

MECHANICAL HIP PROSTHETIC

Aiden Camisa, Victoria Lyon, Matt
Martinez, Quinn O'Neill

Project Description

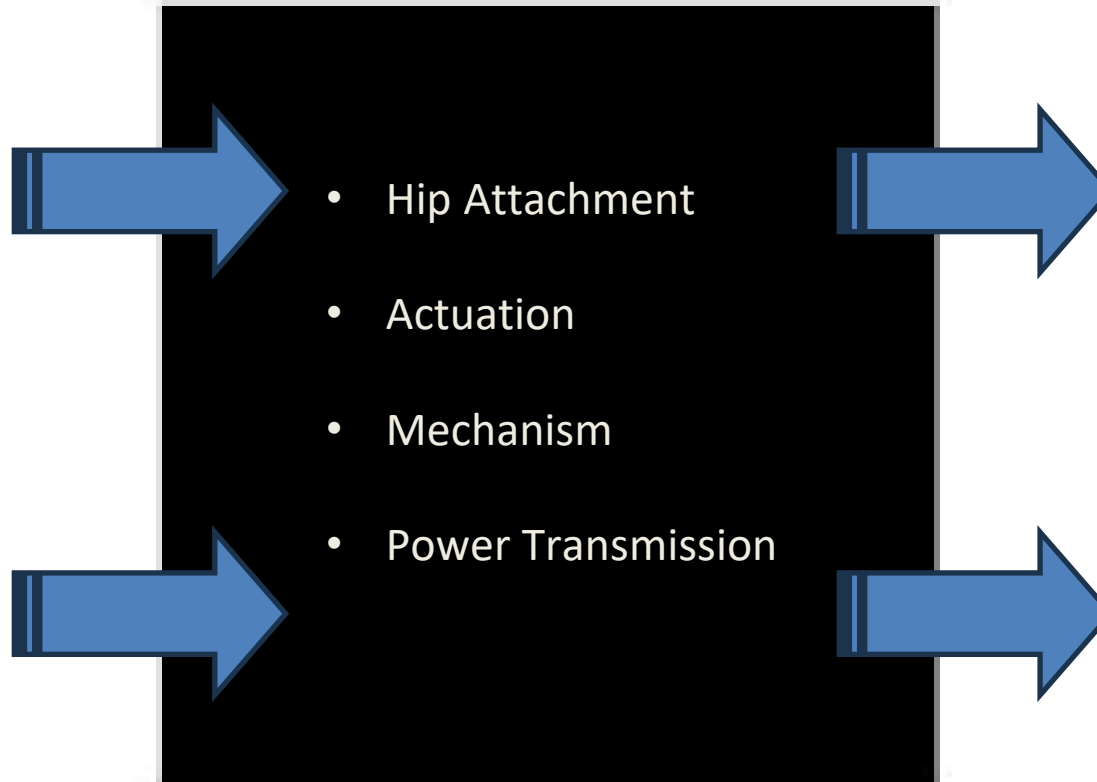
- The scope of the project is to create a mechanically active actuated hip prosthesis for patients that have experienced total hip disarticulation. Ideally, the product will help restore patient lifestyle and ability to a degree higher than the current products available.
- Our team's clients are Dr. Dante Archangeli & Dr. Reza Razavian, MechE Faculty members
- Our team has been sponsored by **NextStep Prosthetics!** Providing us with:
 - Mentorship from the Lead Prosthetist, Mike Kayser
 - Direct patient outreach and insight
 - Access to tools, workbench, and 3D Printers
 - Testing materials [prosthetic knees, ankles/feet, adapters]
 - General access to their facility as a workspace
 - Ping Pong table



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 up stairs.



Outputs

- Standard fittings for Lower leg prosthetics
- Degree of freedom should be about 120 to -30
- Aim for the prosthetic itself to weigh as little as possible.
- Powered system that allows for full better assistance in difficult movements.

Physical Decomposition: Steps and the Parts

Steps

1. We looked at the industry standard, Ottobock design, and our customer requirements for parts
2. For each part, we then defined what it meant in this context.
3. We brainstormed examples of what each part could be or systems that act like these parts.

Helix 3D Ottobock



<p>Actuation: Means of Motion Ex: Linear Actuators</p>	<p>Motor: Supplies mechanical power Ex: Servos</p>	<p>Power Transmission: Movement of Energy Ex: Gears</p>	<p>Battery: Stores energy for system Ex: 12V & 24V</p>	<p>Mechanism: Modifies type of Motion Ex: Joints</p>
<p>Hip Attachment Style: Connects to the waist socket Ex: Standard Ottobock design</p>	<p>Materials Ex: Carbon Fiber</p>	<p>Pylon: Connects the knee to the hip</p>	<p>Knee Adapter: Standard pattern used in all prosthetics</p>	<p>Motor Control: Controls the motor Ex: Raspberry Pie</p>

Concept Generation

Narrowing it Down

- Knee adapter is standardized
- Pylon is simple
- Material is relatively standardized in prosthetics to aluminum
- Battery and Motor can be decided based on the power and torque needed on our final design as they will be externally loaded
- Motor control will be our last step decided on (likely second semester)

What's Left to Decide on

- Actuation
- Power Transmission
- Mechanisms
- Hip Attachment style

Concept Generation

Morphological Chart

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
Suspension / Attachment Configuration	Dual attachment [2 components bolted to socket]	Lateral [side socket attachment]	Singular front bolt [typical use]	Angled alignment [lower corner attachment,

Linear is very straightforward, while variable stiffness can be very complicated
Gears and the electrostatic clutch are non-moving and can be linked more easily. But cable and belt are simpler
The Stewart platform allows for the most control, but is the largest and most complicated
The lateral socket can be very awkward to use, but it has a direct lateral alignment to the hip joint

Engineering Calculations – Static Force Analysis on Attachments

Using a static force analysis on the connector to determine which attachment design provides the strongest structural performance under body weight loading?

