Below the Knee Exoskeleton

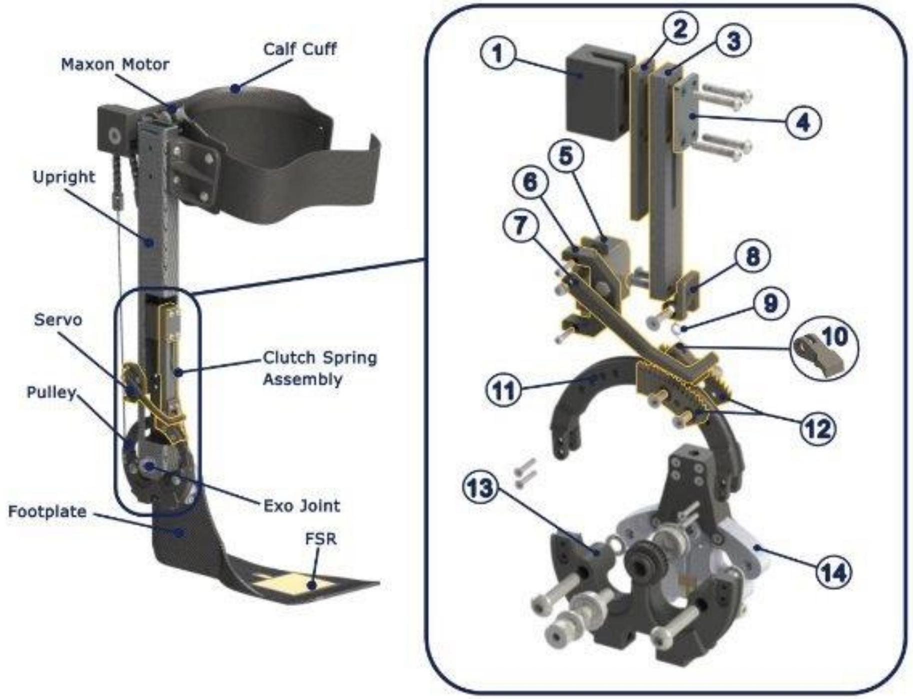
Team:
Ryan Oppel (Budget Lead), Alexandra Schell (Team Lead),
Nicolas Watkins (Website and CAD Lead)

Project Description

Goal:

Change existing design to encompass the following items completely below the knee rather than on the waist

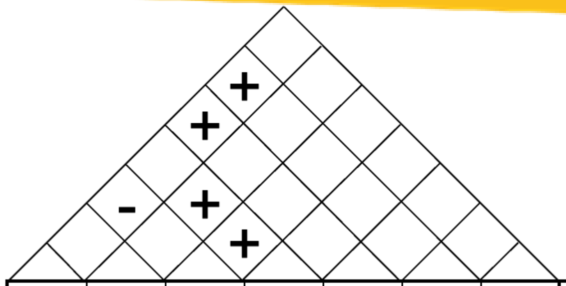
- Battery selection
- Cover and ingress protection design
- Motor evaluation and mounting hardware design.



Our Client:

•Prof Zach Lerner, head of Biomechatronic Lab. They develop lightweight wearable robotic exoskeletons to improve the movement of people with walking impairment.
•W.L. Gore

Design Requirements



Customer Requirements \ Design Requirements	Importance (1-5)	Energy efficient	Accommodate different shoe sizes	High torque	Support users of all weights	Under 3 kg	Temperature of motor	Battery Capacity	1 Worst	2	3	4	5 Best
Improvement Direction													
Durable	3		3		6	6	6			C	AB		
High range of motion	5			9							B	AC	
Comfortable	4		3		3							A	
High battery life	3	9					9					B	
Adjustable	3		3		6							C	A
Lightweight	5					9						B	AC
Affordability	5							9		C	B		
Technical Importance: Absolute		27	30	45	48	63	45	45	A	Caplex Exo			
Technical Importance: Relative		9%	10%	15%	16%	21%	15%	15%	B	Utah Knee			
Design Competitive Assessment — Worst: 1								B	C	ETM Motor			
Design Competitive Assessment — 2					C		B	C					
Design Competitive Assessment — 3		AB		B		C	C						
Design Competitive Assessment — 4				C	A	B							
Design Competitive Assessment — Best: 5		C	A	A		A							
Target Value		90	0.3	100	90	2	70	1000					
USL		60	0.27	150	120	3	155						
LSL		30	0.22	60	30	1.5		500					
Units		mins	m	mNm	kg	kg	C	mAh					

