Below-the-Knee Exoskeleton

Project Management

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NORTHERN ARIZONA UNIVERSITY

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DISCLAIMER

EXECUTIVE SUMMARY

For our team's capstone project, we are tasked to improve upon a previous capstone design for an Ankle Exoskeleton through our client Dr. Lerner. Dr. Lerner's previous capstone team had built a working Ankle Exoskeleton that consists of a mechanical boot that consists of a boot-like frame that houses a motor and gearbox which provides leverage to the ankle joint. The motor located on the frame of the ankle draws power through wires running up the user's leg connected to a battery pack and microcontroller situated on a belt located on the waste of the user.

Our task as a team is to take all the components of the previous design and situate them all below the knee of the user. On top of making the design below the knee, we will be upgrading the motor, microcontroller, and battery. To fit all of these components below the knee we will need to work through a couple of different steps. First, we need to redesign the frame of the boot. Doing this will give us more space to work in the battery and microcontroller below the knee. Some constraints we need to consider when making this design are; to not limit the range of motion, a universal design that fits all users, and lightweight to not fatigue the user. Second, our design needs to have ingress protection for our electrical components. Our electrical components need to be resistant to dust and water to ensure it accrues no damage while the user is operating the Exoskeleton. Some constraints that we need to consider while implementing ingress protection are not limiting the range of motion and a lightweight design. Our last step in our implementation is thermal and stress testing our design under strain. As the Exoskeleton is in use, the motor, microcontroller, and battery will heat up which might be uncomfortable for the user if we don't properly insulate each electrical part. To do this we have to find out how hot each component gets and then properly insulate each part to not reduce the effectiveness of the exoskeleton.

The entirety of our design contributions will include a new frame that will be harnessed to the user, a protective covering for the electrical components, and overall, a different configuration to the components on the frame.

What we have done in our project so far has surrounded the analysis of the new parts we need and the design of the frame to take these new parts. Based on what we analyzed from the last project, our new motor will be a Maxon ECX flat 32L with a 35:1 gear ratio. This new motor will give our Exoskeleton more stable torque. Based on our new constraints, the battery we will use will be a Cell E-Flite which will provide enough power to run our new motor. Our new design for the frame includes paneling behind the calve muscle that can house the battery and microcontroller. CAD models for our new design can be found further down within this report.

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1 Reflection

1.1 Project Management - Successes

- Delegation of tasks – The team worked well with separating the work on projects into smaller more manageable sections. For example, for a report or a presentation submission, the team separated the work evenly amongst each team member and for the most part completed said section. If we were cutting it close on time, team members were flexible on picking up sections that were taking longer than expected or needing work.
- Communication – The team was constantly in communication on tasks to be completed and research to be added. As we completed aspects of the project, such as a new CAD model or a new article that pertains to the model, the team members ensured the rest of the team was up to date.
- Fundraising on purchasing products – During the course of the first semester, we were able to fundraise over half of our delegated amount of $400. We were also prompt with the purchasing of the necessary parts for future design and building. We currently have all of the parts necessary to complete the final build and are only awaiting their delivery.

1.2 Project Management – Room for Improvement and Action Items

- Time management – The team occasionally completed assignments for the class at the last minute. While we were consistent in keeping on schedule, it was occasionally too close for comfort. This can especially be seen in the creation of our prototypes. We occasionally waited to print our parts until the weekend before submission, which often left pieces missing, or involved us having to get creative with the submission. To counteract this, we plan on starting projects at least a week before. When it comes to prototype submissions, we plan to print parts as the design is completed, so we can always remain up to date on what works and what needs to be reprinted or redesigned.
- Communication with the client – When it comes to communication with the client, the team maintained general communication as issues arise, but there is room for improvement in the way we work with the client to ensure our product is up to standard. This was specifically with the budget and the determination of what parts were available to us already and what had to be purchased. For example, we were shown the motor for our project in the initial weeks and had a miscommunication with our client and were unaware we needed to purchase our own until a few weeks later. We also were under the impression that we could test our models on existing designs in the lab but had to alter our plan to print the main structure before working on the prints for our specific parts. To counteract this, we plan to be more specific in our communications in the future and confirm what we are unsure of before too much time passes, so if there is a miscommunication, we can correct it.