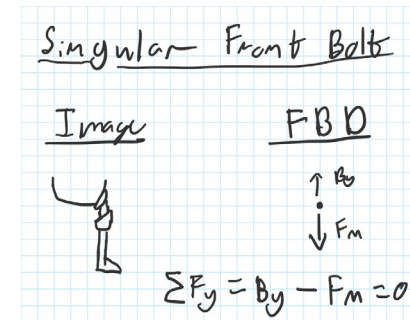
Assumptions

- 90 kg = User Mass
- $g = 9.81 \text{ m/s}^2$
- Standing position of the user.
- Bolt sizing and screws following Ottobock Helix 3D designs.

Equations

- $F = m(g)$
- $M = F \cdot D$ (D = Distance between bolts)
- $F_b = F/n$ (n=number of bolts)
- $\sigma = F_b/(d \cdot t)$ (d = bolt diameter and t = backing plate thickness)
- $\tau = F_b/A$ (A = Area of

Free Body Diagram



The option that I chose is the dual attachment as it has the lowest shear stress in the bolt and lowest moment about them as well.

Type	Force (N)	Moment (N*m)	Force per Bolt (N)	Bearing Stress (MPa)	Shear Stress in the bolt (MPa)
Dual Attachment	882.90	52.974	441.45	13.80	8.78
Laterally Mounted	882.90	70.632	882.90	27.59	17.56
Singular Front Bolt	882.90	88.29	882.90	27.59	17.56
Angled Corner	882.90	105.948	882.90	27.59	17.56

Engineering Calculations – Actuation Static Force Analysis

Using Static force and moment analysis to determine which actuators would allow for a 100 degree range of motion of the Hip

Assumptions

Prosthetic resembles weight of sound leg for a 90 kg person

Greatest max moment required is at highest point of leg lift (100 degrees)

Actuator is .3m away from hip attachment in parallel

	Thigh	Shank	Foot
COM (%)	43	43	42
Mass (kg)	10.01	4.54	1.24
Length (m)	.429	.411	.26

[3]

Formulas and Results

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

$$M = F \times d \qquad F = mg$$

Moment Caused by movement of leg to 100 degrees = 42.854Nm

$$F = M/d$$

Required force of linear actuator = 142.8 N

Decision

Looking online for Hydraulics, Pneumatics, and electronic Linear Actuators that fit the criteria:

Actuated length ~ 200-300mm,
Diameter ~ 40-60mm,
Speed >~ .2 m/s,



[6]



[5]



[7]

All Three types of linear actuator will work reliably.
So, what do we choose?
The Cheapest

Engineering Calculations – Joint & Motor Analysis

- Determine motor and electrical requirements needed to reproduce human hip motion during gait.
- AK80-9 V3.0 KV100 from CubeMars [8]
- Normal adult hip gait data in the sagittal plane [3]

$$\tau_{hip} = -BW \cdot \tau$$

$$t = 1.2 \text{ seconds}$$

$$\omega_{hip} = \frac{d\theta}{dt}$$

$$P_{hip} = \tau_{hip} \cdot \omega_{hip}$$



$$k_t(\text{Torque Constant}) = 0.09 \frac{N \cdot m}{A}$$

$$R(\text{Resistance}) = 0.16 \Omega$$

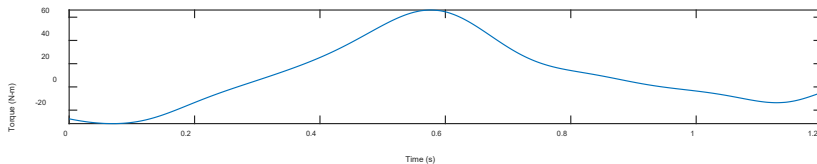
$$J_m(\text{Motor Inertia}) = 5.79 \cdot 10^{-5} \text{ kg} \cdot \text{m}^2$$

$$V_{rated}(\text{Rated Voltage}) = 48V$$

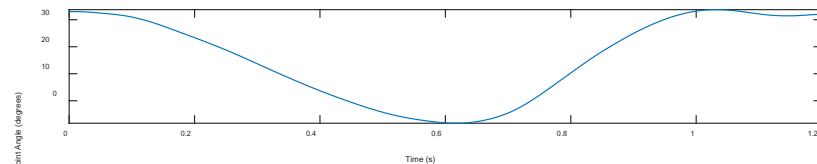
$$\tau_{peak}(\text{Peak Torque}) = 22N \cdot m$$

