy over from home to document,capstone,
3) Use Bin to CSV to change names and then run to create CSV.

Results and Graphs

Inputs for torque test code, IMU controlled, and Manual Mode

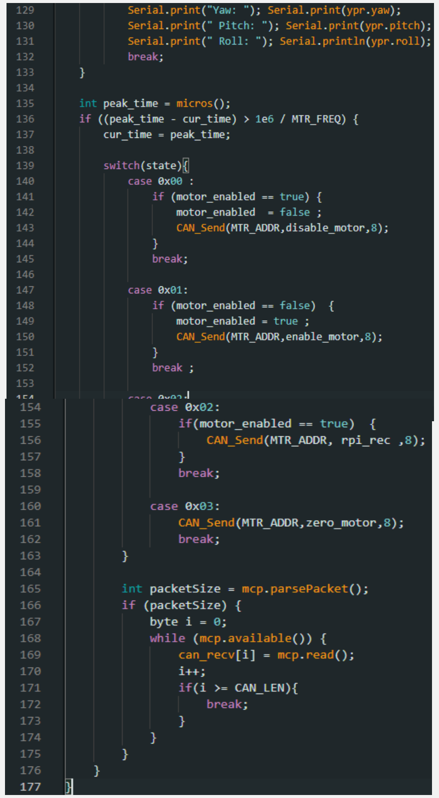
Code Outline – C++

```cpp
// I2C Communication
#include <Wire.h>

// Basic demo for readings from Adafruit BNO08x
#include <Adafruit_BNO08x.h>

// set up IMU
#define BNO08X_RESET -1

struct euler_t {
  float yaw;
  float pitch;
  float roll;
} ypr;

Adafruit_BNO08x  bno08x(BNO08X_RESET);
sh2_SensorValue_t sensorValue;

#define SDA_W1 (D0) //TX
#define SCL_W1 (D1) //RX

#define ADDR_0 (64) //peripheral address
uint8_t state = 0x00;

// CANBUS Communication
#include <Adafruit_MCP2515.h>
#define CS_PIN    (D19)
#define CAN_BAUDRATE (1e6)
#define MTR_ADDR (0x01)
#define MTR_FREQ (100)
#define CAN_LEN (8)

Adafruit_MCP2515 mcp(CS_PIN);

uint8_t rpi_rec[CAN_LEN] = {0x0,0x0,0x0,0x0,0x0,0x0,0x0,0x0};
uint8_t can_recv[CAN_LEN] = {0x0,0x0,0x0,0x0,0x0,0x0,0x0,0x0};

uint8_t enable_motor[CAN_LEN]  = {0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFC};
uint8_t disable_motor[CAN_LEN] = {0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFD};
uint8_t zero_motor[CAN_LEN]    = {0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFE};

uint32_t mtr_cmd = 0x0;

uint cur_time = micros();
bool motor_enabled {false};

char x = 0;

#define i2c_send_LEN 10                // new
uint8_t i2c_send[i2c_send_LEN];         // new
void quaternionToEuler(float qr, float qi, float qj, float qk, euler_t* ypr) {
    float sqr = qr * qr;
    float sqi = qi * qi;
    float sqj = qj * qj;
    float sqk = qk * qk;

    ypr->yaw   = atan2(2.0 * (qi*qj + qk*qr), (sqi - sqj - sqk + sqr));
    ypr->pitch = asin(-2.0 * (qi*qk - qj*qr) / (sqi + sqj + sqk + sqr));
    ypr->roll  = atan2(2.0 * (qj*qk + qi*qr), (-sqi - sqj + sqk + sqr));

    ypr->yaw   *= RAD_TO_DEG;
    ypr->pitch *= RAD_TO_DEG;
    ypr->roll  *= RAD_TO_DEG;
```

