Feasibility Testing Report – Muscle Optimization Stage I

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Related System: Actuate Muscle (ABBBBA)

The reason for this test is to find:

a) What supplies are needed to make an air muscle?
b) How can we regulate the pressure?
c) What is the relationship between strain and pressure?
d) What is the relationship between force and strain?
e) What is the relationship between strain and size?
f) What are the next steps for muscle optimization stage II?

Testing Procedure

Supplies

1. Orange Muscle (M1)
    a. 4.5 inch orange muscle sleeve
    b. 4.5 inch latex surgical tubing
    c. Plastic end cap plug
    d. Plastic inlet fitting
    e. Wire ties
    f. Worm clamp
    g. Black air line tubing (approx. 1 ft)
2. Red Muscle (M2)
    a. Premade with unknown components
3. Pressure regulator
4. Transparent air line tubing (approx. 4in)
5. 1/4in quick connect to shop tank quick connect (2 pieces screwed together)
6. Shop air tank
7. Packing tape/wire ties
8. S-carabiner
9. Key-ring
10. Ruler (2) with clamp to increase length
11. Weights (see Table 1: Individual Weights)

Setup

The weights used in the tests consisted of the following individual weights:

Weights	lbs
Weight (1)	4.59
Weight (2)	4.63
Hangar (3)	0.93
Dumbells (4)	2.00

Table 1: Individual Weights

The weights were configured in one of three arrangements as shown in Table 2:

Weight Configuration	lbs	Config. #
Two main weights (1)(2)(3)	10.1	W1
One main weight (2)(3)	5.6	W2
Hangar and dumbells (3)(4)	2.9	W3

Table 2: Weight Configurations

Two muscles were testing in this phase. The first (M1) was an orange muscle that was constructed in house with supplies on hand in the shop as listed in Supplies. The second (M2) was a longer Red muscle that was found premade in the BAD Lab. The approximate initial lengths were measured as well as the inflated width at 60psi with no loading.

Muscles	Muscle #	Width (in) @ 60 psi & 0 lbs	L_0 (in)
Orange - Homemade	M1	0.59	4.5
Red - Premade	M2	0.63	7.0

Table 3: Muscle Information

A series of six tests were conducted since there were two muscles and three weight configurations. Table 4 is provided as a reference of the test configurations.

Total Configuration	Test #	lbs	Test Name
Orange (M1) & W1	Test 1	10.1	M1) 10.1lb
Orange (M1) & W2	Test 2	5.6	M1) 5.6lb
Orange (M1) & W3	Test 3	2.9	M1) 2.9lb
Red (M2) & W1	Test 4	10.1	M2) 10.1lb
Red (M2) & W2	Test 5	5.6	M2) 5.6lb
Red (M2) & W3	Test 6	2.9	M2) 2.9lb

Table 4: Test Configurations Reference

The test rig was set up as shown in Figure 1. The muscles were fixed to an overhang and attached to the weight hangar. The initial height from the floor (H_0psi) was measured separately for each test and used as a reference for corresponding displacement.