1.3 Remaining Design Efforts

- Thermal protection - The team still needs to analyze ways to minimize overheating in the design. The current motor housing design, for example, prioritizes protection but will be prone to overheating. The design will need to fit both design requirements before it can be manufactured.
- Design for manufacturing – Several of the new features must be machined to fit the required design, and because of the required strength, will need to be metal. The parts should be assessed and redesigned while considering material cost, as well as the ability to machine the designs using the available resources.
- Ingress design – a form of improvement on our current design is to balance out our ingress design with our thermal protection. The idea is that we strike a balance between making each electrical component unable to be affected by water and dust while still making it so that the part can breathe.
- Compact design – creating the part so that the final design is not cumbersome where it would defeat the purpose of making it easier to walk for the user.

2 Gantt Chart

Figure 1 shows the major milestones for the second semester. Among those, the biggest milestones include the hardware status updates that confirm that we are on track to have a final product complete by the end of the semester. We have three checks, one in February, March, and April. The milestones that are essential to accomplish the hardware check are as follows:

- Engineering Model – Allows the team to analyze and improve upon the product using mathematical statements.
- Hardware Status Check – Analyze the progress of the team towards the final product.
- CAD Check – Ensure that the designs of the team can work in both the prototype and real-world scenarios.
- CAD Simulations and Testing – Test that the final design can hold up to the customer's requirements.
- Website Check – Keep up to date with maintaining accurate progress on reports, designs, and presentations.
- Final Testing – Ensure the product meets all customer and engineering requirements.

3	**Major Deadlines 2nd Semester**					
WBS Number	Task Title	Task Owner	Start Date	End Date	Duration	% Done
3.1	Engineering Model	Team	1/13/25	1/23/25	10	0%
3.2	Test 2nd Prototype	Alex S	12/13/24	1/20/25	37	10%
3.3	Analysis of 2nd Prototype	Alex S	1/13/25	2/1/25	18	0%
3.4	Hardware Status Check 1	Team	1/13/25	2/13/25	30	0%
3.5	Order all parts	Ryan O	1/13/25	2/13/25	30	0%
3.6	Website check	Nick W	1/13/25	2/27/25	44	0%
3.7	Testing Plan	Ryan O	3/1/25	3/27/25	26	0%
3.8	Hardware Status Check 2	Team	2/13/25	3/6/25	23	0%
3.9	Final CAD	Ryan O	3/6/25	4/3/25	27	0%
4	Final Hardware Status and Prototype	Team	3/6/25	4/3/25	27	0%
4.1	Website check	Nick W	2/28/25	4/17/25	47	0%
4.2	Test and Analyze Protype	Alex S	4/3/25	4/17/25	14	0%
4.3	Final Report	Team	4/1/25	4/17/25	16	0%

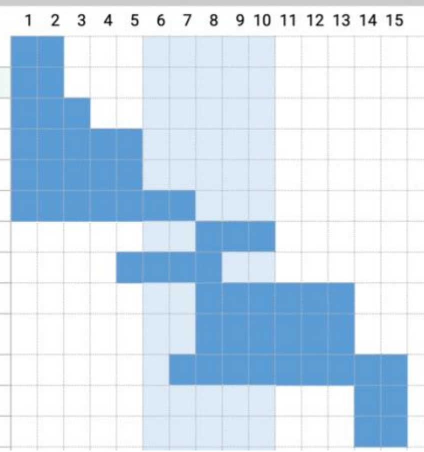

Figure 1: Gantt Chart for Second Semester

Figure 2 shows the work breakdown structure for the entire year. It was created at the beginning of last semester and has been altered to show an updated chain of events for the upcoming semester. It allows the team to see the steps needed to complete the steps listed in the Gantt chart and eventually, the project.