Define Variables

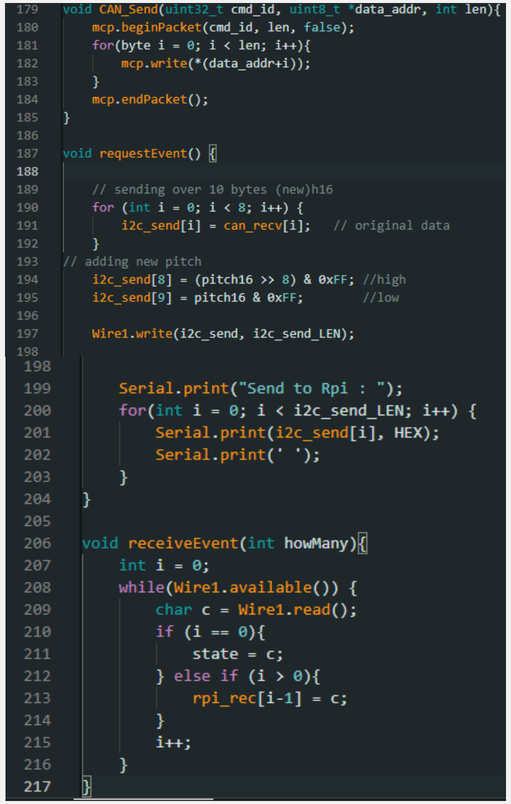
```cpp
void setReports() {
  if (!bno08x.enableReport(SH2_GAME_ROTATION_VECTOR)) {
    Serial.println("Could not enable game rotation vector");
  }
}

void setup() {
    Wire1.setSDA(SDA_W1);
    Wire1.setSCL(SCL_W1);

    Serial.begin(115200);

    Wire1.begin(ADDR_0);
    Wire1.onRequest(requestEvent);
    Wire1.onReceive(receiveEvent);

    if (!mcp.begin(CAN_BAUDRATE)) {
        while(1) delay(10);
    }

    cur_time = micros();

    while (!Serial) delay(10);

    if (!bno08x.begin_I2C(BNO08x_I2CADDR_DEFAULT, &Wire)) {
        while (1) { delay(10); }
void loop() {
    delay(10);

    if (bno08x.wasReset()) {
        setReports();
    }

    if (!bno08x.getSensorEvent(&sensorValue)) {
        return;
    }

    switch (sensorValue.sensorId) {
        case SH2_GAME_ROTATION_VECTOR:
            quaternionToEuler(
                sensorValue.un.gameRotationVector.real,
                sensorValue.un.gameRotationVector.i,
                sensorValue.un.gameRotationVector.j,
                sensorValue.un.gameRotationVector.k,
                &ypr
            );

            // pitch conversion to 16 bit
            pitch16 = (int16_t)((ypr.pitch + 180.0) * (65535.0 / 360.0));


            Serial.print("Yaw: "); Serial.print(ypr.yaw);
```

IMU reading



```cpp
            Serial.print("Yaw: "); Serial.print(ypr.yaw);
            Serial.print(" Pitch: "); Serial.print(ypr.pitch);
            Serial.print(" Roll: "); Serial.println(ypr.roll);
            break;
    }

    int peak_time = micros();
    if ((peak_time - cur_time) > 1e6 / MTR_FREQ) {
        cur_time = peak_time;

        switch(state){
            case 0x00 :
                if (motor_enabled == true) {
                    motor_enabled  = false ;
                    CAN_Send(MTR_ADDR,disable_motor,8);
                }
                break;

            case 0x01:
                if (motor_enabled == false)  {
                    motor_enabled = true ;
                    CAN_Send(MTR_ADDR,enable_motor,8);
                }
                break ;

            case 0x02:
                if(motor_enabled == true)  {
                    CAN_Send(MTR_ADDR, rpi_rec ,8);
                }
                break;

            case 0x03:
                CAN_Send(MTR_ADDR,zero_motor,8);
                break;
        }

        int packetSize = mcp.parsePacket();
        if (packetSize) {
            byte i = 0;
            while (mcp.available()) {
                can_recv[i] = mcp.read();
                i++;
                if(i >= CAN_LEN){
                    break;
                }
            }
        }
    }
}
```

Case Selection



```cpp
void CAN_Send(uint32_t cmd_id, uint8_t *data_addr, int len){
    mcp.beginPacket(cmd_id, len, false);
    for(byte i = 0; i < len; i++){
        mcp.write(*(data_addr+i));
    }
    mcp.endPacket();
}

void requestEvent() {

    // sending over 10 bytes (new)h16
    for (int i = 0; i < 8; i++) {
        i2c_send[i] = can_recv[i];   // original data
    }
// adding new pitch
    i2c_send[8] = (pitch16 >> 8) & 0xFF; //high
    i2c_send[9] = pitch16 & 0xFF;        //low

    Wire1.write(i2c_send, i2c_send_LEN);


    Serial.print("Send to Rpi : ");
    for(int i = 0; i < i2c_send_LEN; i++) {
        Serial.print(i2c_send[i], HEX);
        Serial.print(' ');
    }
}

void receiveEvent(int howMany){
    int i = 0;
    while(Wire1.available()) {
        char c = Wire1.read();
        if (i == 0){
            state = c;
        } else if (i > 0){
            rpi_rec[i-1] = c;
        }
        i++;
    }
}
```

Send Protocol

Testing

Test Experiment Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed
Exp 1 – Device Weight Check	ER2 – Less than 15 lb	Scale
Exp 2 – Attachment Verification	CR5 - Ensure standard attachment above and below	Lamination plate, female pyramid adapter
Exp 3 – Energy Test	CR4 – Battery should last throughout the day ER 7 - Last 1 hour of use	Electrical System Lower leg prosthesis Secure Suspension System
Exp 4 –ROM Test	ER4 - (- 20°) to 135° sagittal ROM	IMU OR Digital inclinometer OR Markers, paper, camera Mounting System
Exp 5 – Static Stand Test	CR1 – Support 90 kg user	Bypass Support or rail for safety Scale Lower leg prosthesis
Exp 6 – Stand to Sit Test	CR7 – Stand to sit	Chair Rail/Support Bypass Position Sensor Camera