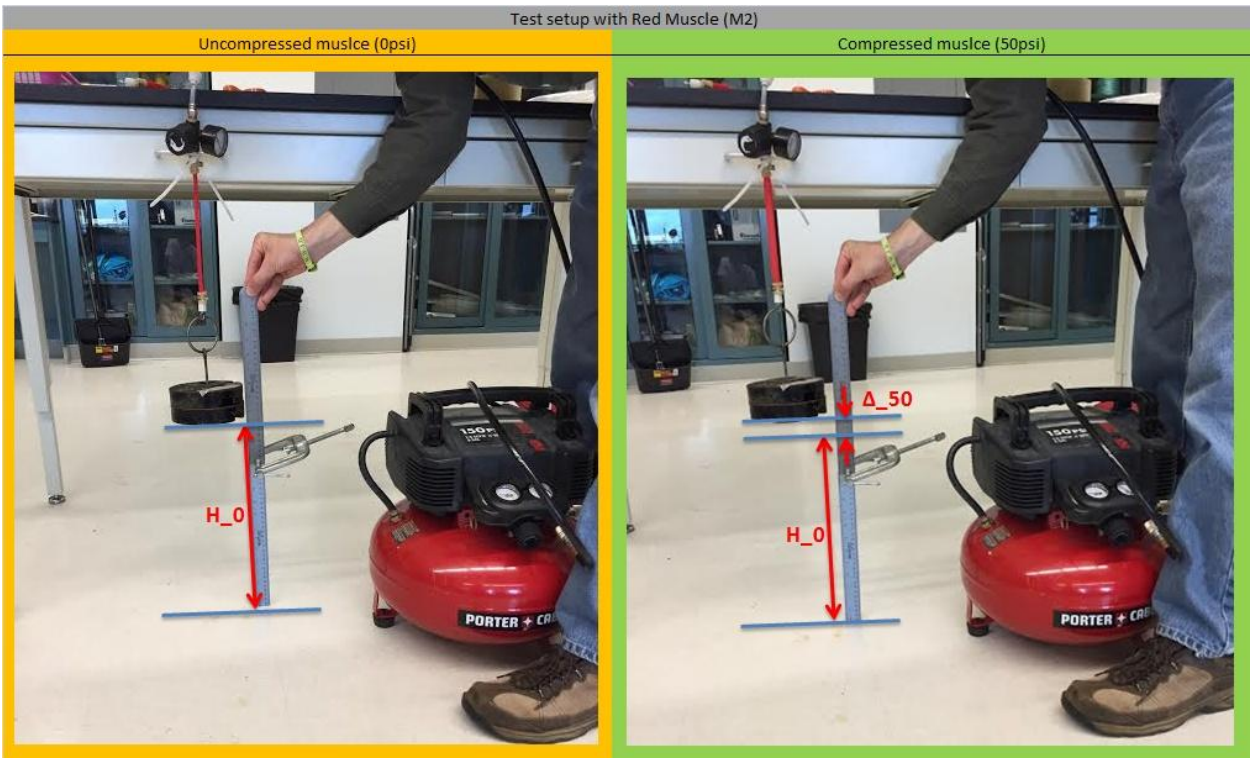

Figure 1: Test Rig

Procedure

The tests were performed by varying the pressure and measuring the height from the floor. There is little deflection from 0-30psig so measurements began at 30psi and increased by 5 or 10psi as shown in Table 5.

		Pressure (psig)										Notes
		0	30	35	40	45	50	55	60	65	70	80
Raw Height	Test 1	15.94			16.06		16.38		16.63		16.75	Leak and no change
	Test 2	15.63	16.00	16.06	16.19		16.50		16.75		16.88	
	Test 3	15.69	15.81	16.00	16.25	16.38	16.50	16.63	16.75			Leak at 60
	Test 4	14.00	14.13	14.25	14.38	14.75	15.00	15.13	15.25	15.38	15.50	
	Test 5	14.13	14.25	14.63	15.00	15.25	15.50	15.63	15.75	15.81	15.88	
	Test 6	13.75	14.06	14.50	14.88	15.13	15.25	15.38	15.50	15.63	15.69	

Table 5: Raw Height Data

All units in the test matrix are inches except for the **Pressure** which is psig. Test 1 pushed the upper limits and found that the homemade muscle leaked at 80psi with no change in deflection from 70psi. (it also leaked at 60 psi in Test 3.

Results

In order to better interpret the data, the change in deflection for each test was calculated and arranged in Table 6.

		Pressure (psig)									
		0	30	35	40	45	50	55	60	65	70
Deflection Δ	M1) 10.1lb	0.00			0.13		0.44		0.69		0.81
	M1) 5.6lb	0.00	0.38	0.44	0.56		0.88		1.13		1.25
	M1) 2.9lb	0.00	0.13	0.31	0.56	0.69	0.81	0.94	1.06		
	M2) 10.1lb	0.00	0.13	0.25	0.38	0.75	1.00	1.13	1.25	1.38	1.50
	M2) 5.6lb	0.00	0.13	0.50	0.88	1.13	1.38	1.50	1.63	1.69	1.75
	M2) 2.9lb	0.00	0.31	0.75	1.13	1.38	1.50	1.63	1.75	1.88	1.94

Table 6: Deflection and Pressure Results

The results of Table 6 were plotted directly into Figure 2 to show the relationship between strain and pressure **(c)**.

