Mechanical Hip Prosthetic

Finalized Testing Plan

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HORIZON HIP
EMPOWERING EVERY STEP

Project Sponsor: NextStep Prosthetics
Faculty Advisor & Sponsor Mentor: Dr. Dante Archangeli, Dr. Reza Razavian
Instructor: Professor David Willy

Design Requirements Summary

The design and development of the powered prosthetic hip are guided by a comprehensive set of requirements derived from the needs of hip disarticulation patients seeking to regain an active lifestyle. These Customer Requirements prioritize the creation of a stable leg (CR1) capable of supporting a 90 kg user and providing the functional ability to walk (CR2). To ensure the device is practical for daily life, the design must emphasize easy and comfortable use (CR3). This is a CR that could be tested with additional patients; however, at this time we will be using ourselves to test and to keep the bias out of the results we will wait for patient data. Ensure a efficient battery life (CR4) that lasts throughout the day. Additionally, the system must offer adaptable use (CR5) to ensure compatibility with standard lower leg prosthetics and existing hip sockets. Finally, the device should assist with movement of the user while going from sitting to standing. (CR6) and from standing to sitting (CR7)

These qualitative needs are translated into quantifiable Engineering Requirements that serve as the technical benchmarks for the testing phase. To ensure safety and durability, the device must maintain structural integrity over a minimum of 18 testing cycles/experiments in which the system is powered and load is applied (ER1), which will be assessed across the entirety of testing. Physical constraints include a total weight (ER2) of less than 15 lbs and a system length (ER3) of no more than 14 inches to match natural anatomical proportions. Functional performance is defined by a sagittal range of motion (ER4) spanning -20° to 135°, supported by a motor that must provide 66.2 Nm of torque (ER5), and a walking speed (ER6) of 1.25 step per second. Finally, the power system is designed for a target battery endurance (ER7) of 1 hour under regular usage conditions.

Top Level Testing Summary

Table 1: Test Summary Table

Experiment/Test	Relevant DRs	Testing Equipment Needed	Other Resources
Exp 1 – Device Weight Check	**ER2** – Less than 15 lb	Scale	NextStep Facility
Exp 2 – Attachment Verification	**CR5 -** Ensure standard attachment above and below	Lamination plate, female pyramid adapter	
Exp 3 – Power Usage Test	**CR4** – Battery should last throughout the day **ER 7 -** Last 1 hour of use	Electrical System Lower leg prosthesis	
Exp 4a –ROM Test: Without Lower Leg	**ER4 -** (- 20°) to 135° sagittal ROM	IMU OR Digital inclinometer OR Markers, paper, camera Mounting System	NextStep Facil ity
Exp 4b – ROM Test: With Lower Leg	**ER4 -** 20° to 135° sagittal ROM	IMU OR Digital inclinometer OR Markers, paper, camera Lower leg prosthesis	NextStep Facility

		Mounting System	
Exp 5a – Static Stand Test: With Sound Leg	**CR1** – Support 90 kg user	Bypass Support or rail for safety Scale Lower leg prosthesis	NextStep Facility
Exp 5b – Static Stand Test: Without Sound Leg	**CR1** – Support 90 kg user	Bypass Support or rail for safety Scales Lower leg prosthesis	NextStep Facility
Exp 6a – Stand to Sit Test: With Sound Leg	**CR7** – Stand to sit	Chair Rail/Support Bypass Position Sensor Camera	NextStep Facility
Exp 6b – Stand to Sit Test: Without Sound Leg	**CR7** – Stand to sit	Chair Rail/Support Bypass Position Sensor Camera	NextStep Facility
Exp 7a – Sit to Stand Test: With Sound Leg	**CR6** – Sit to stand	Chair Rail/Support Bypass Position Sensor Camera	NextStep Facility
Exp 7b – Sit to Stand Test: Without Sound Leg	**CR6** – Sit to stand	Chair Rail/Support Bypass Position Sensor Camera	NextStep Facility
Exp 8a – Motor Torque Performance Check: Constant Velocity	**ER5** – Torque of 66.2Nm	Mounting System Weight-tension system Camera	NextStep Facility
Exp 8b – Motor Torque Performance Check: Oscillating Velocity	**ER5** – Torque of 66.2Nm	Mounting System Weight-tension system Camera	NextStep Facility
Exp 9 – Motor Cadence Performance Check	**ER6** – Cadence of 1.25 steps per second	Mounting System Weight-tension system Camera	NextStep Facility