Test Experiment Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed
Exp 7 – Sit to Stand Test	CR6 – Sit to stand	Chair Rail/Support Bypass Position Sensor Camera
Exp 8– Motor Torque Performance Check: Constant Velocity	ER5 – Torque of 66.2Nm	Mounting System Weight-tension system Camera
Exp 9 – Motor Cadence Performance Check	ER6 – Cadence of 1.25 steps per second	Mounting System Weight-tension system Camera

Testing Plan

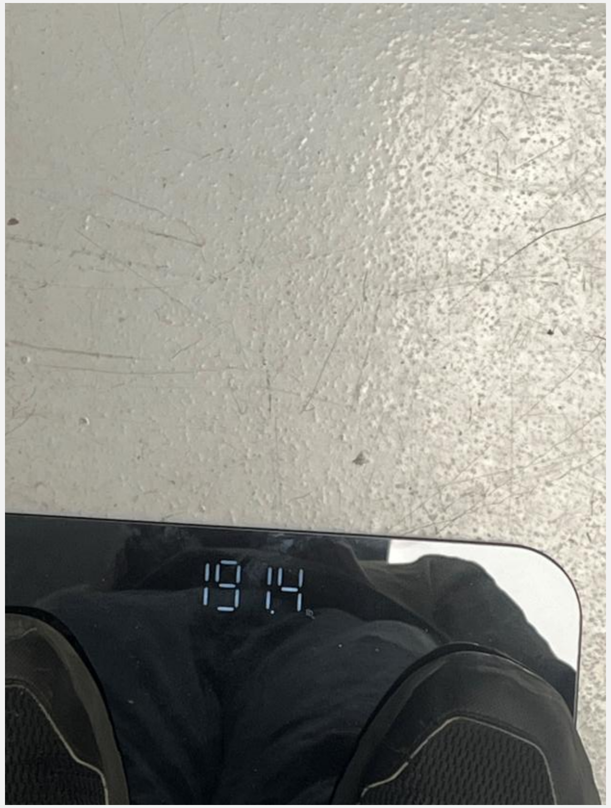
Category	Experiment 1 – Weight Check (ER2)
Goal	Verify device weight < 15 lbs
Method	Measure using calibrated scale
Procedure (Short)	Weigh device, repeat 3×
Results	10.2 lbs
Conclusion	Meets ER2

Experiment 1 Results | Weight

Device Weight Check

(Initial weight = Teammate)
(Final weight = teammate holding prosthesis)

ER2 met!



Initial Weight: 191.4 lbs

Final Weight: 201.6 lbs

Prosthesis 10.2 lbs

Testing Plan

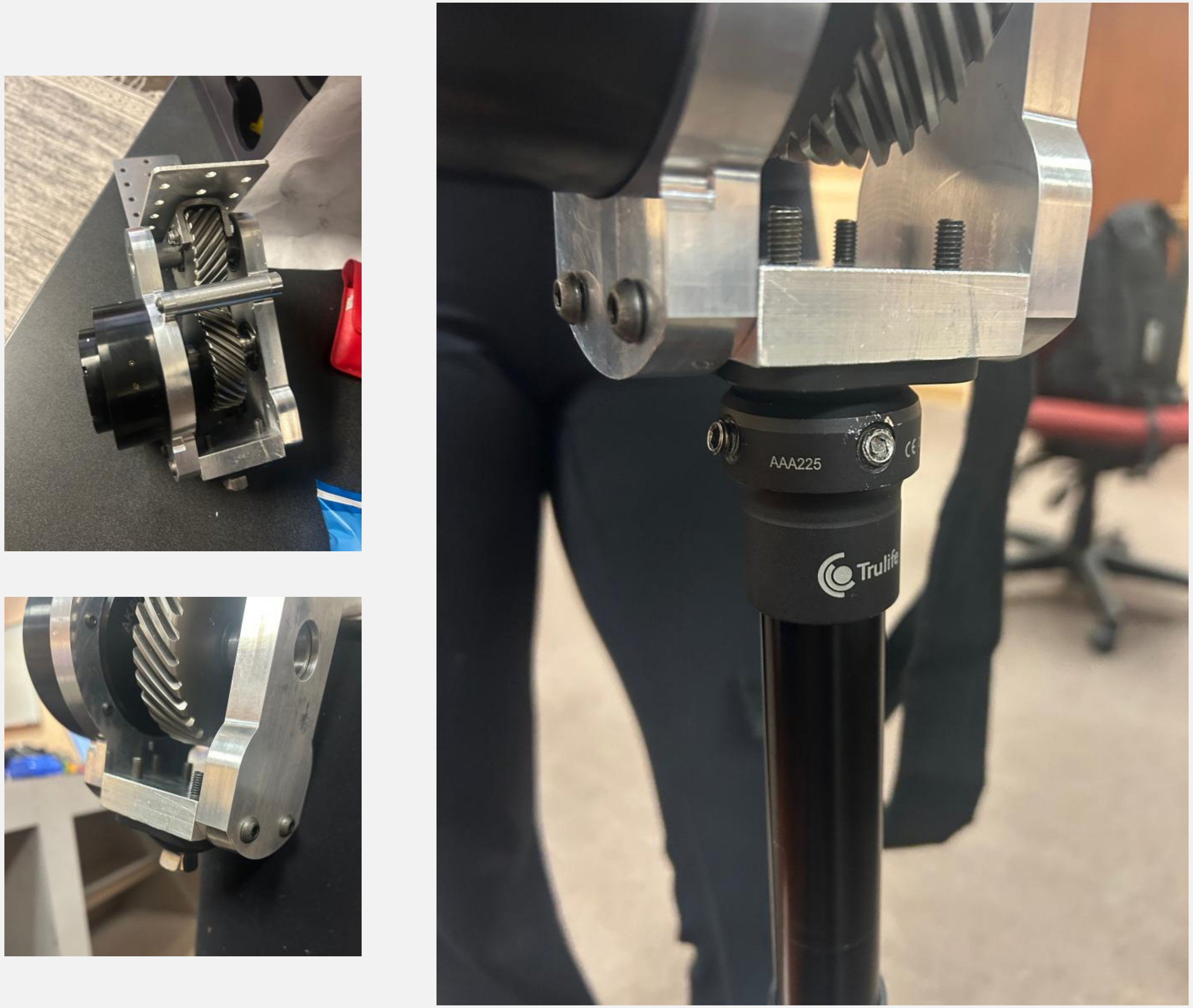
Category	Experiment 2 – Attachment Verification (CR5)
Goal	Verify compatibility with prosthetic components
Method	Attach to lamination plate & pyramid adapter
Procedure (Short)	Assemble components, check alignment
Results	Secure fit, no misalignment. Ease of assembly
Conclusion	Meets CR5