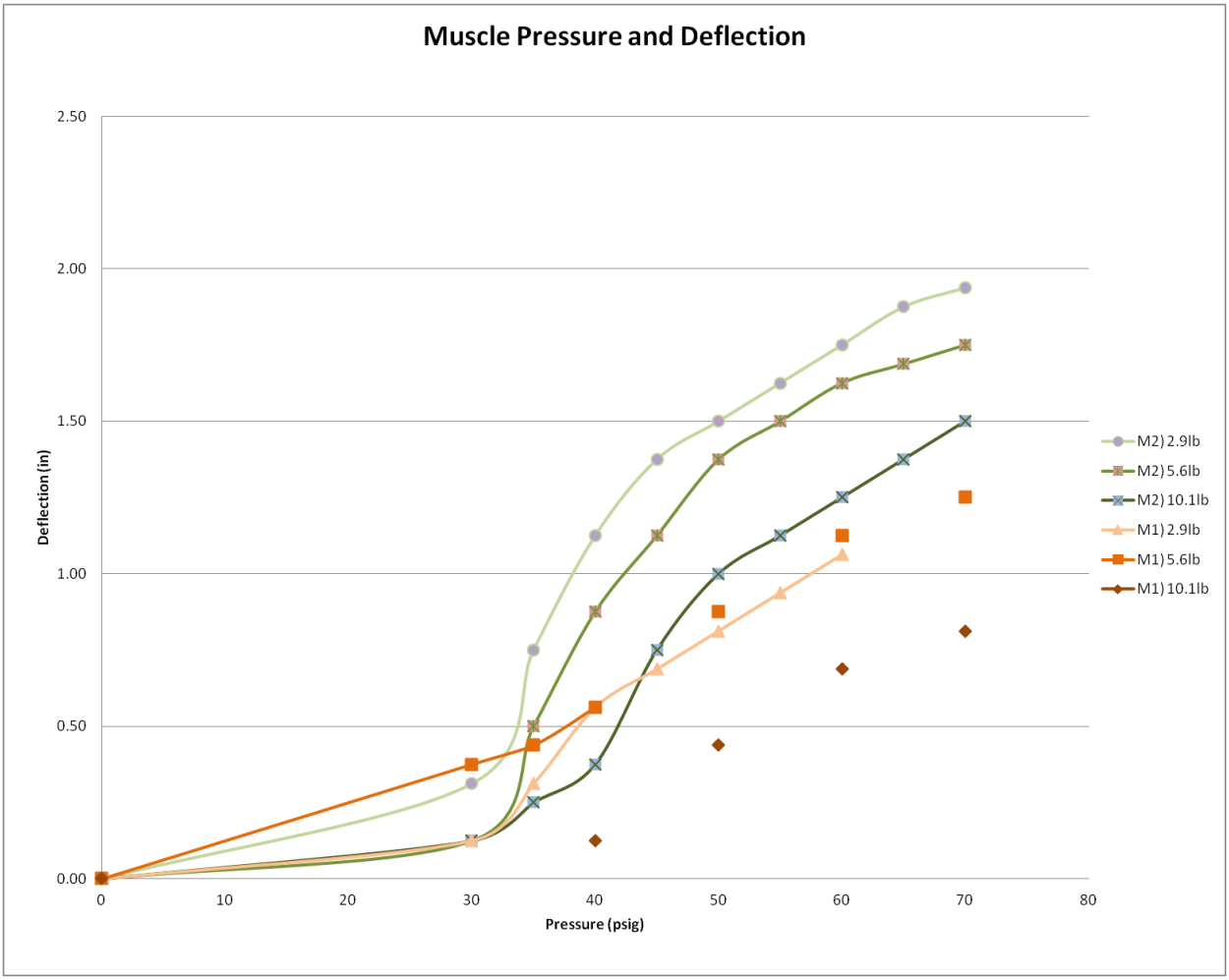

Figure 2: Muscle Pressure and Deflection

In order to better visualize the relationship between strain and force, the data from each muscle was plotted separately.

