Measuring Forces

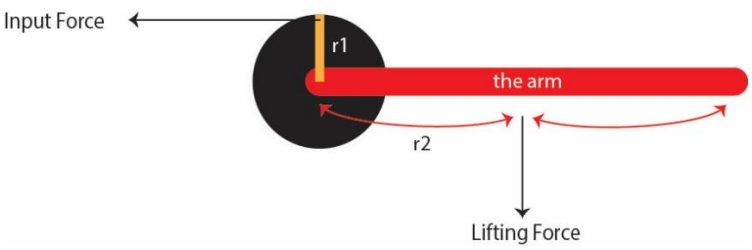


Figure 1: Force Diagram

Table 1: Equations Used

Torque (τ)	$F * r * \sin\theta$
Lifting force (F)	$F = \frac{f * r1}{r2}$ where f is the input force, r1 is the radius of the wheel, and r2 is the length of the arm

Table 2: Length of Measured Segments

Joint Name	Pulley Radius (m)	Segment Length (m)
Elbow	0.03	0.37
Arm	0.05	0.66
Shoulder	0.06	0.86

Results

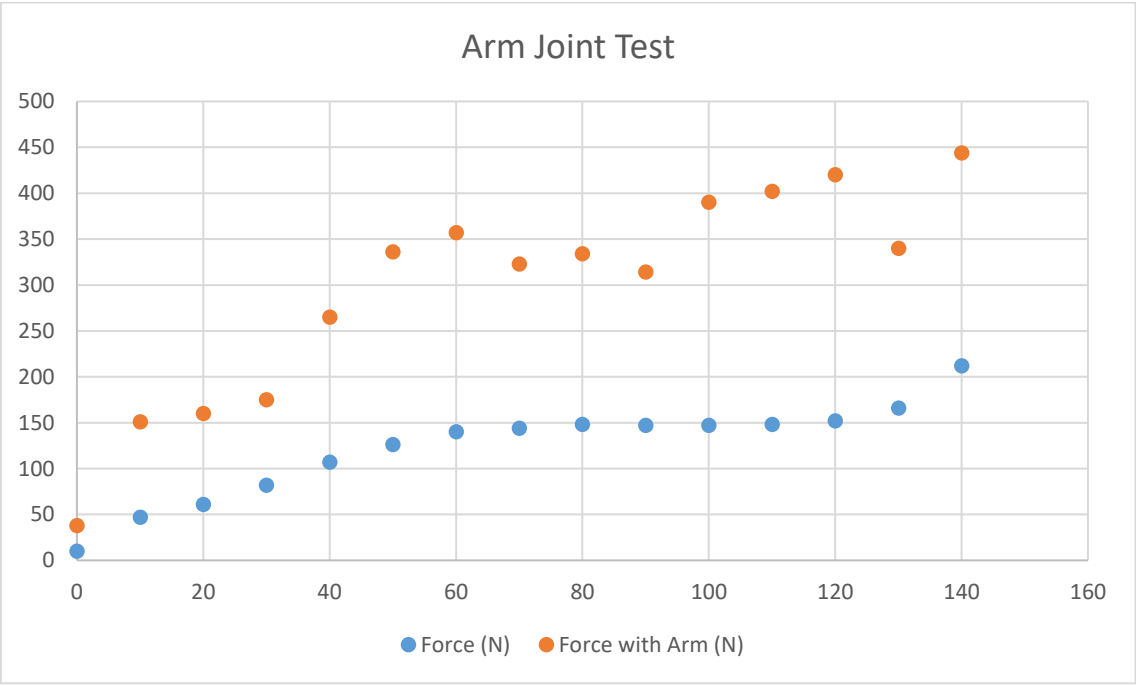


Figure 2: Results from Arm Test

Table 3: Summary of Results – Testing the Arm Joint

Test	Input Force Max. (N)
No Arm	212
Lifting Arm (little acceleration)	444
Lifting Arm (dynamic test)	753
Overall Max.	753