Experiment 2 Results | Attachment

Attachment Proof

Alignment is good, and the device attaches to the female pyramid adapter and the lamination plate

CR5 met!



Testing Plan

Category	Experiment 3 – Energy Usage (ER7, CR4)
Goal	Verify Energy Usage and battery life
Method	Run power intensive activities and measure used power and energy per activity, compare to max battery life
Procedure (Short)	Run sit to stand protocol with propper loading
Result Criteria	28.8 J per stand up. With a 33.8 J upper limit for additional power of electronics
Conclusion	Meets if under 33.8 J

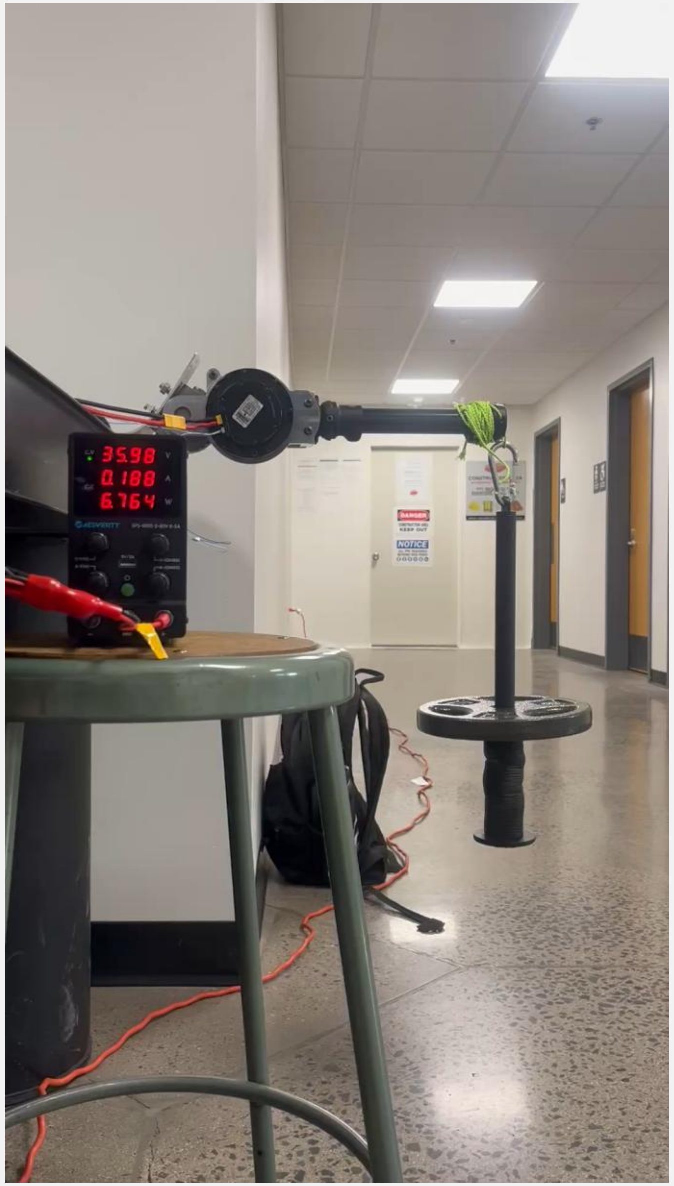
Experiment 3 Results | Power

Each sit-to-stand simulation took 1.433 s

The average Energy used was 33.12 J per sit to stand

Given that our battery has a capacitance of 2.2 Ah and runs at a voltage of 36 V, it carries and energy of 285120 J