Detailed Testing Plans

Experiment 1 – Device Weight Check

Test Experiment Summary

This test will evaluate whether the total weight of the hip prosthesis meets the requirement for user comfort. The design requirement being tested is **ER2**, which specifies that the device must weigh less than 15 lbs. The test will see if the device meets that limit. A scale will be needed in order to determine the weight of the full hip prosthesis, which means there will be no necessary calculation, only direct measurement.

Procedure

1. Calibrate the scale
2. Place the fully assembled prosthesis on the scale
3. Record measured weight
4. Depending on scale, repeat measurement 3 times to ensure accuracy

Results

- Weight < 15 lbs.

Conclusion

If the measured weight is less than 15 lbs., the device meets **ER2**

Experiment 2 – Attachment Verification

Test Experiment Summary

This test verifies that the prosthesis properly interfaces with the standardized prosthetic components. The requirement tested is **CR5**, which ensures compatibility with the lamination plate and pyramid adapter. A lamination plate and female pyramid adapter are required for fit and alignment verification.

Procedure

1. Attach prosthesis to lamination plate
2. Attach pyramid adapter
3. Check alignment and secure fit

Results

- Secure attachment
- No misalignment or looseness

Conclusion

If all components attach securely, **CR5** is met.

Experiment 3 – Power Usage Test

Test Experiment Summary

To analyze battery life reliability in use, this experiment will ensure that **ER 7** is met, providing a minimum of 1 hour of full continuous use. To perform this experiment, a secure location and suspension of the system are needed, along with a timer—the system will be suspended securely so that it may operate for the desired duration without a user needed to wear the system for the test. This experiment may be done multiple times within one day to further fulfill **CR 4**, so that the power system can last throughout the full operating time of the day.

Procedure

1. Attach prosthesis to secure suspension system
2. Check electronic and power system connections, calibrate if necessary
3. Simultaneously begin motor actuation and timer
4. Monitor the system for 1 hour

Results

- System continuously operates for 1 hour and experiment is replicable

Conclusion

With the group's calculations rating the average power per step of 24W, step time of 1.2s and a battery life of 4.4Ah, it is expected to be able to last for 16 hours. But with limited time and our set requirements, if the system is able to operate for 1 hour continuously multiple times throughout the course of 1 day, then both **ER 7** and **CR 4** are met.

Experiment 4 – ROM Test

Test Experiment Summary

This experiment will be completed by setting the leg to mimic the IMU and the IMU angle to be read. The leg will have to move under the desired ROM on - 20° to 135° sagittal ROM without intersecting with the person that it is attached to. 0° is defined as the leg at a standing straight up position.

Procedure

1. Set up prosthetic to be attached to subject using testing apparatus
2. Set motor into IMU mimic mode
3. Rotate IMU from ranges of - 20° to 135°
4. Record if the leg intersects with the subject at any point that isn't the point of attachment

Results

- Leg rotates from - 20° to 135° freely

Conclusion

If the leg rotates without intersecting patient, it meets **ER4**

Experiment 5 – Static Stand Test

Test Experiment Summary

Within this test we perform experiments to verify the devices' ability to support up to a 90 kg or 198.4 lb individual as seen in **CR1**. This test is done in two different experiments in 5a the individual would look to support their weight by using their sound leg in addition to the prosthesis over a time of 30s and in 5b the individual would attempt to balance on just the prosthesis to have the device hold up their weight also for the 30s. To keep the experiment consistent, we will be having the same individual perform these experiments, we will have them done in the same place, and we will isolate outside factors from disturbing them during the duration

Procedure

1. Clear testing area to remove any dangers or objects that could interfere with experiments.
2. Set up prosthetics to be attached to the subject by use of testing apparatus.
3. Assist individual to starting stance
4. Begin timer as assistant removes support
5. Individuals will stand on either just the prosthetic or with the sound leg according to each experiment.
6. Stopping timer for 30 seconds or when an individual may fall.
7. Record data and repeat for a total of three times.