Customer Competitive Assessment

QFD

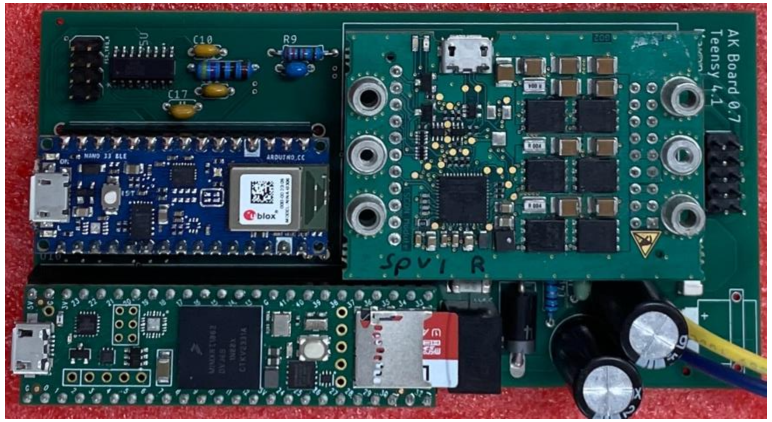
ECX FLAT 32 L, Ø32 mm, brushless

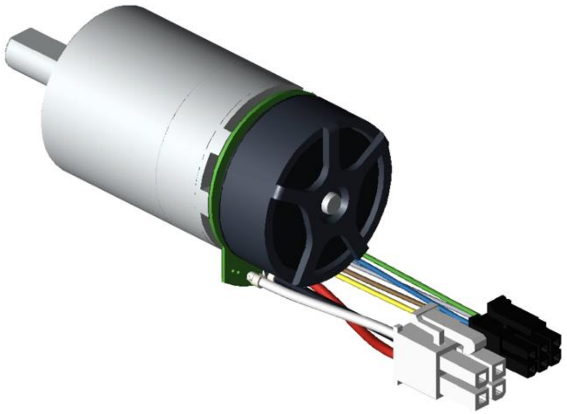
- Nominal Torque: 103 mNm
- Ambient Temperature: -40…+100C
- Max Temperature: 150C