Hip Joint Kinematics During Gait

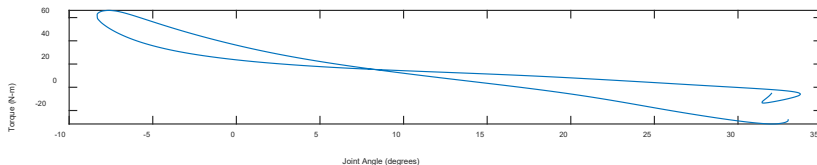
Hip Joint Torque During Gait Cycle



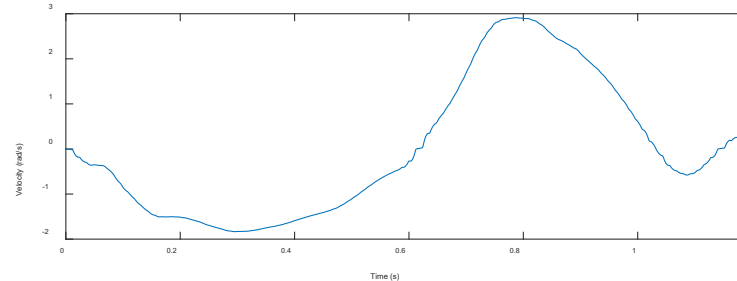
Hip Joint Position During Gait Cycle



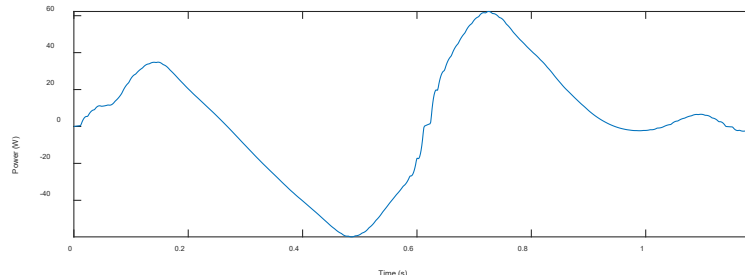
Hip Torque vs Hip Position



Hip Joint Velocity During Gait Cycle

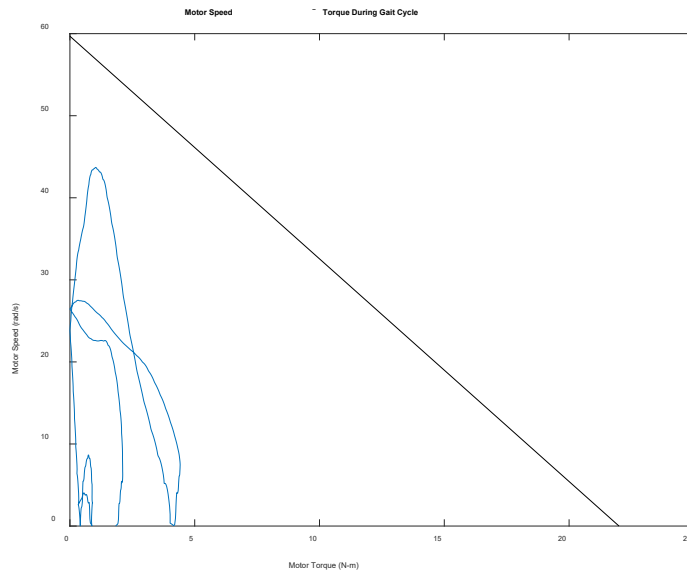


Hip Joint Power During Gait Cycle



Engineering Calculations – Joint & Motor Analysis

- Model Equivalent Motor Behavior
- Gear ratio of 15 for the motor torque to reach the maximum torque in the hip

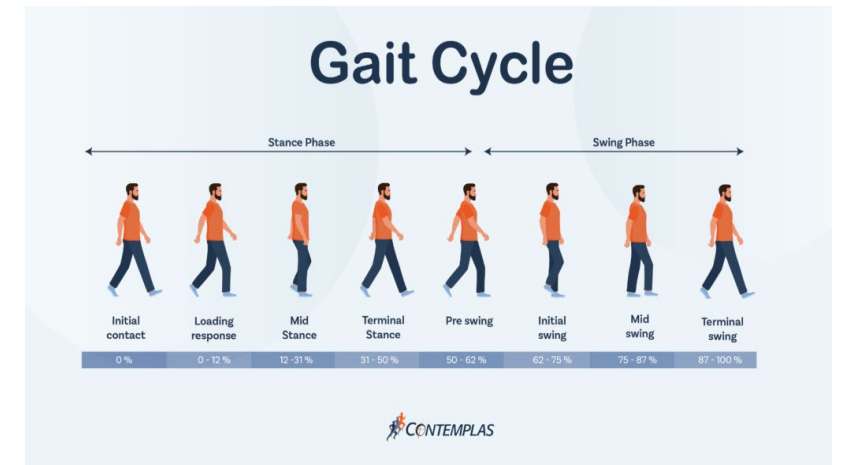
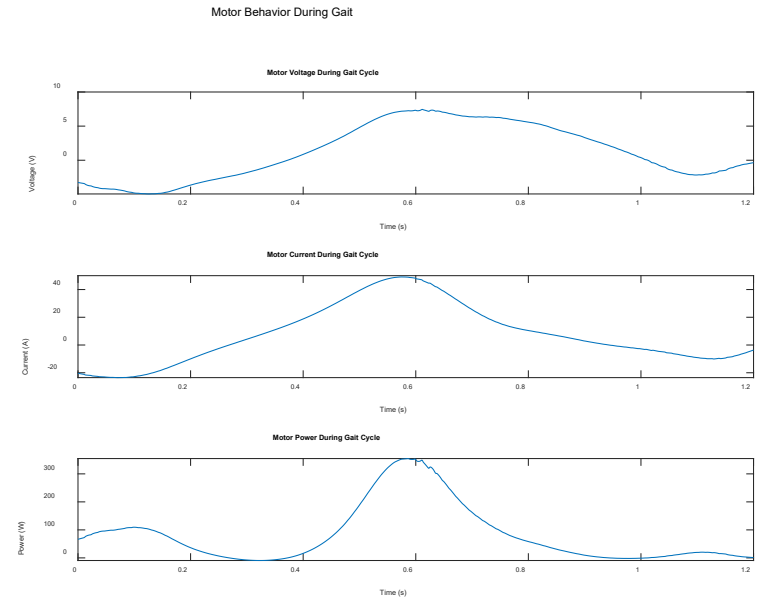