Results

- Based on calculations, the device will be able to support the individual's weight. For 30 seconds for each leg. The initial force comes from our calculations to be F=mg where we get the force of the 882.9N. We used this calculation through all our design and stress analyses, and this force should easily be withstood in our device.

Conclusion

In conclusion, this experiment will test the ability to support a 90 kg individual. It does this by holding different static positions, one legged or two, for a set amount of time.

Experiment 6 – Stand-to-Sit Test

Test Experiment Summary

These tests evaluate the controlled descent of the user during sitting, both with assistance of the sound leg, and without it. The requirement being tested is **CR7**, in which the device must allow the user to go from standing to a seated position. To conduct this test, some sort of chair or seat, safety rail/support, a bypass, an IMU, and a camera are all needed. The variables to be measured are joint angles and time.

Procedure

1. Equip user with prosthesis and bypass
2. Calibrate sensor to 0 degrees
3. Perform stand-to-sit action with assistance of sound leg
4. Record angle and time data
5. Repeat for 5 trials
6. Repeat steps 3-5 without assistance of sound leg
7. Compare data

Results

- Smooth increase in flexion
- No loss of control
- Consistent motion across trials

Conclusion

If the device provides controlled, stable descent in both conditions without instability, **CR7** is met.

Experiment 7 – Sit-to-Stand Test

Test Experiment Summary

Experiments 7a and 7b will measure the system's ability to assist the user from a sitting position to an upright standing position. Specifically, experiment 7a will test the system with the addition of the sound leg, while experiment 7b will test the system solo without the assistance of the sound leg. With these experiments, **CR 6** will be tested, in which the system must assist the user to a standing position from being seated.

Procedure

1. Equip user with prosthesis and bypass
2. Calibrate sensor to 0 degrees
3. Perform sit-to-stand action with assistance of sound leg
4. Record angle and time data
5. Repeat for 5 trials
6. Repeat steps 3-5 without assistance of sound leg
7. Compare data

Results

- System provides necessary torque
- Completes desired range of motion without loss of control
- Motion is replicable across trials

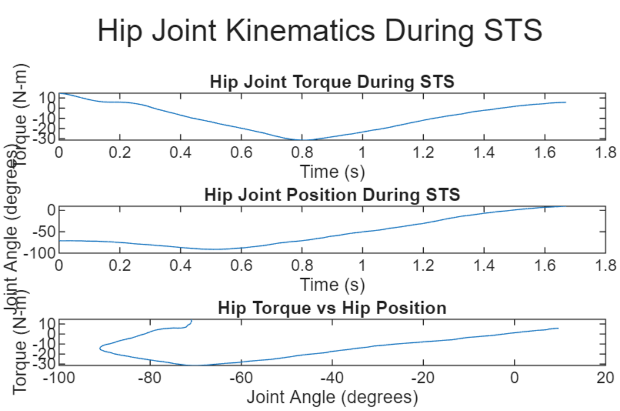


Figure 1: Sit-to-Stand Hip Joint Analysis

Conclusion

Previous analysis above shows that the required hip joint torque to stand from a seated position is

-30 Nm. The system motor is rated at 48 Nm, which will allow for **CR 6** to be fulfilled in this experiment.

Experiment 8 – Motor Torque Performance Check

Test Experiment Summary

In experiments 8a and 8b we will be measuring the torque, found by using max possible velocity of the motor and an oscillating velocity like a traditional gate pattern. Our target torque is 66.2 Nm found within **ER 5**. This will be done by having one end of the device attached and weighing it down to keep it fixed. Then having the velocities set according to the experiment add weight until the device cannot lift the weight. We will perform this experiment by keeping the batteries of the system charged and full for both experiments and all trials. In addition, we will also keep objects that could interfere with the experiment. We will also have the other side of the device in a stable, non-moving fixed position.

