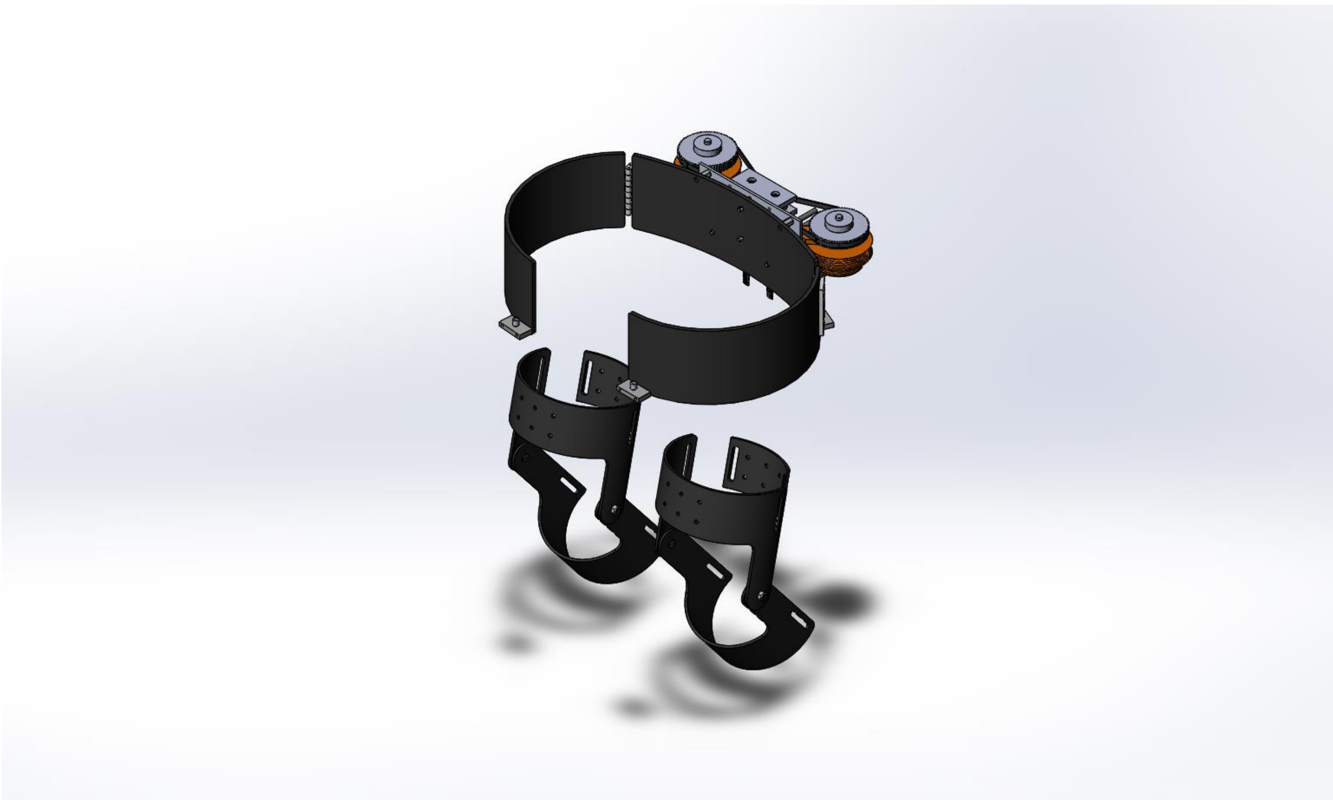
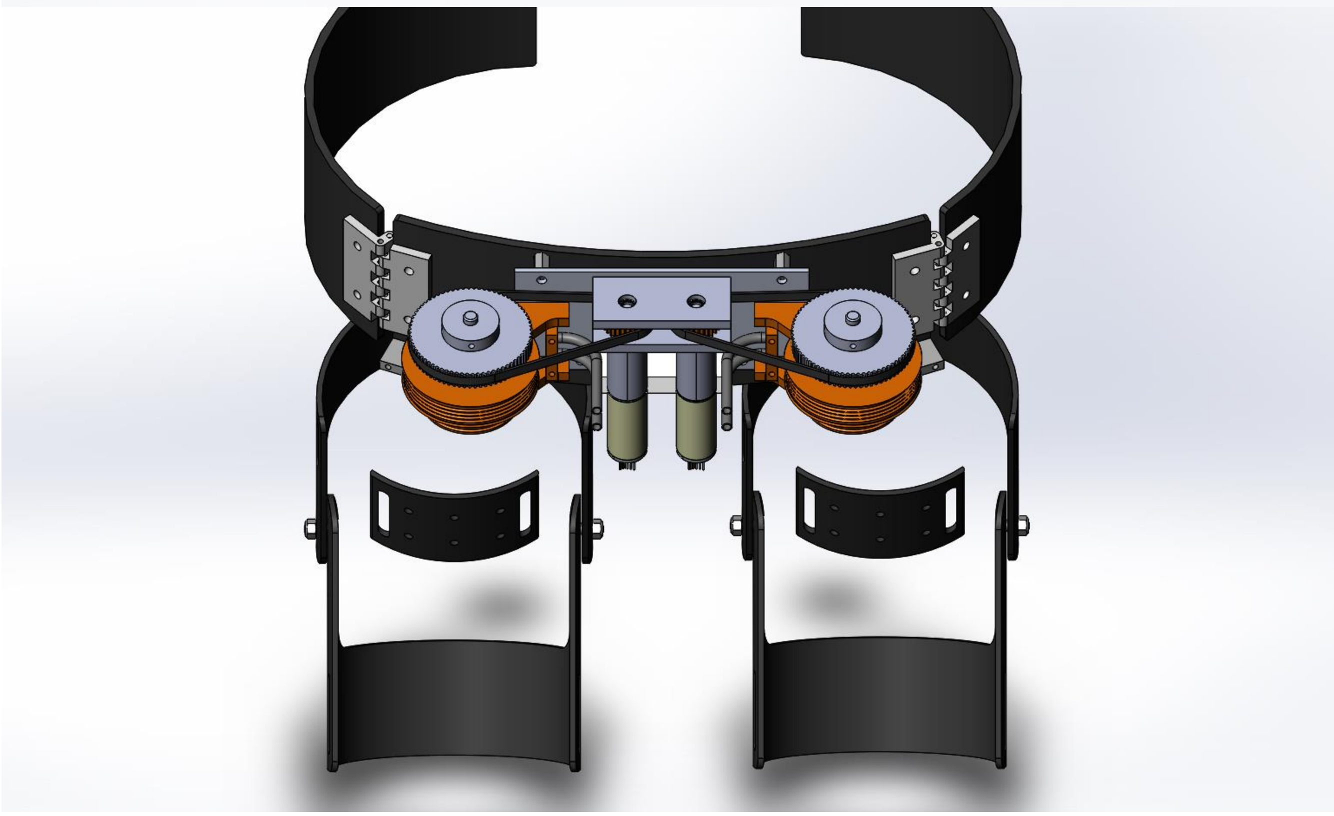
FINAL PRODUCT BREAKDOWN