$$I = \frac{\tau_m}{k_t}$$

$$V = IR + k_t \omega_m$$

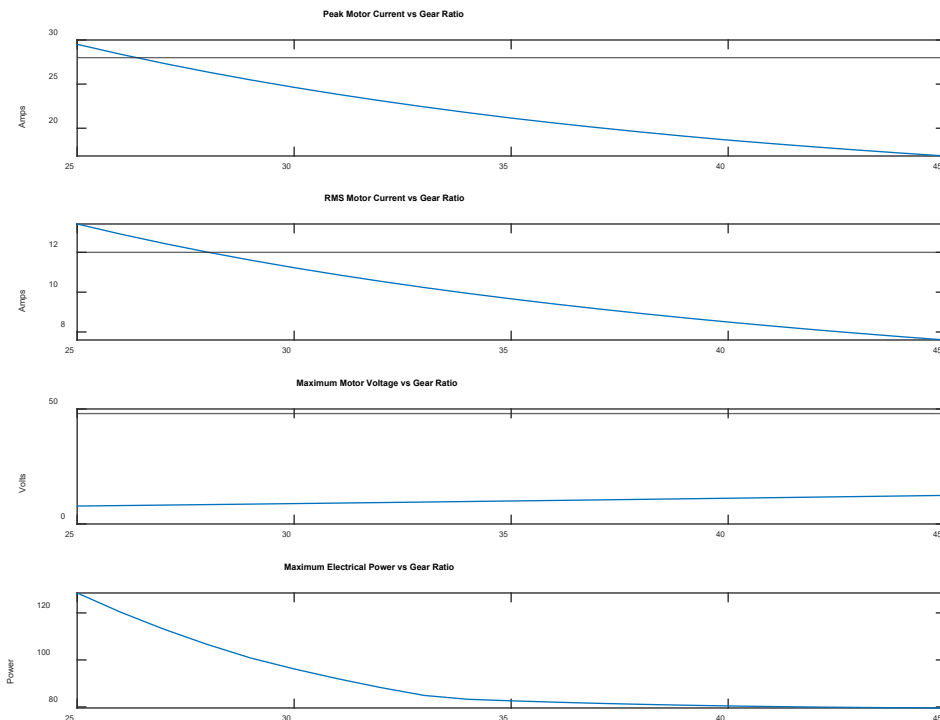
$$P = V \cdot I$$

The curve should stay below the limit for safe operating conditions



Engineering Calculations – Joint & Motor Analysis

- Evaluate gear ratio and system specification feasibility
- The graphs show peak current limit, continuous current limit, and voltage limit
- Gear ratio 25:40



Increasing the GR decreases current demand and raises the voltage

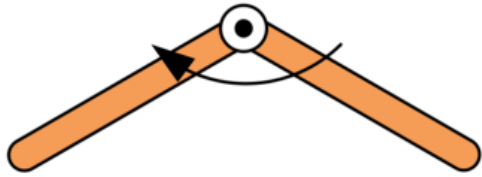
Optimal GR range: 30-35

Motor and gears would be mechanically inefficient and support the use of linear actuators.

Planetary gearbox?

- Complex, bulky, poor backdriveability

Engineering Calculations – Mechanism Analysis



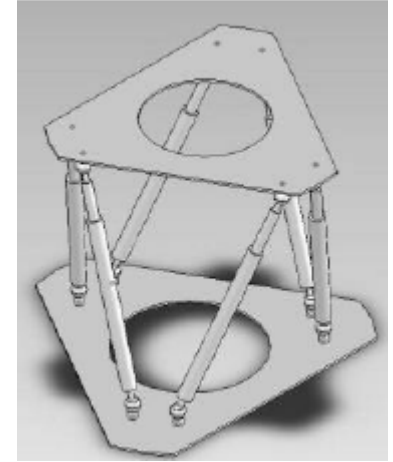
Mechanical Link



Ball Screw



Universal Joint



Stewart Platform

- Building on Motor Analysis- calculating mechanism torques to best support power and electrical requirements

Mechanism	Equation Used
Mechanical Link	$T = F * l$
Ball Screw	$T = (F * l) / 2\pi$
Universal Joint	$T = P / n$
2 DOF Stewart Platform	$T = F * 2 * l$