Procedure

1. Fix leg to a support and attach to pulley system.
2. Position the leg vertically attached in the sagittal plane
3. Measure and record distance from pivot to attached weight.
4. Starting with zero weight attached to the other end with the leg lowered, slowly increase weight until the leg cannot lift the leg.
5. Keep either max constant velocity (8a) or oscillating velocity following traditional gate speeds (8b).
6. Record the max weight the motor is able to lift.
7. Repeat steps 1-4, for a total of 3 times.
8. Calculate torque from the radius and weight.

Results

- With our results we desire a 66.2 Nm torque which is the max joint torque during the gait cycle.

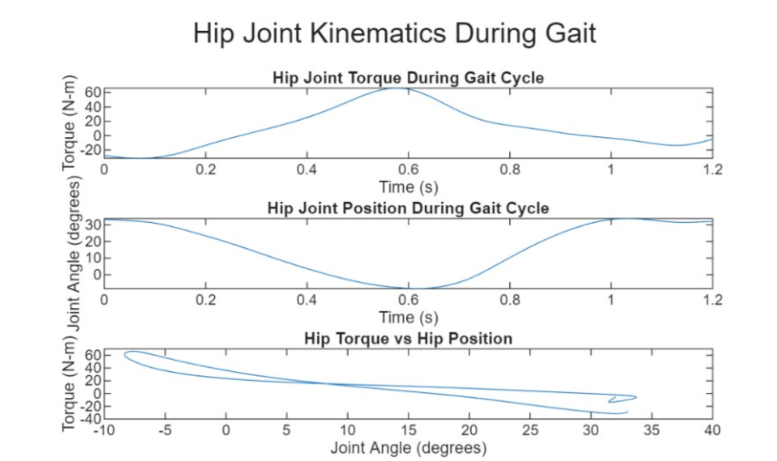


Figure 2: Hip Joint During Gait Analysis

Conclusion

In conclusion, this experiment will measure the torque at the hip joint to make sure it can support and assist individuals. This allows for the 66.2 Nm torque necessary for the device to be helpful.

Experiment 9 – Motor Cadence Performance check

Test Experiment Summary

Within this experiment, we are testing the cadence of the device as it is in use. This is for **ER6** and keeping a cadence of 1.25 steps per second. To do this we have a designated spot that is the cadence spot. We keep a consistent speed as the weight increases to make sure; we can still get the 1.25 steps per second.

Procedure

1. Attach leg to solid structure, such as a bar held down by weight
2. Then position the leg vertically attached in the sagittal plane
3. Measure distances from start to designate 1.25 cadence distance away.
4. Starting with zero weight attached to the other end with the leg lowered, slowly increase weight until the leg does not go
5. Keeping a consistent velocity
6. Record the max weight the motor can lift.
7. Repeat steps 1-4, for a total of 3 times.
8. Calculate torque from the radius and weight.

Results

For these results we found a average step cadence and are using that as a slightly decreased goal.

Conclusion

In conclusion, this experiment will place the device on its side and measure the swing at a consistent speed to make the speed of the device remains constant, despite increasing torque.