If the leg were to run its most energy intensive activity repeating, it would be able to do this for 3.533 hours

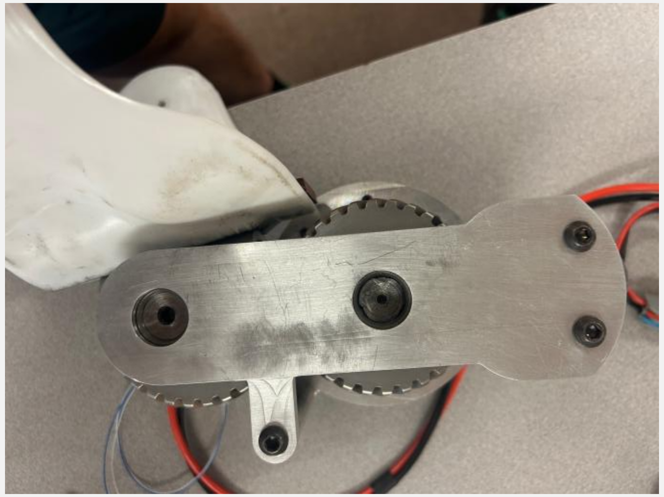


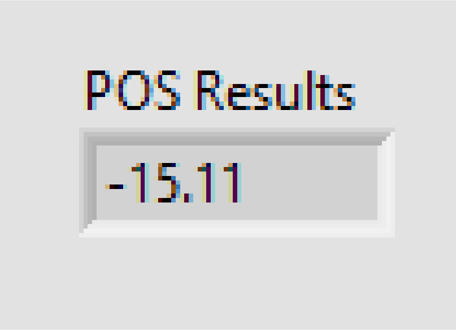
CR4 and **ER7** are met

Testing Plan

Category	Experiment 4 – Range of Motion (ER4)
Goal	Verify ROM from -20° to 135°
Method	Controlled motion testing with IMU
Procedure (Short)	Rotate through full angle range until collision
Result Criteria	–20° to 135°
Conclusion	Meets ER4 if goal met

Experiment 4 Results | Range of Motion



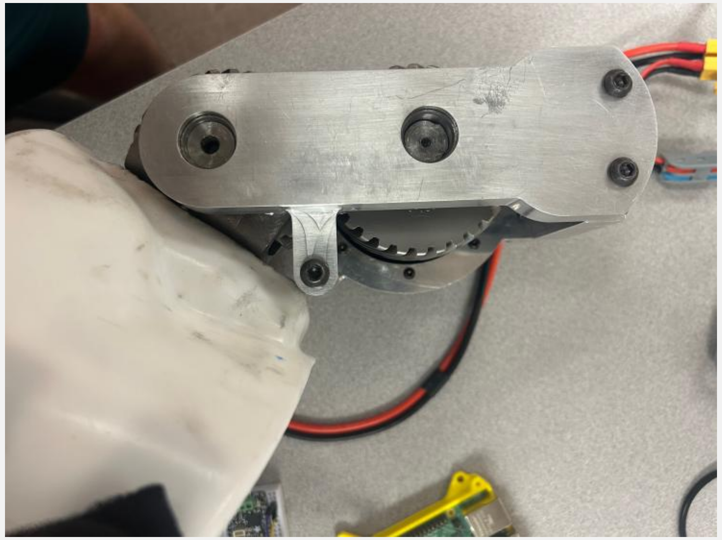


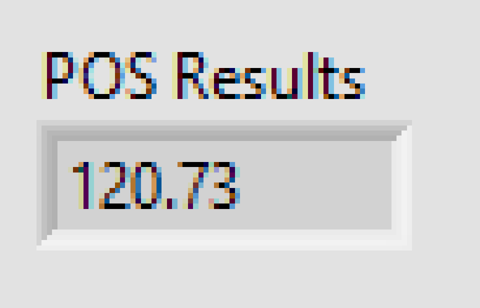
POS Results

-15.11

Maximum range of motion of 135 degrees (Measurements in degrees)