Where,

$T = \text{Torque}$

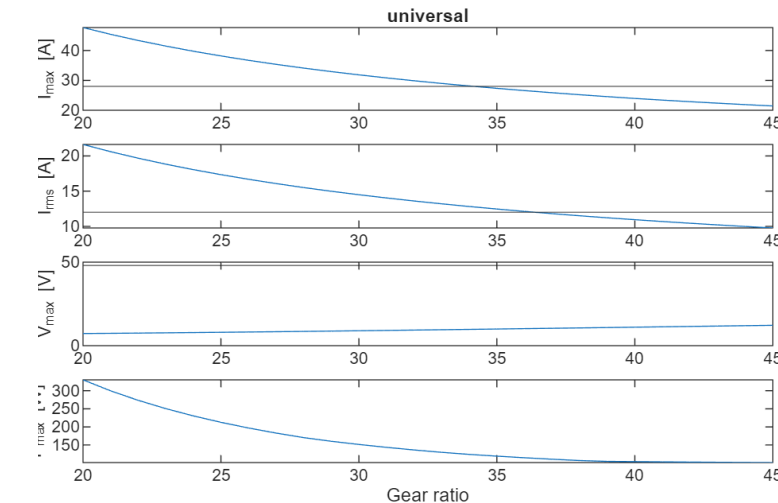
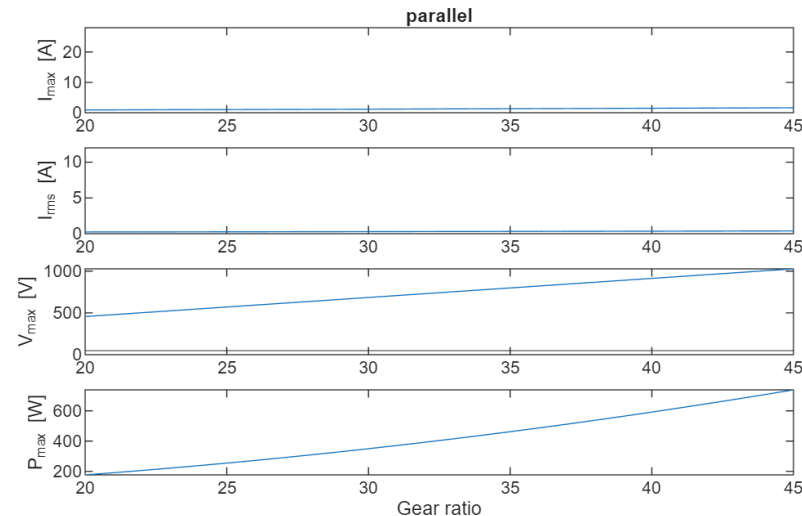
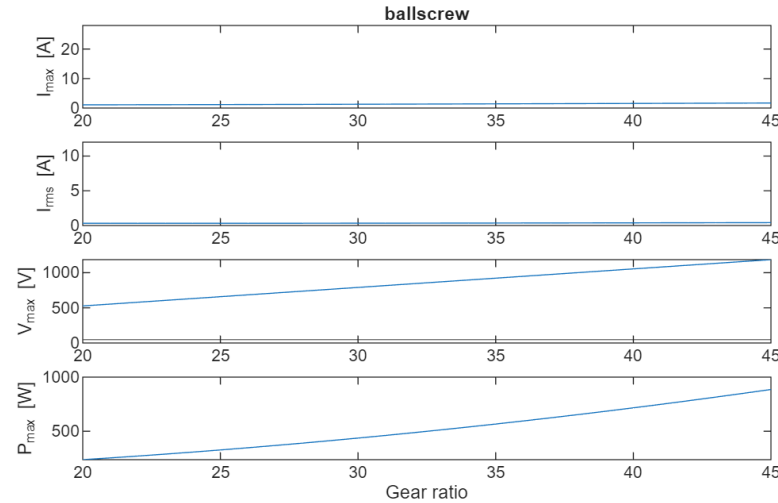
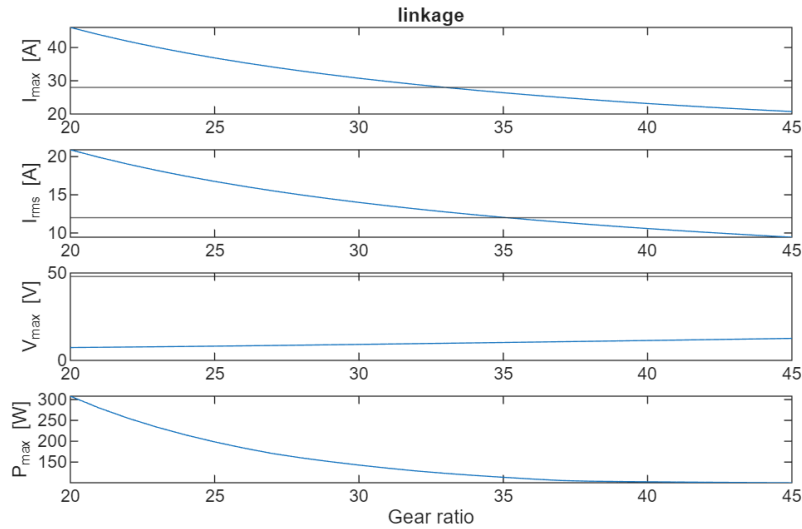
$F = \text{Applied Force}$

$l = \text{length}$

$P = \text{Power}$

$n = \text{speed}$

Engineering Calculations – Mechanism Analysis



- **Mechanical Links & Universal Joint:** Current drops as GR increases, low voltage requirement, higher power with lower GR
- **Ball Screw & Stewart Platform:** Little to no current, but very high voltage increasing with GR, Power increases with GR.

Final Choice: Mechanical Links [Lower GR, simplicity, weight, adaptability]

Concept Evaluations

- Concepts weren't evaluated using conventional charts
- We chose each component we chose based on calculations, industry standards, and talks with professionals, mentors, and patients.

We evaluated means of connection based on what would be the safest and soundest loading for the leg, as well as speaking to people with hip disarticulation prosthetics

Mechanisms were decided based on what best allowed for the most freedom in the rest of our design

Power transmission was determined based on systems we already know the most about and would be the simplest to apply to both our motor and leg

We decided to use a linear actuator after consulting with our mentors, who suggested it as a suitable means to change length and provide an easily understandable axial force output on specific parts of the prosthetic.

Concept Selection

- Linear actuators assist knee lift and leg swing, chosen for controllable axial force and simplicity.
- Motor link assists leg elevation, integrated with mechanical links for structural reliability.
- Gearbox included where moderate torque amplification is needed.
- Dual connectors and mechanical links ensure safe and sound load transfer.

- Design decisions based on calculations, industry standards, and consultations with mentors, professionals, and prosthetic users.
- Chosen mechanisms should maximize design freedom, maintain backdrivability, compliance, and simplify power transmission.
- Linear actuator with mechanical links offers a practical solution while avoiding the complexity of alternative mechanisms such as the universal joint or Stewart platform.