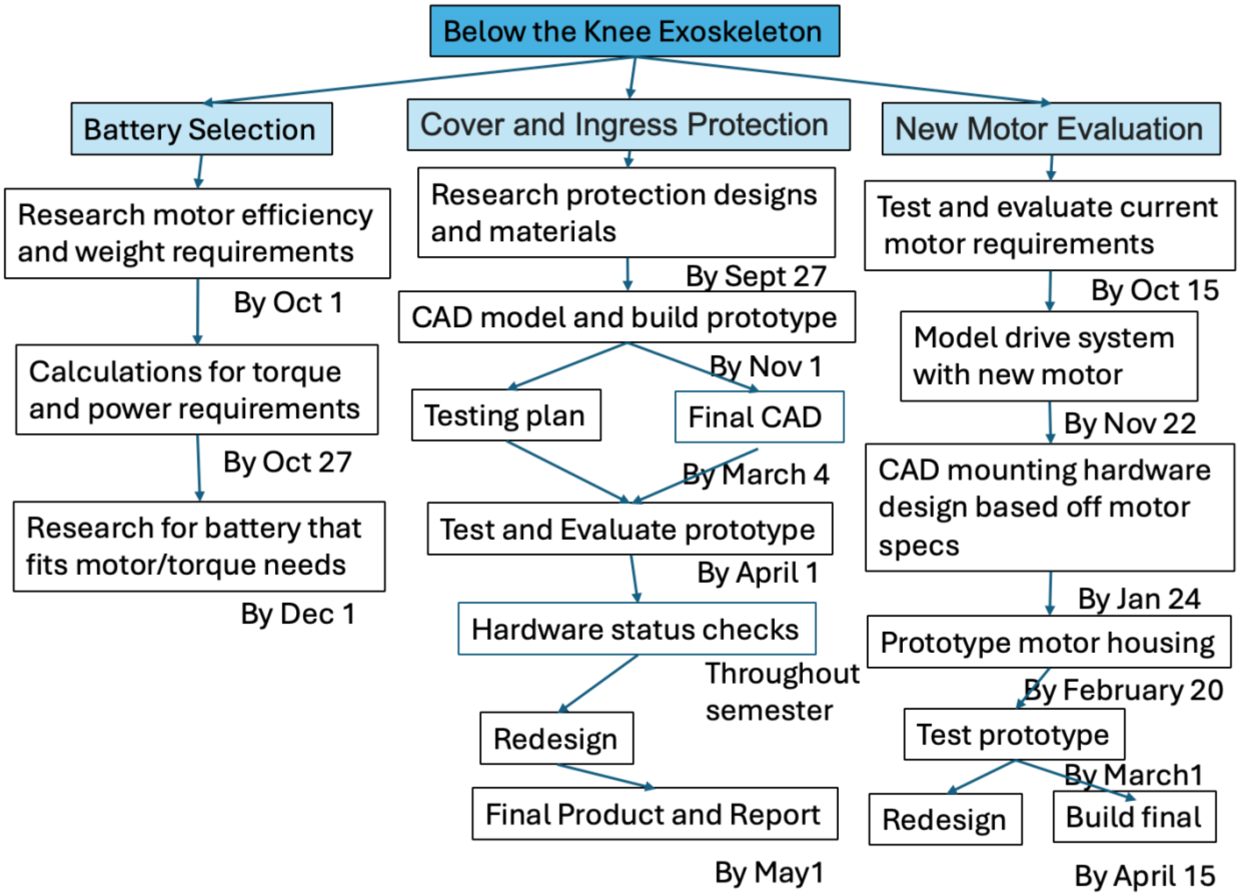

Figure 2: Work Breakdown Structure

3 Purchasing Plan

3.1 Bill Of Materials

Our purchasing plan for our project is unique being that we are working off a previous model provided by the client. Because of this, most of the parts that we will be working with will be provided by the client and will be labeled as "Donated" in our bill of materials. This is our up-to-date bill of materials.