ER4 not met
Will meet with clients





POS Results

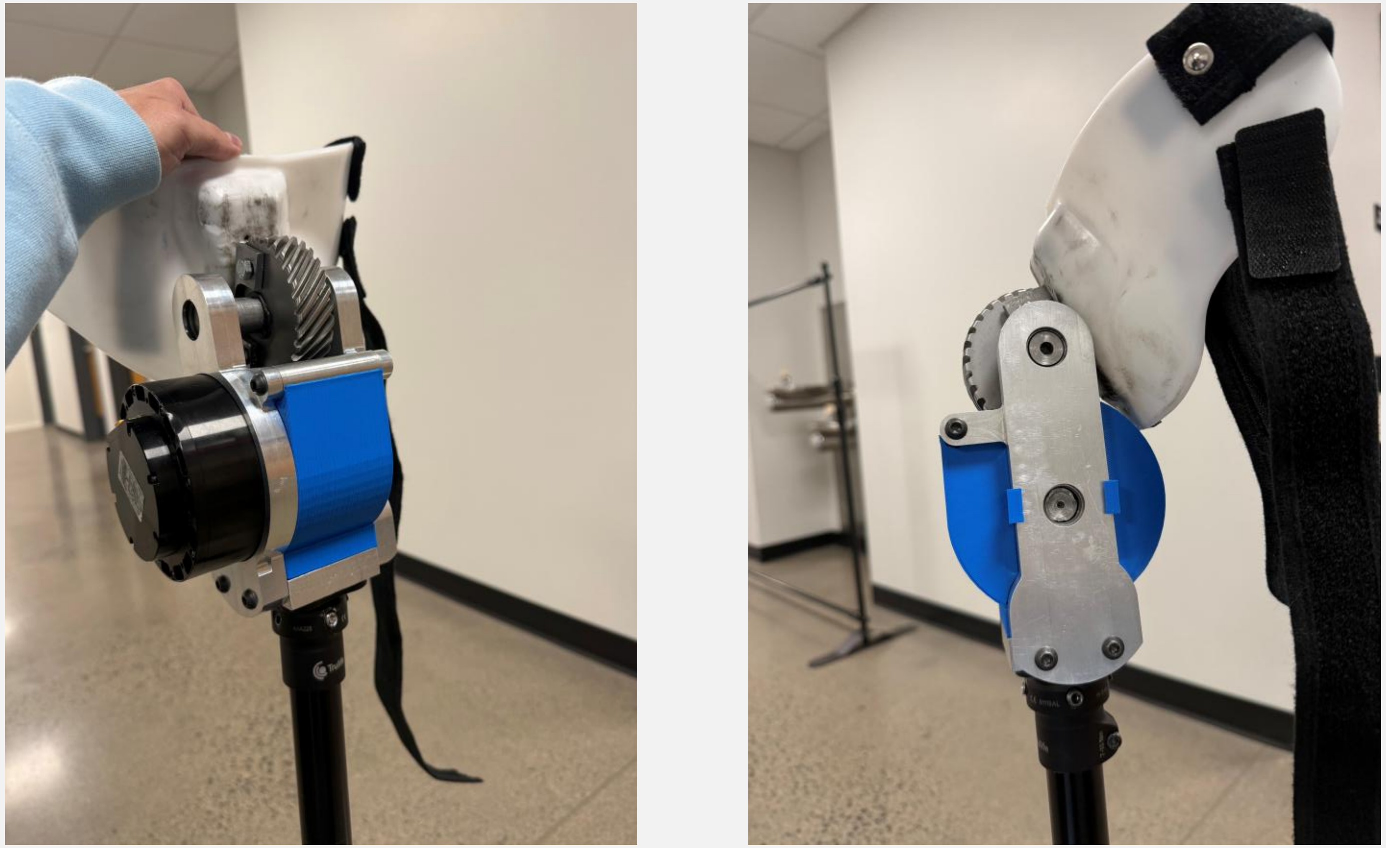
120.73

Testing Plan

Category	Experiment 5 – Static Stand (CR1)
Goal	Support 90 kg user
Method	30s standing tests
Procedure (Short)	Timed standing trials
Result Criteria	Holds weight for 30s
Conclusion	Meets CR1 if criteria met

Testing Setup

Hip restricting bypass



Gear Cover

Experiment 5 Results | Static Stand

Trial 1: Left = 114lbs, Right = 82.4lbs

- 27.7% loading difference

Trial 2: Left = 105lbs, Right = 95.2lbs

- 9.3% loading difference

Up to 106.8lbs !

- -6.8% loading difference

Testing Plan

Category	Experiment 6 – Stand-to-Sit (CR7)
Goal	Controlled sitting motion, impedance control
Method	Motion tracking with position sensors
Procedure (Short)	Perform sit motion, record data
Result Criteria	Smooth, stable descent. Range of motion meets anatomical stand-to-sit (~100° flexion)
Conclusion	Meets CR7 if action is performed

Experiment 6 Results | Stand-to-sit

- Range of motion met and is repeatable
- Testing setup needs further improvement
    - Fixing foot in place
    - Additional upper body support
    - Bypass fixes

Testing Plan

Category	Experiment 7 – Sit-to-Stand (CR6)
Goal	Assist user to stand
Method	Motion tracking with position sensors and a Video Recording
Procedure (Short)	Perform stand motion, repeat trials
Result Criteria	Smooth, repeatable motion. Range of motion meets anatomical sit-to-stand (~100° flexion)
Conclusion	Meets CR6 if action is performed