Design Model

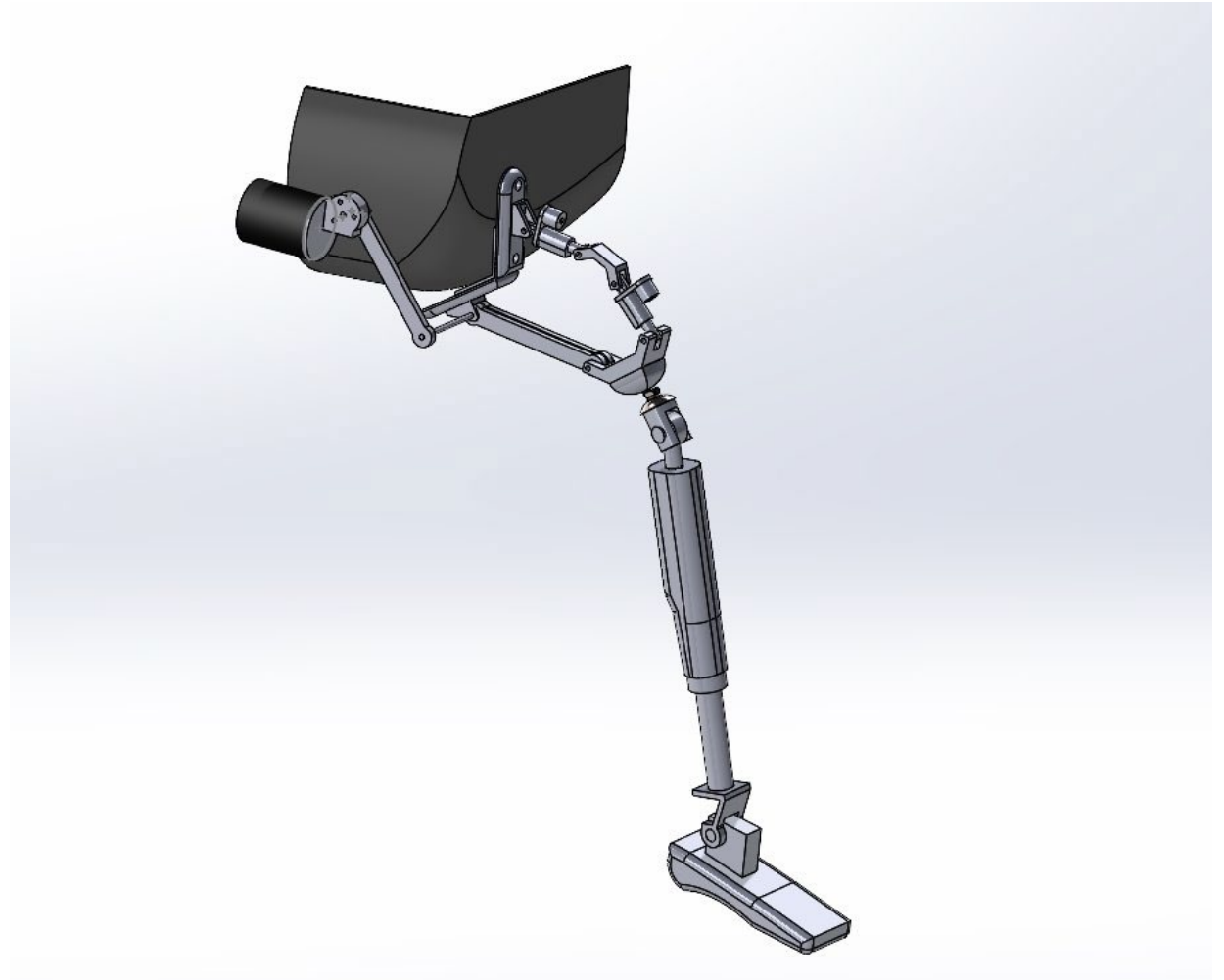
CAD Model – In this Cad we have our tentative design. It has two linear Actuators to help assist with movement to lift the knee. In addition, we have a motor attached to the lower bar to assist in the elevation of the leg.