Part:	Cost:	Materials:	Purchased or Manufactured:	Vendor:	Part #:	Qty	Lead Time/ Part Status:
6mm Ball Bearing	Donated	Stainless Steel	Provided by Client	McMaster	7804K143	1	-
8mm Ball Bearing	Donated	Stainless Steel	Provided by Client	McMaster	7804K147	1	-
Nylon-Insert Locknut	Donated	Steel	Provided by Client	McMaster	90576A102	2	-
M5 Button Head Torque Screws	Donated	Stainless Steel	Provided by Client	McMaster	90991A128	2	-
M3 Socket Head Screw	Donated	Steel	Provided by Client	McMaster	91290A136	2	-
Roller Chain Sprocket	Donated	Steel	Provided by Client	McMaster	2302K92	1	-
Bondable Flex Circuit	Donated		Provided by Client			1	-
M3 Button Head Screw	Donated	Steel	Provided by Client	McMaster	92095A168	1	-
Cable Chain Interface	Donated	Steel	Provided by Client			2	-
Cable Crimp	Donated	Steel	Provided by Client			2	-
Clearance Cable	Donated	Steel	Provided by Client			1	-
Cover Bolt	Donated	Steel	Provided by Client			1	-
Cuff Locknut	Donated	Steel	Provided by Client	McMaster	94645A102	2	
E-flite - EFLB910	53.29	N/A	Purchased	Prop Shop Hobbies	EFLB9106S30	1	Arrived
FSR Sensor	Donated	Steel	Provided by Client			1	
Inner Link	Donated	Steel	Provided by Client	McMaster	6027K73	11	

M3 Nut	Donated	Steel	Provided by Client	McMaster	90592A085	2	
Motor Cover	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A	1	not yet Manufactured
Maxon Motor	599.91	N/A	Purchased	Maxon	B7FFC8204F6C	2	4-6 weeks

Outer Link	Donated	-	Provided by Client	McMaster	6027K73	12	-
PCB Housing	518.5	PLA Carbon Fiber Filament	Manufactured	Markforged	F-FG-0005	1	Arrived
PCB	Donated	-	Provided by Client		-	1	-
Pogo Pin Connector	Donated	-	Provided by Client		-	1	-
Pulley w/ Washer	Donated	-	Provided by Client		-	1	-
Quick Connect Footplate	Donated	-	Provided by Client		-	1	-
Motor - Upright	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A		not yet Manufactured
Motor Mount - leaf	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A		not yet Manufactured
STTR Upright	Donated	Carbon Fiber	Provided by Client	McMaster	2040N16	1	-
Slider Spacer	Donated	-	Provided by Client	-	-	1	-
Small Motor Cover Cable Clamp	Donated	-	Provided by Client	-	-		-
Calf Cuff Adjuster	Donated	-	Provided by Client	-	-	1	-
Strain Gage	Donated	-	Provided by Client	-	-	2	-
Terminal Pads	Donated	-	Provided by Client	-	-	1	-
Motor O-ring	16.91	Fluorine Rubber	Purchased	Amazon	N/A		1 week

PCB Housing O-ring	16.9	Rubber	Purchased	Amazon	N/A		1 week
Torque Sensor Quick Connect	Donated	-	Provided by Client	-	-	1	-
M3 25mm w/ Bolt	Donated	Steel	Provided by Client	McMaster	90236A125	2	-
M5 12mm w/ Bolt	Donated	Steel	Provided by Client	McMaster	90991A127	2	-
Motor Bracket	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A		not yet Manufactured
motor cap	254.97	PLA Carbon Fiber Filament	Manufactured	Markforged	F-MF-0001		Arrived
Cuff assembly	Donated	-	Provided by Client	-	-		-
All Other screws	Donated	-	Provided by Client	-	-		-

Figure 3: Bill Of Materials

Part:	**Cost:**	**Materials:**	**Purchased or Manufactured:**	**Vender:**	**Part #:**	**Lead Time**
E-flite - EFLB910	53.29	N/A	Purchased	Prop Shop Hobbies	EFLB9106S30	Arrived
Motor Cover	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A	not yet Manufactur
Maxon Motor	599.91	N/A	Purchased	Maxon	B7FFC8204F6C	4-6 weeks
PCB Housing	518.5	PLA Carbon Fiber Filament	Manufactured	Markforged	F-FG-0005	Arrived
Motor Mount - leaf	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A	not yet Manufactur

Motor - Upright	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A	not yet Manufactur
PCB Housing O-ring	16.9	Rubber	Purchased	Amazon	N/A	1 week
Motor O-ring	16.91	Fluorine Rubber	Purchased	Amazon	N/A	1 week
Motor Bracket	Undetermined	7075 Aluminum Alloy - O (ss)	Manufactured	N/A	N/A	not yet Manufactur
motor cap	254.97	PLA Carbon Fiber Filament	Manufactured	Markforged	F-MF-0001	Arrived

Figure 4: Bill of Purchase Materials

3.2 Purchased Items

Our team currently has parts and materials purchased for the prototyping and future testing, here is a list of some purchased items and plans we have for these items.