Specification Sheet Preparation

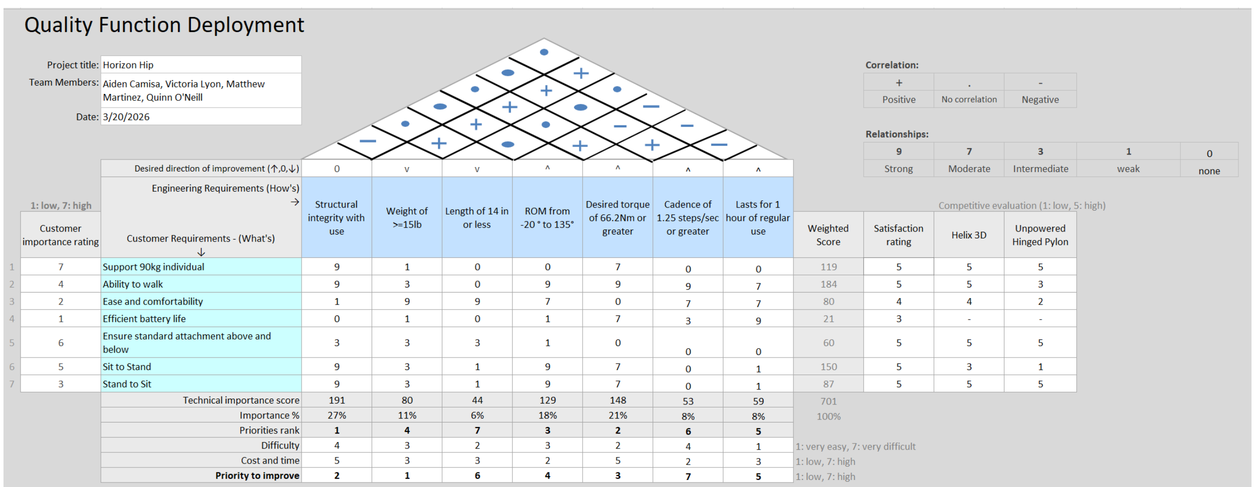
Table 2: CR Summary Table

Customer Requirement	CR Met? (Yes/No)	Client Acceptable (Yes/No)
CR 1 - Support 90kg individual		
CR 2- Ability to walk		
CR 3 - Ease and comfortability		
CR 4 - Efficient battery life		
CR 5 - Ensure standard attachment above and below		
CR 6 – Sit to Stand		
CR 7 – Stand to Sit		

Table 3: ER Summary Table

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	$\pm$ 1 experiment			
ER 2 – Weight of Device	>15lb	$+\ 2\ lbs$			
ER 3-- Length of Device	14 in	$\pm$1 in			
ER 4 – Range of Motion	-20 ° to 135°	$\pm$5°			
ER 5 – Desired torque of device	66.2 Nm	$-2\ Nm$			
ER 6 –Cadence	1.25 steps/s	$\pm$0.50 step			
ER 7 – Last for regular use	1 Hour	$-\ 5\ minutes$			

QFD


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

	Customer importance rating (1: low, 7: high)	Customer Requirements - (What's) ↓ / Engineering Requirements (How'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
		Desired direction of improvement (↑,0,↓)	0	v	v	^	^	^	^		Competitive evaluation (1: low, 5: high)		
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			

Figure 3: Quality Function Deployment

The Quality Function Deployment establishes a direct relationship between the Engineering Requirements and Customer Requirements, in which satisfied ERs results in satisfied CRs. This can be seen throughout the proposed testing plan, such as the device weight test, Exp 1, which evaluates **ER2** (system weight less than 15 lb), is intended to support **CR3** (ease and comfortability), reflecting the strong relationship between weight and user comfort identified in the QFD. In contrast, some experiments are designed to directly satisfy customer requirements without relying on ERs. The attachment verification test, Exp 2, directly addresses **CR5** (standard attachment above and below), ensuring compatibility with existing prosthetic systems. Other experiments primarily validate ERs that are strongly tied to customer needs; for example, the range of motion tests (Exp 4a and 4b), targeting ER4 (−20° to 135° sagittal motion), support **CR2** (ability to walk) and transition-based CRs, while motor torque tests (Exp 8a and 8b), verifying **ER5** (66.2 Nm torque), support both **CR1** (load-bearing capability) and **CR2** (walking ability). Similarly, the structural tests (Exp 5a and 5b) directly validate **CR1** (support of a 90 kg user), while also relating to **ER1** (structural integrity) and **ER5** (torque capacity). The power usage test (Exp 3), which evaluates **ER7** (minimum 1 hour of operation), supports **CR4** (battery life) and contributes to overall usability, while the motor performance test (Exp 9), targeting **ER6** (cadence of 1.25 steps per second), supports **CR2** by ensuring a realistic walking speed.

Overall, the testing plan reflects a combination of direct CR validation and ER-based validation, consistent with the QFD structure. This ensures that customer needs are addressed both explicitly through targeted tests and implicitly through the successful achievement of the engineering requirements.