Sub-Assemblies

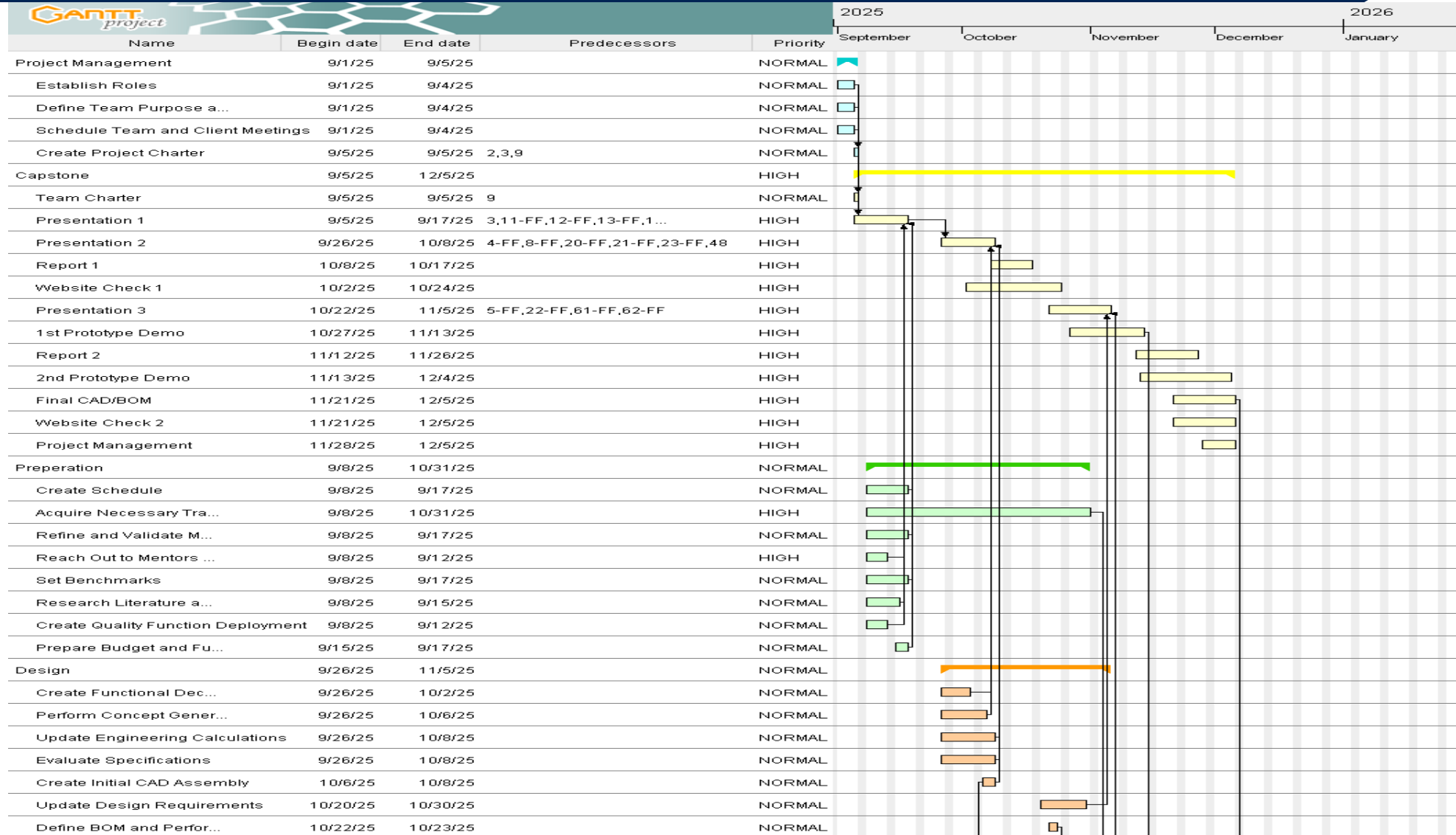
- Upper Linear Actuators
- Motor link
- Standard Lower limb prosthetic
- Gear box

Next Steps in our design

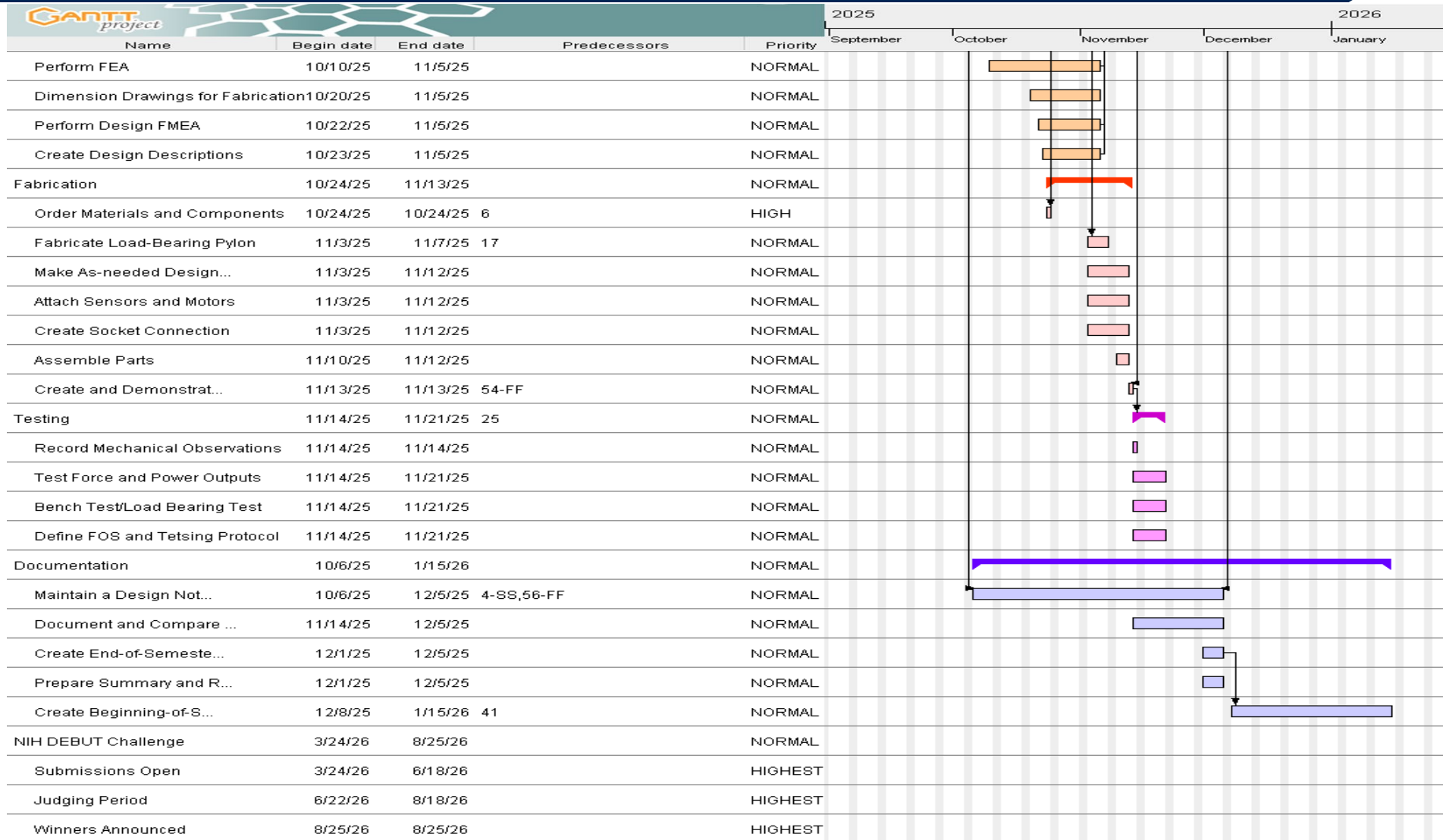
- We plan to continue our design by talking to our clients, users, and our sponsors/mentors. This will get us feedback which will be helpful for our designs.
- In addition, we will be looking to test this design during prototyping to see if it would work or be possible.