E-flite 910mAh 6S 30C LiPo Battery

- Capacity: 910 mAh
- Voltage 22.2V

Design Description





CAD

- Motor Cover
- Motor Mount Assembly
- Ingress Protection

Engineering Calculations

Thermal Analysis

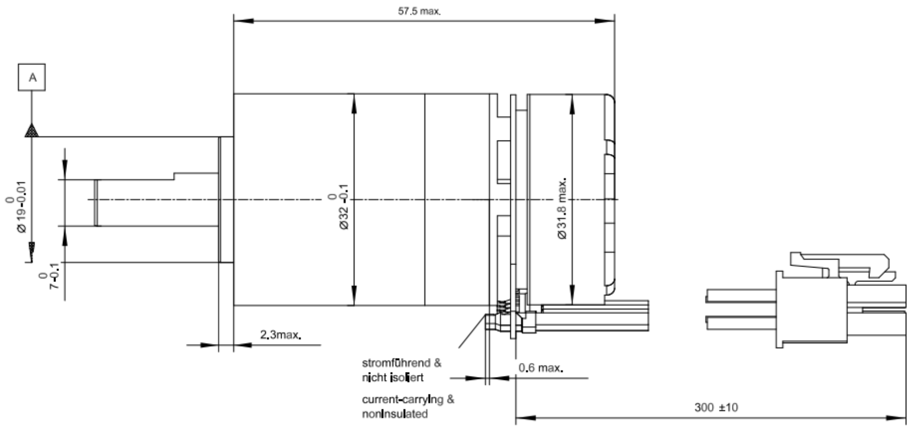
I began with a thermal analysis of the motor with no cover. Since the efficiency is 82.7%, and there is no additional materials to add resistance, rate of heat dissipation = the loss of power. This equals 11.3 W, using the below equations. Can add fins, insulation, fan. Assumptions: Nominal Speed (184.3rpm) and Torque (2811.9mNm); Aluminum; Heat transfer coefficient = 5W/m^2K

$$P_{\text{mech}} = T \cdot \omega$$

Mechanical Power
T = Torque
ω *= angular velocity*

$$P_{\text{loss}} = \frac{P_{\text{mech}}}{\eta} - P_{\text{mech}}$$

Loss of Power
η *= Efficiency*



$$Q = h \cdot A \cdot (T_{\text{motor}} - T_{\text{ambient}})$$

Rate of Heat Dissipation

$$\Delta T = \frac{P_{\text{loss}}}{h \cdot A}$$

Change in Temperature
h = convective heat transfer coefficient
A = Area

Design Validation

FMEA Chart:

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Maxon Motor	Exessive force	Motor is less functional or broken	System is mishandled	200	Add more protection to cover
	Thermal deformeatipon	Motor can sieze	Improper termal management	30	Add more thermal management
	Abraisive wear	Motor is less functional or broken	Regular use	500	Add more protection to cover
	Corrosion from outside elements	Motor won't work with other components	Improper ingress protectiont	50	more ingress protection
Motor support	Exessive force	Motor could sag	Regular use	500	brace suppot
	Tempurature induced deforation	Support could break or become brittle	Used out in freezing weather	50	Add more thermal management
	Cycle fatigue	Support could wear	rubbing from cloths	200	Add more protection to cover
Motor ingress protection	Tempurature induced deforation	O-ring could go bad	extreme temperatures	300	different design
	Exessive force	Cover can fracture	System is mishandled	200	Add more protection to cover
	Thermal fatigue	Cover can become brittle	extreme temperatures	50	Add more thermal management
	Impact wear	Cover can fracture	Regular use	500	Add more protection to cover
PCP	Impact fracture	PCP can break	System is mishandled	200	Add more protection to cover
	Thermal fatigue	PCP can overheat	not enough thermal management	30	Add more thermal management
	Cycle fatigue	Small parts can wear	Regular use	500	different design
	Corrosion from outside elements	PCP can overheat or short circuit	left in weather for extended period	50	add more ingress protection

Risk trade-off pieced of our project:

most of our recommended actions consist of adding more protection or more thermal management properties, what we need to do as a team is find the balance point between making the Exo-Ankle bullet proof and light weight.

Design Validation

FMEA Chart:

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Battery	Cycle fatigue	Battery can loose power	Regular use	500	different design
	Tempurature induced deforation	Can compromise battery life	overloading the battery	300	Add more thermal management
	Corrosion from outside elements	Can kill the battery	water seeps in	30	add more ingress protection
	Stress Rupture	Can break protective seal	overloading the battery	50	different design
	Exessive force	Can break protective seal	System is mishandled	100	Add more protection to cover
PCP/ Battery ingress protection	Exessive force	Cover can fracture	System is mishandled	100	Add more protection to cover
	Tempurature induced deforation	O-ring could go bad	Improper termal management	300	different design
	Thermal fatigue	Cover can become brittle	extreme temperatures	50	Add more thermal management
	Impact wear	Cover can fracture	System is mishandled	100	Add more protection to cover
Themal management of PCP/ Battery	Adheisive wear	Loose effective dissipation	misclaculated shifting of parts	100	fix it's mounting
	Exessive force	Can brittle the material	System is mishandled	300	Add more protection to cover
	Corrosion from outside elements	Loose effective dissipation	water seeps in	50	add more ingress protection
	Cycle fatigue	Can brittle the material	Regular use	500	Add more thermal management
Themal management of Motor	Adheisive wear	Loose effective dissipation	misclaculated shifting of parts	100	fix it's mounting
	Exessive force	Can brittle the material	System is mishandled	300	Add more protection to cover
	Corrosion from outside elements	Loose effective dissipation	water seeps in	50	add more ingress protection
	Cycle fatigue	Can brittle the material	Regular use	500	Add more thermal management

Summary: most of our recommended actions are to better brace the motor, PCP, Battery and cover which will be better accessed in testing of the Ankle-Exo.

Design Validation

Testing Procedures:

our testing procedures will be done in the robotics lab with our client Zach Lerner in a controlled area where we will be stress testing our prototypes. Once we have a successful prototype, we will then use it around campus to experiment how it handles a non-controlled environment.

Tools needed for testing:

Zack Lerner’s PCP design is wirelessly controlled by a phone app that has a control panel that calibrates the Ankle-Exo. In the lab there is a in-ground treadmill and a stair stepper which is combined with different systems that can monitor certain variable from the user such as displaced force and fatigue. These tools will help us calibrate our Ankle-Exo and find weak spots within our design.

Schedule

Overview of the first semester:

Below is the tentative schedule of the first semester based on major deadlines. We are slightly behind as we had to redesign the CAD design for the prototype based on new specs.

2	Major Deadlines 1st Semester																				
WBS Number	Task Title	Task Owner	Start Date	End Date	Duration	% Done	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2.2	Initial CAD Design	Nick W	9/30/24	10/28/24	28	90%															
2.1	1st Protype Demo	Alex S	10/28/24	11/13/24	15	10%															
2.2	Final CAD and BOM	Nick W	10/11/24	12/3/24	52	0%															
2.3	2nd Protype Demo	Alex S	10/11/24	12/4/24	53	0%															
2.4	Analysis of Prototype	Team	12/4/24	12/7/24	3	10%															
2.2	Purchase of Parts	Ryan O	10/11/24	10/26/24	15	80%															
2.3	Test 1st Prototype	Alex S	11/13/24	11/24/24	11	0%															

Budget

Breakdown:

Our team received 4000 dollars from our sponsored W.L. Gore. 5% of the is taken out by NAU and our own fundraising efforts have brought in 275 dollar putting up right back up to 4075 dollars.

Team	Alias	Team #	SubDept Code	Budget Liaison	Email	Primary Budget				Speedchart:
Ankle Exo		F24toSp25_AnkleExo	CP09	Ryan Oppel	rmo88@nau.edu	$ 4,000.00				2920381F25
						$ 809.17	Total Spent			
						$ 3,190.83	**Remaining Balance**			

Purchase Date	HRC #	Vendor	Description	Quantity	Order #	Tracking	Received	Picked Up	Cost	Comments
10/31/2024	Pcard	Markforged	800cc Onyx Filament Spool	1	MF-131611				$ 755.88	
			150cc Carbon Fiber CFF Spool	1						
	Pcard	Prop Shop Hobbies	E-FLIT 22.2 V30C LIPO 6CELL	1	8079				$ 53.29	

W.L. Gore Funding	+4075.00
800cc Onyx Filament	-190.87
150cc Carbon Fiber Filament	-565.01
E-Flight 22.2V battery	-53.29
Maxon ECXFL32L KL A HTQ 24V (X2)	-653.7
Total	+2612.13

The rest of our money will go to further testing and prototyping for future iterations and more carbon fiber material for protective covering.

Thank You!