TEAM: **19F13 Biomechatronic Hip Exoskeleton Team (BHET)**

Due Date:
Monday, May 4, 2020 at 11:59pm

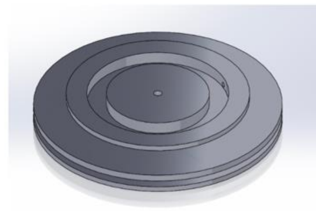
Provide several pics of the completed system here:



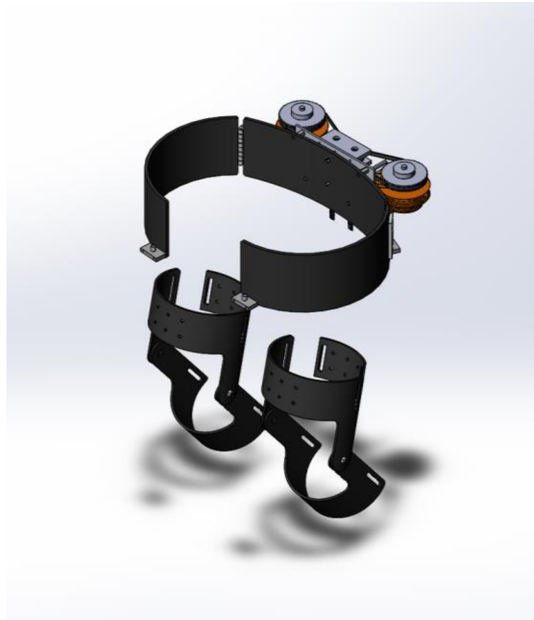


The following are the Action Items each person completed between Hardware Review 2 and the completion of the final product:

Team Member: **Inna Quiambao**

Calculated ratio for the pulley diameters	3/13/20	ie chance of tangling. With a 3-inch pulley, the cord would only have to wrap around tı eing 3 inches, r_{back} can be found by just dividing this total by 1.44. r_{back} ends up being 2 s design is shown below.  *Figure 1 Isometric View of Pulley*  *Figure 2 Top View of Pulley* are through holes in the inner sections of the pulley w
Project overview ('Testing Procedure') section of poster	4/17/20	**Testing** *Testing Procedure 1: Torque/Power Output* This testing procedure is used to record the torque/power output of the assembly. This is done by attaching it to a test fixture and using load cells for torque testing and weights for power testing. *Testing Procedure 2: User Comfort Rating/Survey* A random set of people would wear the exoskeleton and move around with it on, then they would fill out a survey rating it. *Testing Procedure 3: Fitment Tests* The BHET team would wear the system and take measurements such as: range of motion angle and waist measurement. Weight of the system would be taken by itself using a scale. *Testing Procedure 4: Fatigue Failure Modes* While using the same testing fixture as Testing Procedure 1, system will be run as if it's actuating movement. Record number of cycles when wear is shown on cables or motor mounts.
Revised testing procedures	4/27/20	Can be referenced in the final proposal

Team Member: **Keegan Ragan**

Action Item	**Date Completed**	**Result/Proof of Completion**
Revised CAD Drawings, prepped for final report, final product, and CAD submission.	4/30/20	
Finalized BOM	5/1/20	

1				Legend					
2	19F13 - BHET CAPSTONE TEAM			Already Purchased					
3	Bill of Materials			Aquired w/out Purchase					
4	May 4th, 2020			No longer needed					
5									
6	PART NO.	PART (SOLIDWORKS PART NAME)	MATERIAL	DIMENSIONS (in.)	SUPPLIER	QTY.	COST/UNIT	COST	SOURCE
7	1	Base_Plate_V1	6061 T6 AL	0.25 x 3 x 12	OnlineMetals	1	$6.30	$6.30	https://v
8	2	Bearing_Block_V1	6061 T6 AL	0.25 x 1.5 x 48	OnlineMetals	1	$10.05	$10.05	https://v
9	3	Housing Clamps (At motor assembly)							
10	4	Housing Clamps (At cable termination)							
11	5	Face_Plate_V2							
12	6	Mounting_Bracket_V5	6061 T6 AL	0.5 x 1.5 x 24	OnlineMetals	1	$12.06	$12.06	https://v
13	7	KneeBraceTop_V2	Kydex	0.125 x 12 x 12	McMaster-Carr	2	$10.16	$20.32	https://v
14	8	KneeBraceTop-Back_V2							
15	9	KneeBraceBottom_V2							
16	10	Motors	N/A	N/A	Maxxon	2	$815.73	$1,631.46	
17							Total	$1,680.19	
18	*Any part numbers in this section refer to purchasable parts in the CAD drawings*								
19	Part No.	HARDWARE	MATERIAL	DIMENSIONS (in.)	SUPPLIER	QTY.	COST/UNIT	COST	SOURCE
20		M4 x 20mm (100 pack)	SS A2-70	N/A	Copper State	1	$8.76	$8.76	http://cc
21		M4 x 10mm (100 pack)	SS A2-70	N/A	Copper State	1	$6.20	$6.20	
22		M3 x 10mm (100 pack)	SS A2-70	N/A	Copper State	1	$4.09	$4.09	
23		M3 x 20mm (100 pack)	SS A2-70	N/A	Copper State	1	$5.77	$5.77	
24	K3	Shoulder screw	316 SS	0.25 Shoulder, 10-32	McMaster-Carr	4	$5.32	$21.28	https://v
25	K4	Nylon Insert Locknut (50 Pack)	316 SS	10-32 Thread Size	McMaster-Carr	2	$4.71	$9.42	https://v
26	MM1	Timing pulley stock	Aluminum		SDP-SI	1	$45.86	$45.86	http://sh
27	MM7	M5 Threaded Couplers	Steel		McMaster-Carr	10	$0.42	$4.20	https://v
28	MM8	Timing belt	Neoprene		SDP-SI	2	$7.02	$14.04	http://sh
29	MM9	Bearings for Bearing Block Output (Pack of 8)	Steel		Amazon	1	$6.95	$6.95	https://v
30	MM10	Bearings for Bearing_Block_V1	Steel	3mm W, ID 6mm, OD 10mm	McMaster-Carr	2	$12.06	$24.12	https://v
31							Total	$150.69	
32									
33	Part No.	Other Parts to Purchase	MATERIAL	DIMENSIONS (in.)	SUPPLIER	QTY.	COST/UNIT	COST	SOURCE
34	H2	Plastic Hinge	HDPE	N/A	McMaster-Carr	2	4.49	8.98	https://v
35	H4	M5 Bicycle Barrel Adjuster	N/A	N/A	Amazon	1 (10	8.99	8.99	https://v
36									
37									
38									
39									
40		Legend			Shipping - Online Metals			$21.92	
41		Already Purchased			Amount Purchased			$1,681.79	
42		Aquired w/out Purchase			Amount to Purchase			$168.66	
43		No longer needed			Budget			$2,250.00	
44									

