To: Dr. Sarah Oman
From: Team 18F12
Date: 4/12/19
Subject: Testing Proof Summary

Introduction:

To test the prosthetic arm, there were seven engineering requirements established by Dr. Winfree. These engineering requirements were:

1. Scalable Size
2. Weight
3. Budget
4. Durability
5. Force to Actuate
6. Force of Grip
7. Number of Parts

Each engineering requirement had a limit to reach in order to be considered a successful design. The arm needed to be scalable between 6-18 inches in length, weigh less than 4 pounds, and have less than 100 parts in the assembly. When considering its force, it must withstand up to 10 pounds of weight, have an actuation force less than 5 lbf, and have a grip force less than 2 lbs. The entire arm, when fully assembled, must be within a budget of $500.

Tests:

1. The scalability test is done by changing the dimensions of the CAD to ensure that no components fail between size changes. If components fail, or features overlap that should not, then the design needs to be altered. The results at a smaller size are in Figure 1 and the results at a larger size are in Figure 2.

   From this test, the scalability of the design can be found in Table 1. There are multiple parts to the device and each part must be functional at different sizes. Some parts must keep key dimensions in order for other components to to fit together. The purchased parts are not adjustable. Therefore, the CAD must be able to accommodate the purchased items while still being customizable. Due to this, some items and parts are only adjustable in certain directions or not adjustable at all. The table shows which parts can be changed, its scalable direction, and the range in inches for each.

Table 1: Device Parts and Size Ranges in Length, Width, and Height

Part	Scalable? (Yes/No)	Range in Length (in)	Range in Width (in)	Range in Height (in)
Cuff	Yes	N-A	2.5-6	2.5-6
Forearm- Back half	Yes	3-6	2.5-6	2.5-6
Palm	Yes	2-4	N-A	2-4
Fingers	Yes (length)	1.5-4 (in)	N-A	N-A

Each subsystem of the prosthetic could be scaled in the desired directions needed when measuring a new client. The cuff only needs to change in diameter to fit different upper arms, the back half of the forearm needs to increase in length and diameter, the palm needs to increase in length and height, and the fingers need to be scalable in length. This was evident by using SolidWorks to change lengths and diameters of the subsystem.

2. The weight of the arm was measured by using a bucket and a scale. Due to the current state of the product is in multiple pieces due to the electrical components being separate from the mechanical components, the pieces were put into this bucket and weighed individually, with the total weight being the summation. The empty bucket was weighed first to establish the zero value in the analysis. Figure 3 shows the weighing process.

Figure 3: Weighing Test

The resulting weight of the prosthetic was 2 lbs, therefore the prosthetic passes the test.

3. The budget is calculated by summing up the materials used to produce a single prosthetic arm. Table 2 is the bill of materials for one full functioning prosthetic.

Table 2: BOM

Final product Cost for DIY (Excluding shipping and tax)					
Order	**Price**	**Quantity**	**Price*Quantity**	**Catalog #**	**Vender**
XBee exploror	?	2	?	?	?
Battery 1Ahr	9.95	2	19.9	PRT-13813	Sparkfun
Battery 2Ahr	12.95	1	12.95	PRT-13855	Sparkfun
Charger and Booster	15.95	3	47.85	PRT-14411	Sparkfun
Force Sensitive Resistor 0.5"	6.95	5	34.75	SEN-09375	Sparkfun
Force Sensitive Resistor - Sm	6.95	2	13.9	SEN-09673	Sparkfun
Amphenol FCI Clincher Conne	1.95	7	13.65	COM-14194	Sparkfun
SparkFun RedBot Mainboard	52.95	1	52.95	ROB-12097	Sparkfun
XBee 1mW Trace Antenna - S	24.95	3	74.85		Sparkfun
270 Degree Carbon Steel Mus	12.57	1	12.57	3HPF6	Grainger
Shoe insoles	8.37	1	8.37	B07P3J3CGB	Amazon
Foam Pad	14.24	1	14.24	B000VQFSU0	Amazon
Digital Servo x4	25.99	1	25.99	B01GN0715U	Amazon
Virbrating motor x10 need 3	9.99	1	9.99	B076ZS77T1	Amazon
M3 Screws Assortment Pack	10.99	1	10.99		Amazon
PLA per kg needed	17.99	1	17.99	Color Dependent	Amazon
Total:	370.94	33	370.94		

The total budget for one prosthetic is $370.94, which is less than $500. Hence, the prosthetic meets this requirement.

4. The durability test is done by submitting the prosthetic to a large force for a number of times, whether by using a tool or throwing it at the ground. The prosthetic was thrown and hit. In other words, the team treated the arm carelessly and as if the client was banging it into a lot of walls and tables while in use, which is considered an extreme scenario. Figure 4 is the arm prior to testing. Figure 5 shows the result of the durability test after dropping it on concrete from shoulder height. Figure 6 shows the result of throwing the arm down a flight of stairs. Figure 7 shows the result after a few more throws down stairs.