Figure 5: E-flite 22.2V Battery

This is the DC 22.2V battery that we are using to power our Ankle Exoskeleton, currently, we have one purchased and plan to buy another for our second foot, for now, this battery will be sufficient. We plan to prototype some covers for the battery, and we plan to also make a new quick-connect for this battery for ease of use when charging and equipping the battery.

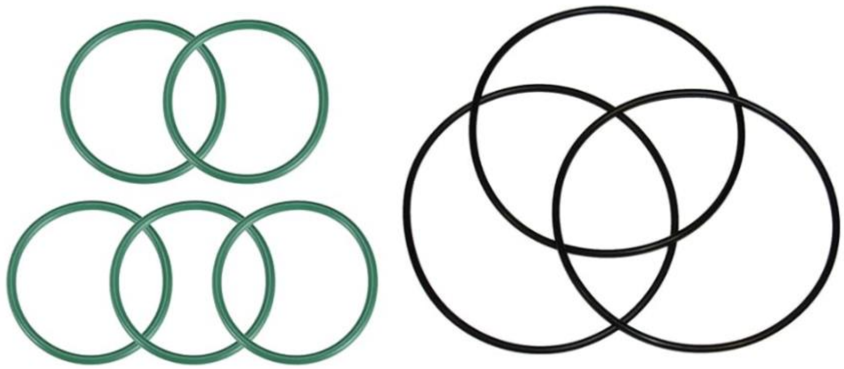

Figure 6: 185mm Rubber O-ring,42mm Rubber fluorine O-ring

Our team has purchased two different types of O-rings, a 185mm Rubber O-ring and a 42mm Rubber fluorine O-ring. The rubber O-ring will be used for providing ingress protection to the PCB box which as of now is the housing unit for the PCB and the Battery. Are plan with this part is to test different prototypes with this part and find a design that will provide a sufficient seal for our PCB box.

The rubber fluorine O-ring will be used for sealing the motor cover. We plan to use this O-ring to prototype different configurations and designs with the motor cover to find the best seal we can and increase our ingress protection on the motor.

Figure 7: Carbon Fiber 3-D printer filament

Our Team has purchased carbon fiber filament and PLA filament. Most of our finished product will be 3-D printed with the carbon fiber filament and our prototyping will be done with our PLA filament. Our plan with these two filaments is to prototype our designs and different configurations for our Ankle Exoskeleton, this will end up being some of our biggest purchases because of the amount and quality of filament we will be needing for our project.

Figure 8: Custom Maxon Motor

Last is our Maxon Motors. Our team has purchased two custom Maxon Motors which will be powering our Ankle Exoskeleton. These two motors will not arrive until early next year, but we plan to use these motors in all our prototyping of designs, and they will be very useful in our stress testing of the design. We have already as a team been thinking of ways to implement protection to this part which will be one of the most important.

4 Manufacturing Plan

Part:	Cost:	Materials:	Manufacturing:	Manufacturer:	Part #:
Motor Cover	Undetermined	7075 Aluminum Alloy	Machined	NAU CNC	N/A
PCB Housing	518.5	PLA Carbon Fiber Filament	3D Printed	Biomechatronics 3D Printer	F-FG-0005
Motor - Mount Upright	Undetermined	7075 Aluminum Alloy	Machined	NAU CNC	N/A
Motor Mount - leaf	Undetermined	7075 Aluminum Alloy	Machined	NAU CNC	N/A
STTR Upright	55.2	Carbon Fiber	Milled	McMaster Carr - Tapped & milled cable clearances	2040N11
Front Cover	518.5	PLA Carbon Fiber Filament	3D Printed	Biomechatronics 3D Printer	F-FG-0005

Table 4-A: Manufacturing Plan

Because our project requires redesigning an existing product, some parts will need to be redesigned. The only new parts will be the motor cover and the PCB housing. The upright, motor mounts and front cover have been manufactured for the previous design but need to be rebuilt for the new motor. We will need to determine how the original designs were manufactured and manufacture the new designs the same way. The upright needs larger clearances for the chain and cable, and the current upright can be milled for the new design.