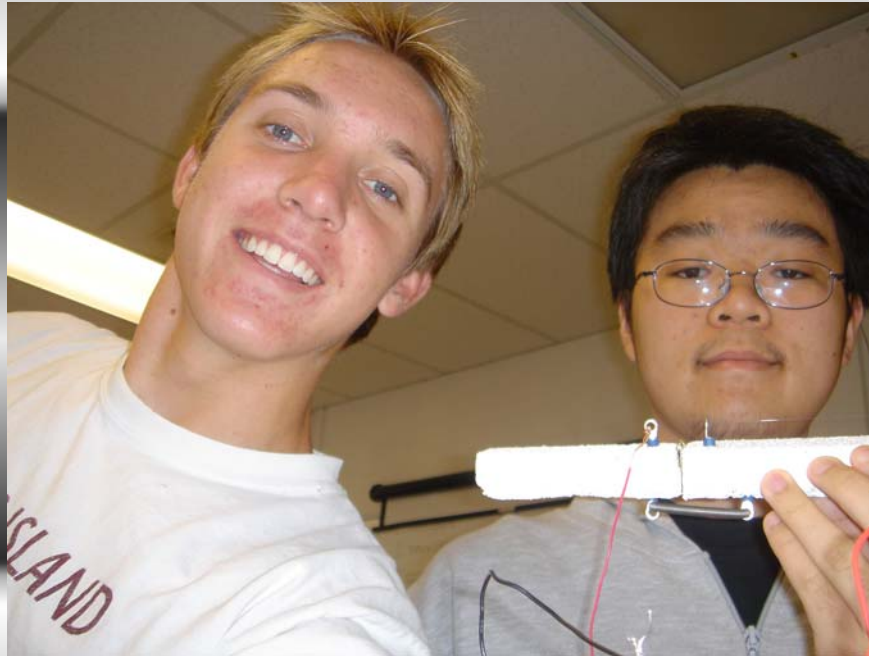


Shape Memory Alloy Hand



By Ian and Alex

Goals

- To create an artificial hand as similar as possible to a human hand.
- We thought that the hand is very useful and could have many applications such as prosthetics and in surgeries.



Model of Human Hand

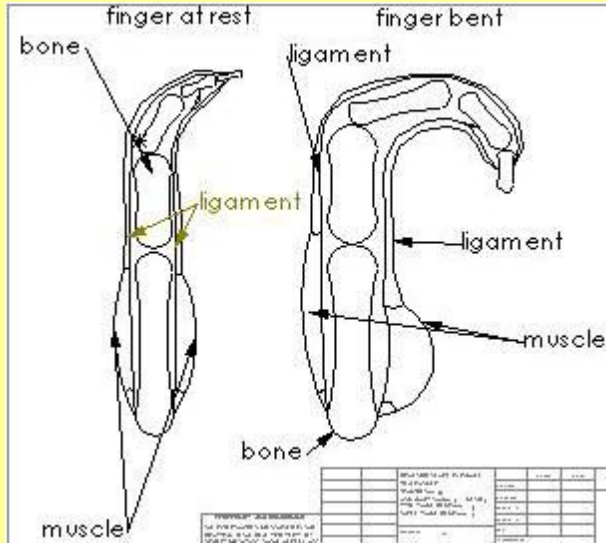
What Are the Applications of an Artificial Hand?