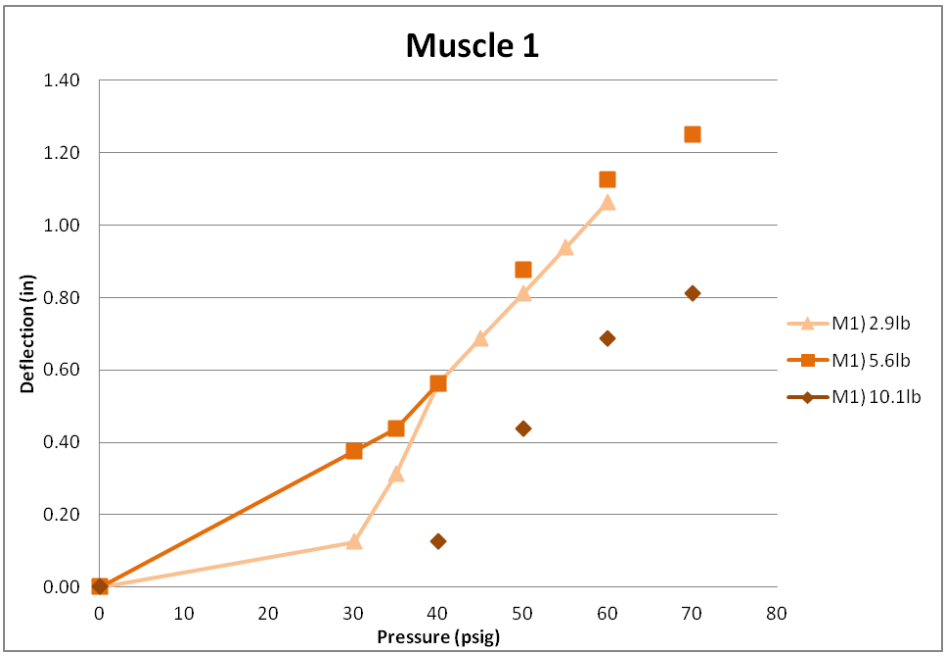

Figure 3: Muscle 1 Strain and Pressure

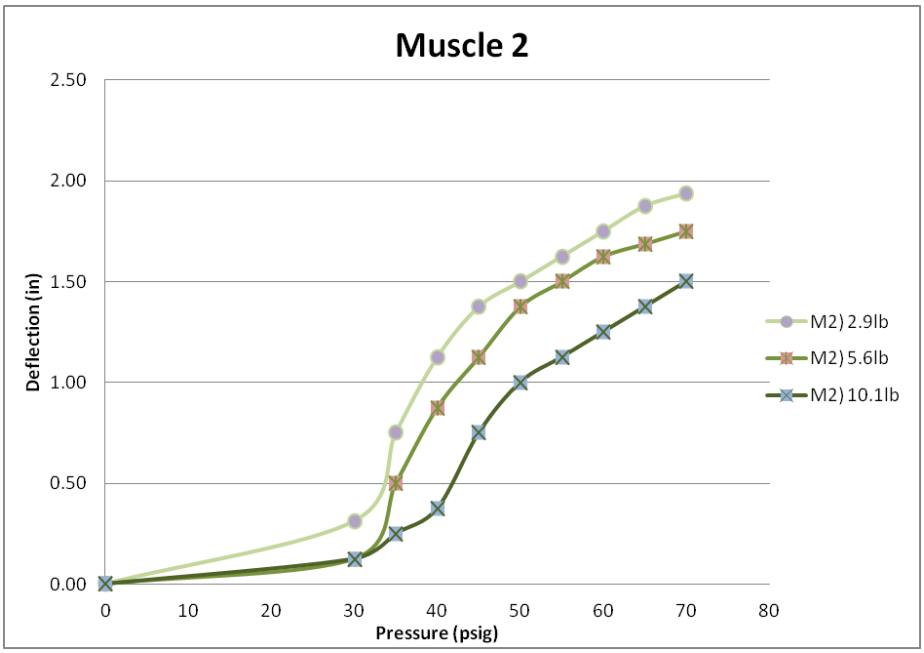

Figure 4: Muscle 2 Strain and Pressure

Figure 3 and Figure 4 demonstrate that the amount of strain tends to decrease with increased force **(d)**. This trend is most visible by observing the gap between the plots of 10.1lbs and 5.6lbs of force. Between 2.9lbs and 5.6lbs there appears to be much less of a disparity and in Figure 3 there appears to be a slight increase in strain from 2.9lbs to 5.6lbs of force. This discrepancy is small and may be due to various measurement errors as well as uncertainty in the muscles and test repeatability.

The relationship between strain and size **(e)** can be seen by comparing the performance of the two muscles under similar loading.