Team Member: **Mohanad Fakkeh**

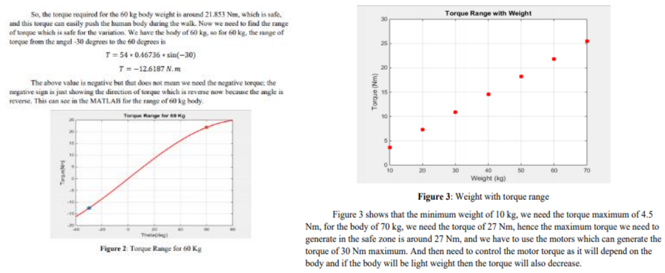
<table>
<tr><th>Action Item</th><th>Date Completed</th><th>Result/Proof of Completion</th></tr>
<tr><td>Knee brace forming and assembly (with Keegan and sean)</td><td>3/5/20</td><td></td></tr>
<tr><td>Revised Torque applied to the user’s hip</td><td>03/13/2020</td><td>
So, the torque required for the 60 kg body weight is around 21.853 Nm, which is safe, and this torque can easily push the human body during the walk. Now we need to find the range of torque which is safe for the variation. We have the body of 60 kg, so for 60 kg, the range of torque from the angel -30 degrees to the 60 degrees is
$$T = 54 * 0.46736 * \sin(-30)$$
$$T = -12.6187\ N.m$$
The above value is negative but that does not mean we need the negative torque; the negative sign is just showing the direction of torque which is reverse now because the angle is reverse. This can see in the MATLAB for the range of 60 kg body.

Figure 2: Torque Range for 60 Kg
Figure 3: Weight with torque range
Figure 3 shows that the minimum weight of 10 kg, we need the torque maximum of 4.5 Nm, for the body of 70 kg, we need the torque of 27 Nm, hence the maximum torque we need to generate in the safe zone is around 27 Nm, and we have to use the motors which can generate the torque of 30 Nm maximum. And then need to control the motor torque as it will depend on the body and if the body will be light weight then the torque will also decrease.</td></tr>
<tr><td>Website for the second check</td><td>04/10/2020</td><td>Edited the website with fully Content up to date (Check2) and here is the link for it:
BHET Project Site</td></tr>
<tr><td>Project overview (Customer Requirements) section of poster</td><td>4/17/20</td><td>
Customer Requirements
The main objective of our design is to actuate movement in the hip. The movement is assisted in extension/flexion but needs to be passive in all other directions. The team's design also needs to sense the torque applied within the system. These three requirements are a priority in the design which is why they are ranked the highest out of all the customer needs. All of the customer needs identified last semester are listed in the below table.
Table 1: Customer Requirements<table><tr><th>Customer Requirements</th><th>Weights</th></tr><tr><td>Hip Actuation</td><td>5</td></tr><tr><td>Full Range of Motion</td><td>5</td></tr><tr><td>Sense Torque</td><td>5</td></tr><tr><td>Minimize Metabolic Cost</td><td>4</td></tr><tr><td>Safe to Operate</td><td>4</td></tr><tr><td>Untethered</td><td>4</td></tr><tr><td>Durable</td><td>3</td></tr><tr><td>Easy to don and doff</td><td>2</td></tr><tr><td>Comfortable</td><td>2</td></tr><tr><td>Reliable</td><td>2</td></tr><tr><td>Within Budget</td><td>1</td></tr><tr><td>Fit small to medium build</td><td>1</td></tr></table></td></tr>
</table>