- As a part of an assembly line
- Used for surgeries
- As a prosthetic

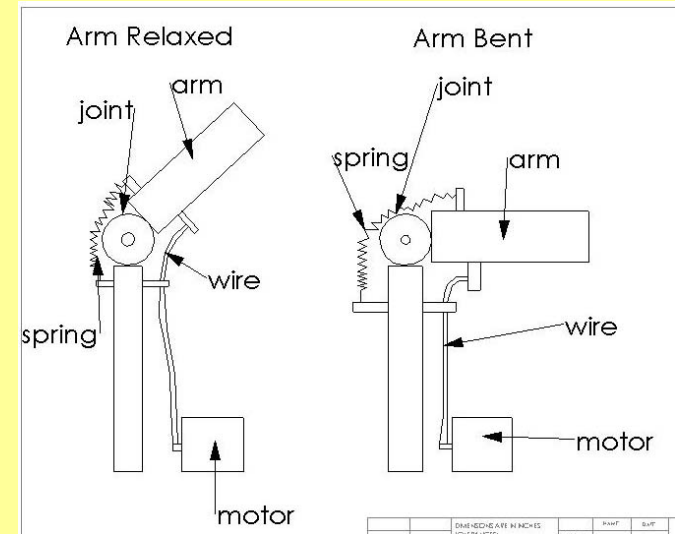


The i-LIMB Prosthetic Hand

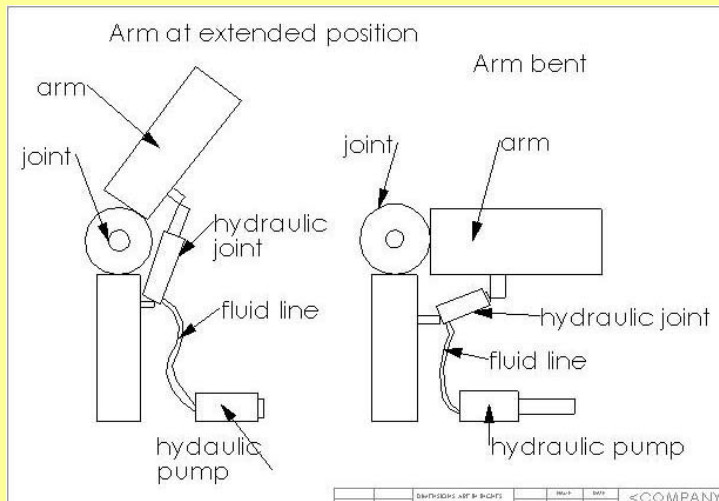
Possible Actuators



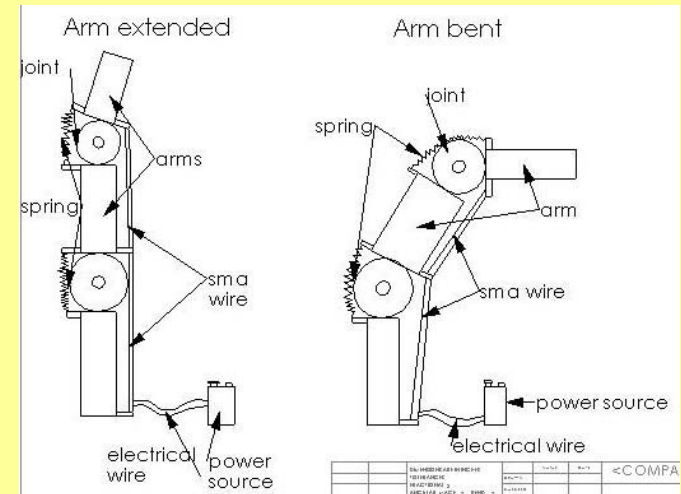
Human Finger



Motor Finger



Hydraulic Finger



SMA finger

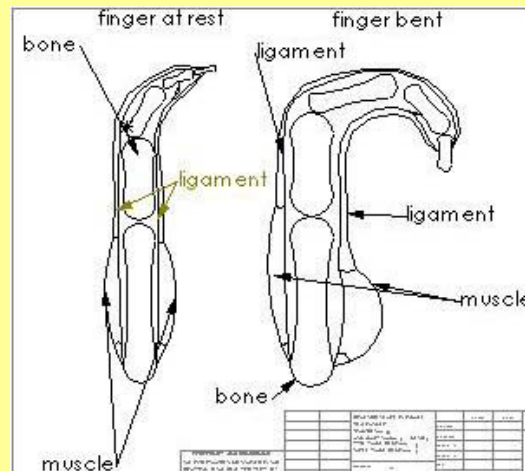
Similarities and Differences Between Designs and Hand

Similarities

- They bend
- Have structural pieces similar to bone
- Connected by joints that hold the structures together
- Mimic the function of a ligament

Differences

- No design uses a second muscle to extend
- Designs all depend either on springs or the ability to push.
- None of the designs are able to move side to side.