Experiment 7 Results | Sit-to-Stand

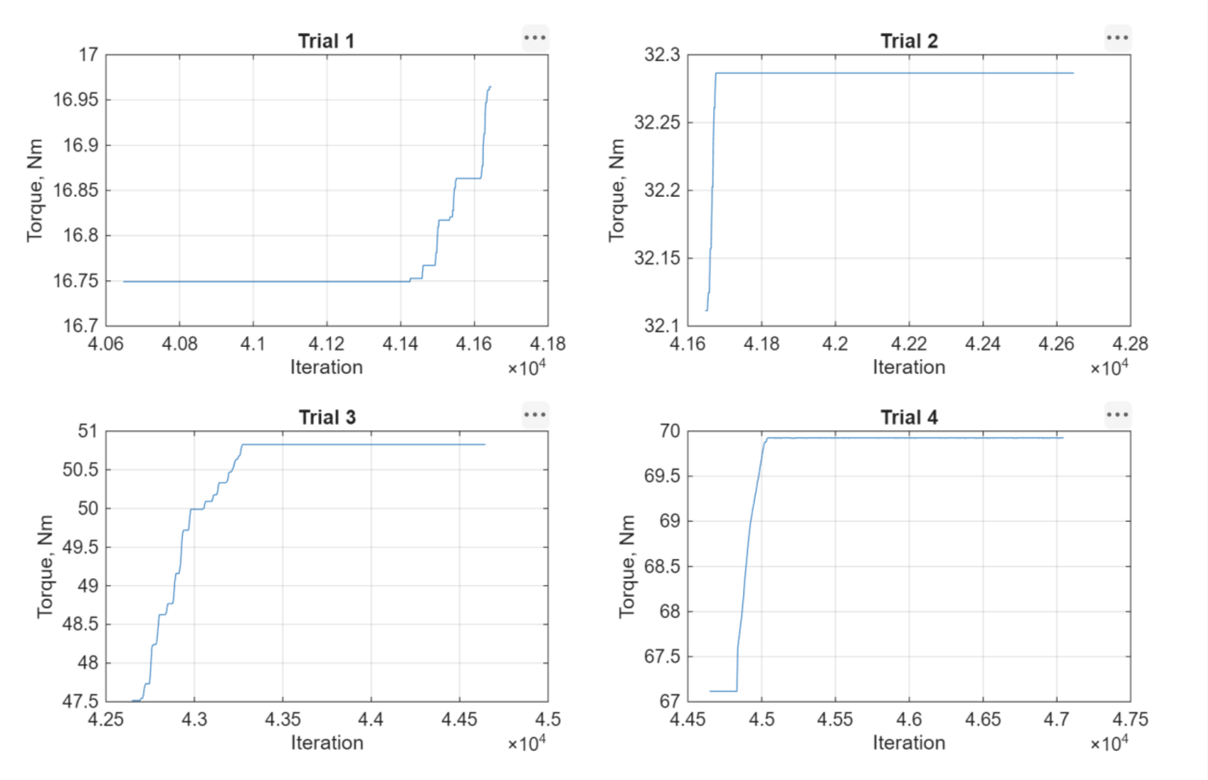
- Range of motion met and is repeatable
- Testing setup needs further improvement
  - Fixing foot in place
  - Additional upper body support
  - Bypass fixes

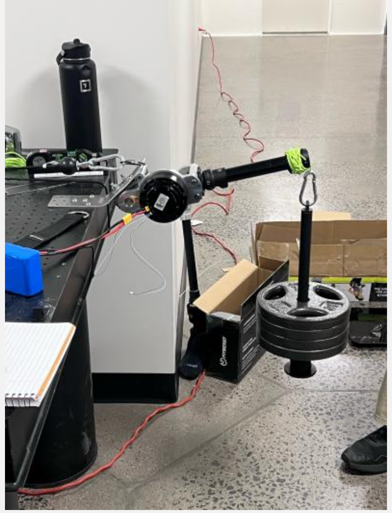
Testing Plan

Category	Experiment 8 – Torque Test (ER5)
Goal	Achieve 66.2 Nm torque
Method	Pulley system with weight moving at constant/ oscillating velocity
Procedure (Short)	Add weight until 66.2Nm reached
Result Criteria	Meets required torque
Conclusion	Meets ER5 if torque produced ≥ 66.2 Nm

Experiment 8 Results

- Device + pylon = 15.2 in
- Determined necessary force = 38.42lbs → 40lbs
  - 10lbs added each trial
- Angle from motor position sensor
- Result: 69.95 Nm
- $T = L * F * \sin(\theta)$