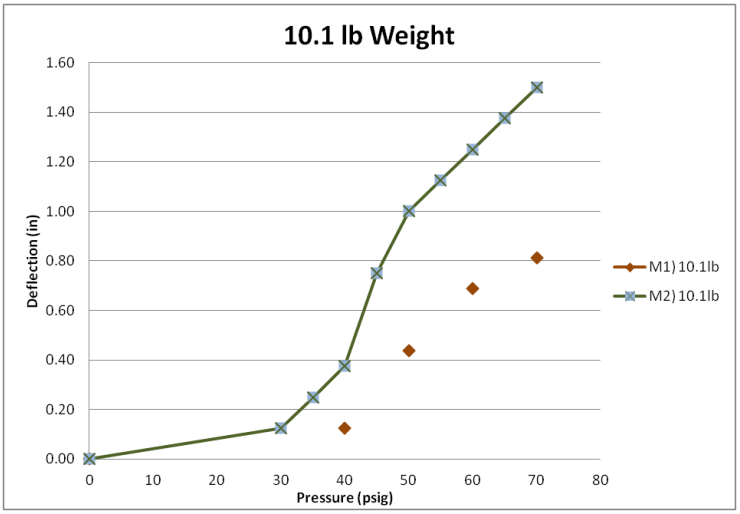

Figure 5: Strain and Pressure 10.1lb Weight

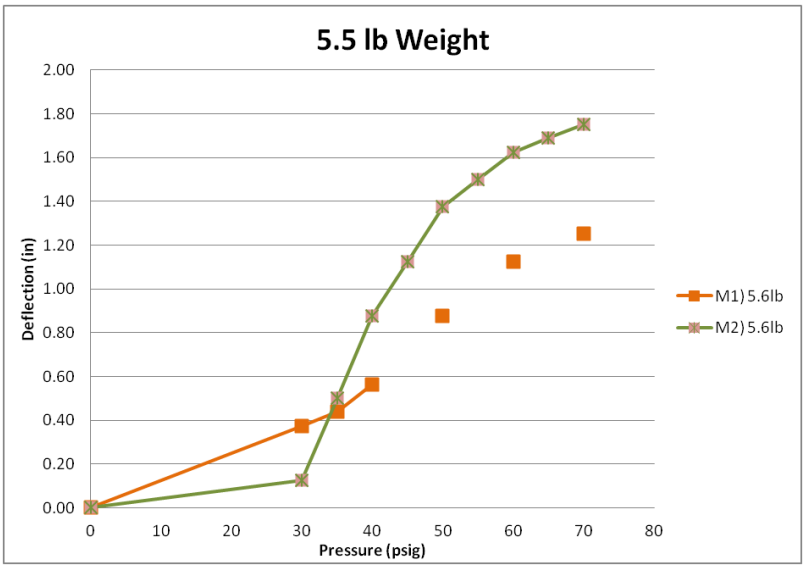

Figure 6: Strain and Pressure 5.5lb Weight

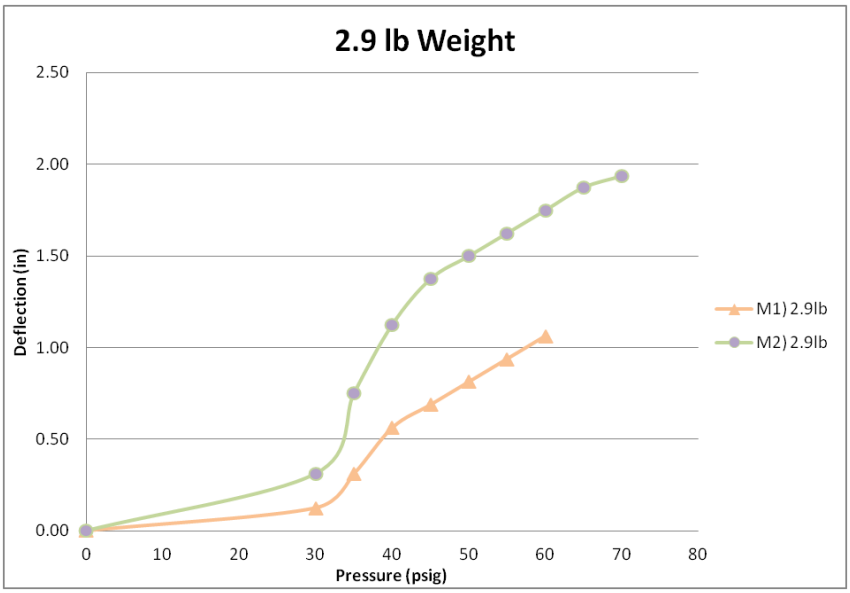

Figure 7: Strain and Pressure 2.9lb Weight

Figure 5, Figure 6, and Figure 7 confirm that the larger muscle (M2) consistently yields more strain than the smaller muscle (M1).

Conclusions

a) *What supplies are needed to make an air muscle?*

The team now has an understanding of the necessary supplies and components which ultimately affect the BOM.

b) *How can we regulate the pressure?*

The team learned that there are functional pressure regulators in the BAD Lab that can be quickly connected to the shop air tank.

c) *What is the relationship between strain and pressure?*

After 30psig the strain increases dramatically with pressure as shown in Figure 2.

d) *What is the relationship between force and strain?*

Strain decreases with force as observed in Figure 3 and Figure 4.

e) *What is the relationship between strain and size?*

Strain increases with size as shown in Figure 5, Figure 6, and Figure 7.

f) *What are the next steps for muscle optimization stage II?*

See below.

Next Steps

A. Identify Needs from Other Tests

B. Design Muscle

C. Construct and Test Optimized Muscle

Identify Needs from Other Tests

The next step is to construct an optimized muscle based on limits, ideals, and information from the following tests:

I. CAIR Tank Regulation and Capacity test
    a. **Need:** Pressure ceiling
    b. **Need:** Volume limitations & model confirmation
II. Lower Foot Attachment Test
    a. **Need:** Local fabric strain
    b. **Need:** Actual lifting force required
III. Upper Foot Attachment Test
    a. **Need:** Local fabric strain
    b. **Need:** Force ceiling
IV. Muscle Optimization Stage I
    a. Found: Pressure vs. strain, relationship & empirical data
    b. Found: Force vs. strain, relationship & empirical data
    c. Found: Size vs. strain, relationship & empirical data

Design Muscle

After all the information above is obtained, the next step would be to analyze all the various constraints and identify the following optimized muscle parameters:

- Length
- Width
- Force
- Strain Capacity
- Operating Pressure
- Plug and fitting specs

Construct and Test Optimized Muscle

Once the stage II optimized muscle is designed, it must be constructed and tested to reveal further iteration requirements.