Figure 4: Before Testing

Figure 5: After test 1

Figure 6: After test 2

Figure 7: Final Aftermath

After test 1, a few of the pins broke on impact, which separated the subassemblies and assembly. However, the individual subassemblies did not have cracks or damage to them. After test 2, the cuff attachments and wrist attachments broke because these were attached to the thinner parts on the arm. However, the individual components were still intact. After test 3, almost all of the pins broke, the palm had a crack in it, and the forearm motor lid was also cracked. Some of the breakage was due to shear on the parts when printing.

As a result of this durability test, the pins need some diameter adjustments and printed flat in order to ensure less shearing fractures or other forms of breakage on impact. This test gave an understanding of the extreme stresses the arm could handle. The arm will survive everyday bumps from tables or walls and can likely survive if the client fell and landed directly on the arm at least once. Any further accidents concerning repeated falls or drops will mean that the components would have to be reprinted.

5. When the engineering requirement of actuation force was given, it was made without consideration of the pressure sensors in the insole. The pressure sensors in the insoles can detect up to 1 lbf. The amount of pressure put on these sensors relates to the amount of actuation the servo motors give to the fingers. Because the sensors can only sense up to 1 lbf, 1 lbf is all that is necessary to actuate. Hence, this requirement is met.

6. The force of grip could not be measured due to the slight dimensional errors for running the wire through the palm and fingers. However, the motors can produce a force of of 9.5 lb*ins. With the wires properly threaded, the force would increase to the user's advantage. thus, it is safe to assume that the force of grip is within the engineering requirements.

7. To determine if the number of parts is less than 100, every piece was counted as a part. This number included pins, screws, wires, sensors, subassembly components, and electrical components. Table 3 and 4 display the part, number, and quantity.

Table 3: Part List and Quantities Pt 1

Part Number	Part Name	Quanity
1	Digit 1 Rotating Base	1
2	Digit 1 Proximal	1
3	Digit 1 Distal	1
4	Digit 2 Proximal	1
5	Digit 2 Distal	1
6	Digit 3 Proximal	1
7	Digit 3 Distal	1
8	Digit 4 Proximal	1
9	Digit 4 Distal	1
10	Digit 5 Proximal	1
11	Digit 5 Distal	1
12	Rotating Base Hinge Pin	1
13	Finger Hinge Pin	5
14	Mini Pressure Sensors	2
15	Palm Pin Long	1
16	Palm Pin Short	2
17	Finger Grips	5
18	Palm	1
19	Palm Cover	1
20	Micro Motor Screws	2

Table 4: Part List and Quantities Pt 2

Part Number	Part Name	Quanity
21	Micro Motor	1
22	Beed Wire	10
23	Servo Motors	4
24	Servo Motor Screws	16
25	Front half	1
26	Back half	1
27	Motor lid	1
28	Motor lid pins	2
29	Forearm key lock	1
30	Palm attachment pins	2
31	Torsion Springs	2
32	Cuff	1
33	Foam roll	1
34	Vibrating motors	3
35	Electronic Cover	1
36	Battery 1Ahr	1
37	Battery 2Ahr	1
38	Charger and Booster	3
39	Amphenol FCI Clincher Connector (2 Position, Female)	7
40	SparkFun RedBot Mainboard	1
41	RedBot Screws	4
42	XBee 1mW Trace Antenna - Series 1 (802.15.4)	3
43	Shoe insoles pack	1
43	Ankle band	2
43	Ankle attachment	2
Total		103

The total number of parts is 103. 103 is more than 100, so this requirement is not met. However, because screws and pins are required to hold the larger components and the electronic components in place while vibration occurs, this number is a necessity to have a fully durable and functional prosthetic. The number of parts can be decreased in some cases. These cases are include items that are redundant. For example, the number of strands of beaded wire can be reduced to 5. The 1 wire will be used for each finger rather than 2. This would reduce the number of parts to be below 100. With this change, it will fit the customer requirements.

Conclusion

Throughout the testing of the prosthetic arm, the different technical and customer requirements were met. These requirements were scalability, weight, budget, durability, actuation force, grip force, and part count. Overall, the arm was successful in meeting the requirements. There are, however, a few exceptions. These failures to meet expectations have simple solutions. The arm successfully met the scalability, weight, budget, durability, actuation, and grip. The number of parts did not meet the limit requirement but this will be rectified by removing redundant parts. The durability will also be improved by making the attachments denser and/or larger. With minor changes, the hand meets all the requirement tested.