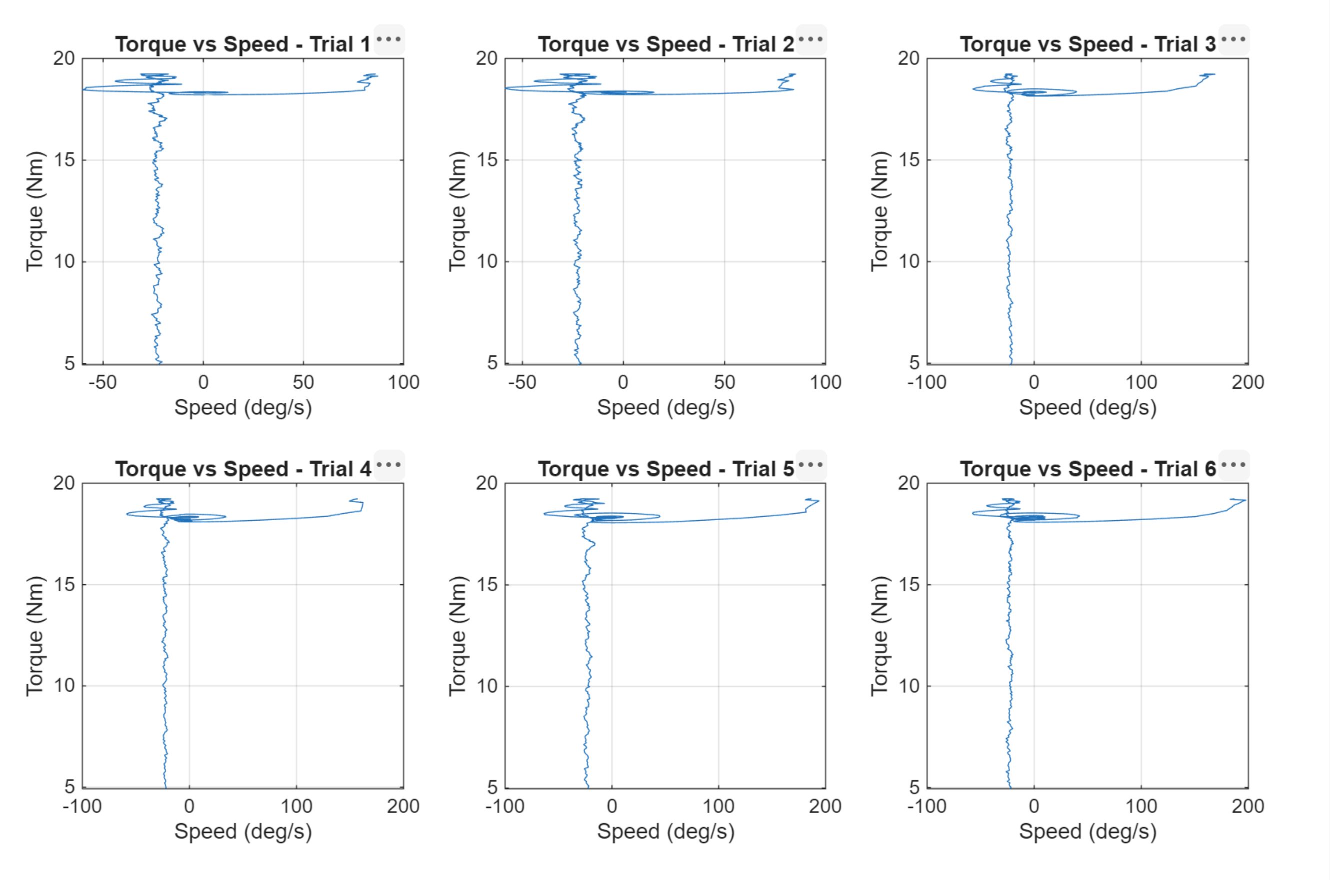


Testing Plan

Category	Experiment 9 – Cadence Test (ER6)
Goal	Maintain 1.25 steps/sec
Method	Measure swing speed under load
Procedure (Short)	Increase weight, track cadence
Result Criteria	Consistent step rate
Conclusion	Meets CR2 and ER6 if cadence is maintained

Experiment 9 Results | Cadence

- Motor speed for trials 1 & 2 = 85 deg/s
- Motor speed for trials 3 & 4 = 172 deg/s
- Motor speed for trials 5 & 6 = 200 deg/s
- Added weight = 10lbs



Final Specification Sheet | Customer

Customer Requirement	CR Met? (Yes/No)	Client Acceptable (Yes/No)
CR 1 - Support 90kg individual	✓	✓
CR 2- Ability to walk	🛇	✓
CR 4 - Efficient battery life	✓	✓
CR 5 - Ensure standard attachment above and below	✓	✓
CR 6 – Sit to Stand	✓	✓
CR 7 – Stand to Sit	✓	✓

Final Specification Sheet | Engineering

Engineering Requirement	Target	Tolerance	Measured/Calculated Values	ER Met (Y/N)	Client Acceptable (Y/N)
ER 1 – Durability of device	Zero structural failure across 18 testing experiments	+5.56% Failure	0	✓	✓
ER 2 – Weight of Device	< 15lb	+2 lbs	10.2	✓	✓
ER 3 - Length of Device	< 14 in	± 1 in	7.1 in	✓	✓
ER 4 – Range of Motion	-20 ° to 135°	± 5°	-15 ° to 120°	🚫	✓
ER 5 – Desired torque of device	66.2 Nm	-2 Nm	69.96 Nm	✓	✓
ER 6 –Cadence	1.25 steps/s	0.5 step	1.25 steps/s	✓	✓
ER 7 – Energy	28.8J	± 5 J	32.12J	✓	✓

Moving Forward

Future work

Mechanical

Environmental Protection & Durability

- Develop weather-resistant enclosures
- Full system dynamic covers

Testing & Validation

Amputee Population Trials | IRB Approved

- Functional wear and comfortability test
- Observe symmetry and fluidity

Electrical & Controls

Closed-loop gait intent recognition

Additional sensors
(EMG, heel force sensors)

Battery & Power Optimization

- Efficient power management
- Extend run time and reduce system weight

THANK YOU!

Questions?