Team Member: **Sean Oviedo**

<table>
<tr><th>Action Item</th><th>Date Completed</th><th>Result/Proof of Completion</th></tr>
<tr><td>Knee brace forming and assembly (with Keegan and Mohanad</td><td>3/5/20</td><td></td></tr>
<tr><td>Performed stress analysis on driven shaft</td><td>3/13/20</td><td>

Individual Technical Analysis 2

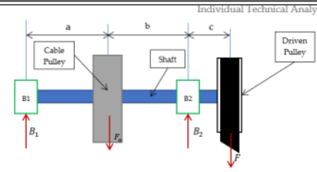


Figure 5.1 Force diagram of output shaft

4.1 Assumptions

1. Calculations will be based on peak torque/speed of the motor gearhead.
2. Frictional losses from bearings will be ignored
3. Timing belt tension ratio of 5:1, [2]
4. The output torque required for the cable pulley is based on the smaller pulley diameter, because the force
5. Axial loads are neglected, per distortion energy failure theory
6. The shaft design will be straight with constant diameter, therefore the stress-concentration factors will be set to a value of 1.

4.2 Peak Torque on Driven Pulley (T_{peak})

Table 4.1 Input values for belt drive design

<table>
<tr><th>Input</th><th>Value</th><th>Units</th><th>Symbol</th></tr>
<tr><td>Gearbox Max input speed</td><td>12000</td><td>rpm</td><td>n_i</td></tr>
<tr><td>Motor Nominal Torque</td><td>45.1</td><td>mNm</td><td>T_i</td></tr>
<tr><td>Gearbox Efficiency</td><td>0.59</td><td></td><td>E_g</td></tr>
<tr><td>Absolute Gearbox Ratio</td><td>$\frac{4617}{52}$</td><td></td><td>R</td></tr>
<tr><td>Torque from drive pulley</td><td>2.36</td><td>Nm</td><td>T_{p1}</td></tr>
<tr><td>Required torque on output shaft</td><td>5.6</td><td>Nm</td><td></td></tr>
<tr><td>Drive Pulley Pitch Diameter</td><td>28.6</td><td>mm</td><td>d_{p1}</td></tr>
<tr><td>Driven Pulley Pitch Diameter</td><td>68.8</td><td>mm</td><td>d_{p2}</td></tr>
</table>

Individual Technical Analysis 2

The peak torque and speed applied to the driven pulley is calculated by [1]:

$$T = T_i E_g R \left(\frac{1m}{1000mm}\right) \quad (1)$$

$$n_o = n_i R \quad (2)$$

The load transferred by the timing belt [1]

$$T_T = \frac{2.5T}{d_{p1}} \quad (3)$$

$$T_S = \frac{0.5T}{d_{p1}} \quad (4)$$

Shaft load analysis [1]

$$B_1 = \frac{Fb}{a} \quad (5)$$

$$B_2 = \frac{F_0 a + F(a+b+c)}{(a+b)} \quad (6)$$

Shaft stress analysis was performed by calculating the combined Distortion Energy theory loads, using Goodman failure criteria [2]:

$$\frac{1}{n} = \frac{\sigma'_a}{S_e} + \frac{\sigma'_m}{S_{ut}} \quad (7)$$

$$\sigma'_a = \left(\left(\frac{32K_f M_a}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs} T_a}{\pi d^3}\right)^2\right)^{1/2} \quad (8)$$

$$\sigma'_m = \left(\left(\frac{32K_f M_m}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs} T_m}{\pi d^3}\right)^2\right)^{1/2} \quad (9)$$

Where σ'_a and σ'_m represent the fluctuating von Mises stresses, M is the bending moment, and T is the torque. The subscripts m and a indicate alternating or midrange loading. K_f and K_{fs} are bending and torsional fatigue stress-concentration factors, as mentioned in the assumptions these have been set to a value of 1 for this analysis. S_e is the endurance modified endurance stress limit and S_{ut} is the material ultimate tensile strength.