Gantt Chart



Gantt Chart



Fundraising & Bill of Materials

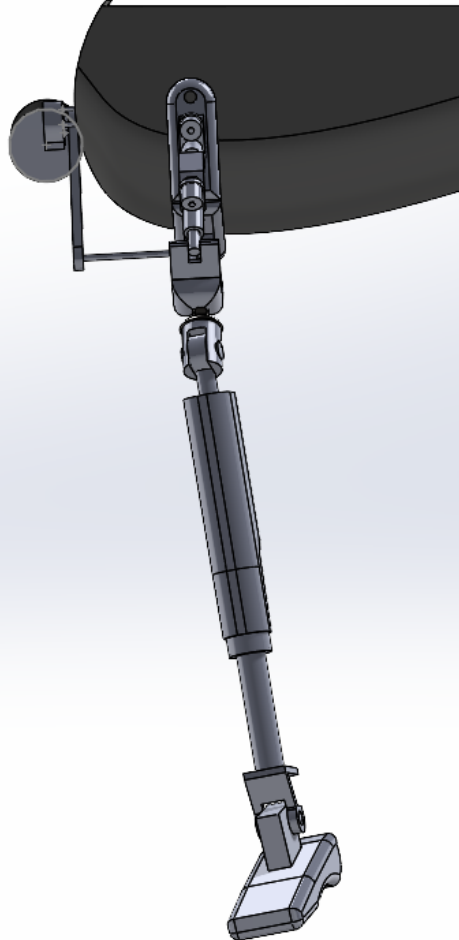
Fundraising:

- NSF I-Corp Aspire Course (+\$3,000)
- NextStep Prosthetics (Testing material, 3D printers, tools/workbench)

Updated Budget:
\$ 7,500

Estimated Costs for Prototype 1:

- DC Motor ~ \$750-1,500
- Electric Linear Actuators ~ \$70-140
- 36V Battery ~ \$85-150
- Bypass system materials ~ \$150
 - Overall Cost ~ \$1,500-2,000



ITEM NO.	PART NUMBER	QTY.
1	socket	1
2	Prostecis_Adaptar_Camlsa	1
3	Upper Static bar	3
4	Liner_Actuator_Base	2
5	Linear_Actuaror_extend	2
6	Elbow Connector	1
7	Attachment base	1
8	Prostetic to Pylon	1
9	Lower Prostetic Adapter	1
10	Part 2	1
11	Rod	1
12	Leg	1
13	Foot ; ; ;	1
14	Ankle	1
15	Ankle shaft	1
16	Part 1	1
17	ARN-025G-DWG-0110-113	1
18	gearbox	1
19	motor	1
20	connectingpin	1

THANK YOU!

Questions?

References

- [1] N. Bong, "Inside an Electric Linear Actuator," *Progressive Automations*, Oct. 26, 2021. <https://www.progressiveautomations.com/blogs/products/inside-an-electric-linear-actuator>
- [2] "DC 12V 24V 80W 50rpm Worm Gear Motor Reversible Electric Geared Motor High Torque Speed Reducing Gearbox Motor," *Made-in-China.com*, 2025. <https://wewinchina.en.made-in-china.com/product/VwgGfbaDuArn/China-DC-12V-24V-80W-50rpm-Worm-Gear-Motor-Reversible-Electric-Geared-Motor-High-Torque-Speed-Reducing-Gearbox-Motor.html> (accessed Oct. 09, 2025).
- [3] G. Bovi, M. Rabuffetti, P. Mazzoleni, and M. Ferrarin, "A multiple-task gait analysis approach: kinematic, kinetic and EMG reference data for healthy young and adult subjects," *Gait & Posture*, vol. 33, no. 1, pp. 6-13, 2011. (jpmer.com)
- [4] ExRx.net, "ExRx.net : Body Segment Data," *Exrx.net*, 2012. <https://exrx.net/Kinesiology/Segments>
- [5] Co., "Electric cylinder 3125...6250 N (Fmax), 0.5...1.0 m/s (vmax)," *Beckhoff Automation*, 2025. [https://www.beckhoff.com/en-en/products/motion/translatory-servomotors/aa3000-electric-cylinder/aa3023.html](https://www.beckhoff.com/en/en/products/motion/translatory-servomotors/aa3000-electric-cylinder/aa3023.html) (accessed Oct. 09, 2025).
- [6] "Mini-hydraulics - HAWE North America," *Hawe.com*, 2025. <https://www.hawe.com/en-us/products/mini-hydraulics/> (accessed Oct. 09, 2025).
- [7] Manufacture Scorpion inc, "Manufacture Scorpion inc.," *Manufacture Scorpion inc.*, 2025. <https://manufacturescorpion.com/en/product/10056726-cyl-iso-6431-dia-100-stroke-250mm-magn-chrom-rod-option-brake-mounting/> (accessed Oct. 09, 2025).
- [8] CubeMars, "AK80-9 V3.0 Robotic Actuator – 9:1 Ratio, 22Nm Peak Torque," CubeMars, [Online]. Available: <https://www.cubemars.com/product/ak80-9-v3-0-robotic-actuator.html>

Other References