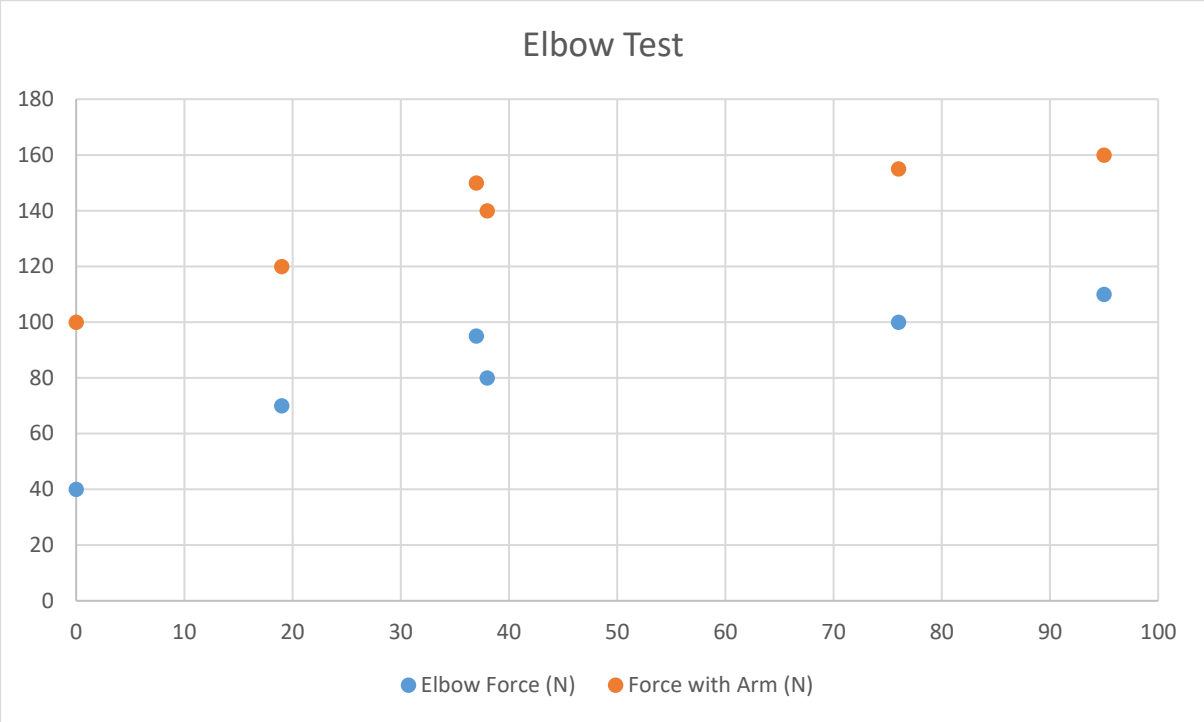


Figure 3: Results from Elbow

Table 4: Summary of Results – Testing the Elbow Joint

Test	Input Force Max. (N)
No Forearm	110
Lifting Forearm (little acceleration)	160
Lifting Forearm (dynamic test)	236
Overall Max.	236

Table 5: Summary of Results – Testing the Shoulder Joint

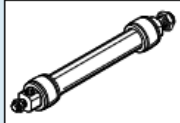
Test	Input Force Max. (N)

No Arm	147
Lifting Arm (little acceleration)	330 (joint has a limited range of movement)
Lifting Arm (dynamic test)	None
Overall Max.	330

Table 6: Summary of Forces Measured

Joint	**Measured Max Force (N)**
Arm	753
Elbow	236
Shoulder	330

Muscle Specifications based on the Forces above

Function	Version	I.D. [mm]	Nominal length [mm]	Lifting force [N]
Single-acting, pulling	Fluidic Muscle with press-fitted connection			
		5	30 ... 1000	0 ... 140
		10	40 ... 9000	0 ... 630
		20	60 ... 9000	0 ... 1500
		40	120 ... 9000	0 ... 6000

I.D. [mm]	Max. permissible pretensioning	Max. permissible contraction	Operating pressure [bar]	→ Page/Internet
Fluidic Muscle with press-fitted connections				
5	1% of nominal length	20% of nominal length	0 ... 6	11
10	3% of nominal length	25% of nominal length	0 ... 8	
20	4% of nominal length	25% of nominal length	0 ... 6	
40	5% of nominal length	25% of nominal length	0 ... 6	

Figure 4: Festo Air Muscle Specifications

Equations Used

$$pulley\ radius = test\ pulley\ radius * \frac{target\ force}{current\ force}$$

$$length\ of\ muscle = \frac{1}{contraction} * 2 * \pi * pulley\ radius$$

Muscle Length Specification for the Arm Joint **(target force 753N)**

Internal Diameter (mm)	Minimum Pulley Radius (m)	Length of Muscle (m)
5	0.25	7.853
10	0.05	1.256
20	0.0	Nil
40	0.0	Nil

Muscle Length Specification for the Elbow Joint **(target force 236N)**

Internal Diameter (mm)	Minimum Pulley Radius (m)	Minimum Length of Muscle (m)
5	0.03	0.942
10	0	Nil
20	0	Nil
40	0	Nil

Muscle Length Specification for the Shoulder Joint **(target force 330N)**

Internal Diameter (mm)	Minimum Pulley Radius (m)	Minimum Length of Muscle (m)
5	0.12	3.769
10	0	Nil
20	0	Nil
40	0	Nil

Nil – These muscles can provide the forces required, and do not need a pulley

Python Code

```
import math

j_names  = ["Shoulder", "Arm", "Elbow"]
j_radius = [0.06      , 0.05 , 0.03   ]
j_forces = [330       , 753  , 236    ]

m_names  = ["5", "10", "20", "40"]
m_forces = [140, 630 , 1500, 6000]
m_contra = [5  , 4   , 4   , 4   ]

eq_minimum_scale = lambda target_f, current_f, current_scale : (target_f / current_f) * current_scale

#for each muscle find its minimum scale
p = [
        [eq_minimum_scale(j_forces[i], c_f, j_radius[i]) for i in range(len(j_names))] for c_f in m_forces
    ]


for i in range(len(m_names)):
    print "diameter, minimum length"
    print m_names[i], ": ", zip(j_names, p[i], [j * m_contra[i] * 2 * math.pi for j in p[i]])
```

My Recommendation

Joint Name	Muscle Diameter (mm)	Pulley Radius (m)	Muscle Length (m)
Arm	20	any	any
Elbow	10	any	any
Shoulder	10	any	any