5 Results

The belt tooth profile was selected using tabulated data from the manufacturer, which rates the torque transfer capability based on operating rpm, tooth profile, pitch diameter, and belt length. Using the manufacturer's specifications for the motor as the torque requirement, the timing profile GT3 with a 3mm pitch and a width of 6mm was selected. It should be noted that this also influenced the timing pulley sizes, initial calculations were performed using arbitrary pulleys that provided the desired reduction, the pulley sizes in Table 5.1 reflect the final components selection.

Results of the shaft stress analysis are shown in Table 5.1 below.

</td></tr>
<tr><td>Revised bearing blocks for driven shaft</td><td>3/13/20</td><td>

Shipping Information [redacted]

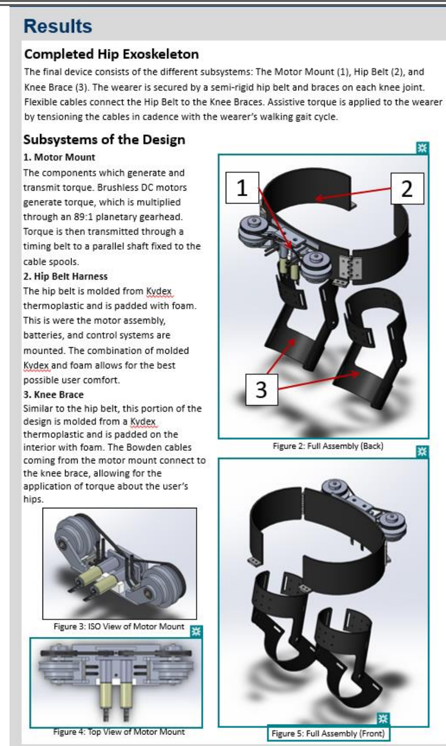
Billing Information [redacted]

Contact Information [redacted]

<table>
<tr><th>Catalog Number</th><th>Unit Price</th><th>Qty</th><th>Subtotal</th></tr>
<tr><td>A36R53M113060</td><td>$7.02</td><td>2</td><td>$14.04</td></tr>
<tr><td>A 6A53M072NF0608</td><td>$21.97</td><td>2</td><td>$43.94</td></tr>
<tr><td>A 6A52M037GT20</td><td>$84.06</td><td>1</td><td>$84.06</td></tr>
</table>

Order Number: C200300491 **Order Date: 3/14/2020 7:13:23 AM**

</td></tr>
<tr><td>Designed Timing belt drive, selected and ordered components</td><td>3/26/20</td><td></td></tr>
</table>

Project overview ('Results') section of poster	4/17/20	 Results **Completed Hip Exoskeleton** The final device consists of the different subsystems: The Motor Mount (1), Hip Belt (2), and Knee Brace (3). The wearer is secured by a semi-rigid hip belt and braces on each knee joint. Flexible cables connect the Hip Belt to the Knee Braces. Assistive torque is applied to the wearer by tensioning the cables in cadence with the wearer's walking gait cycle. **Subsystems of the Design** **1. Motor Mount** The components which generate and transmit torque. Brushless DC motors generate torque, which is multiplied through an 89:1 planetary gearhead. Torque is then transmitted through a timing belt to a parallel shaft fixed to the cable spools. **2. Hip Belt Harness** The hip belt is molded from Kydex thermoplastic and is padded with foam. This is were the motor assembly, batteries, and control systems are mounted. The combination of molded Kydex and foam allows for the best possible user comfort. **3. Knee Brace** Similar to the hip belt, this portion of the design is molded from a Kydex thermoplastic and is padded on the interior with foam. The Bowden cables coming from the motor mount connect to the knee brace, allowing for the application of torque about the user's hips. Figure 2: Full Assembly (Back) Figure 3: ISO View of Motor Mount Figure 4: Top View of Motor Mount Figure 5: Full Assembly (Front)
Final Motor Mount CAD design	5/4/20