Human Finger

Why SMA for Hand?

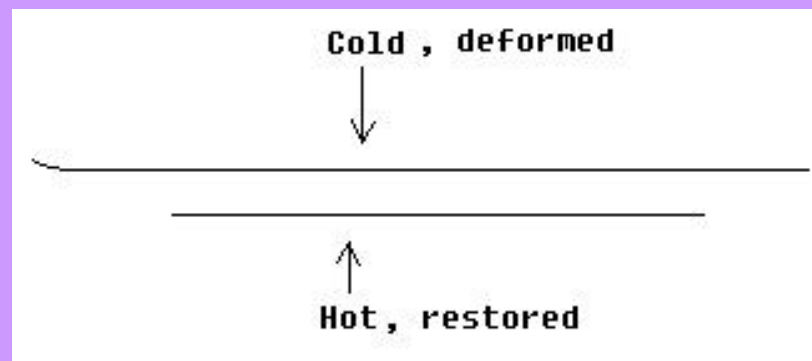
- Requires little space
- Does not make noise
- Closest to simulating human muscle movement



SMA wire

What is an SMA?

- SMA (Shape Memory Alloy)
- Is a metal alloy that can be deformed and restored to its original shape by a change in temperature.
- When SMAs are deformed, they will maintain a deformed shape until they are heated to what is called a transition temperature.
- At the transition temperature, they reconfigure themselves into their original shape.
- SMAs have a limited amount of deformation that they can recover from, so they are not always able to return to the original position if the change in shape is too great.

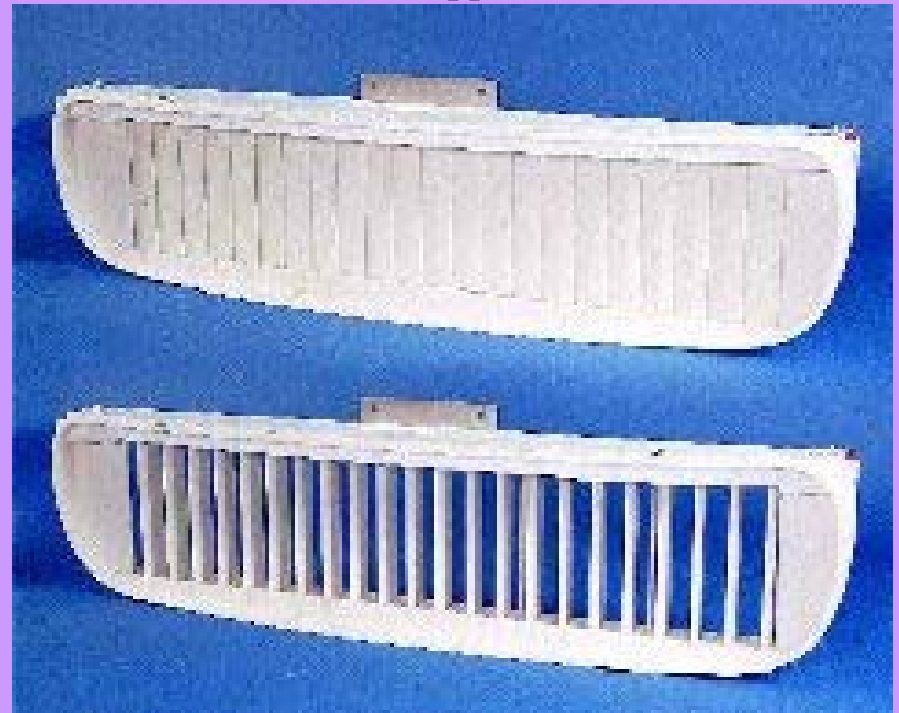


An example of an SMA

Applications of SMA

- Glasses
- Fire Sprinklers
- Shower Heads
- Braces
- Engine Ventilation for Cars

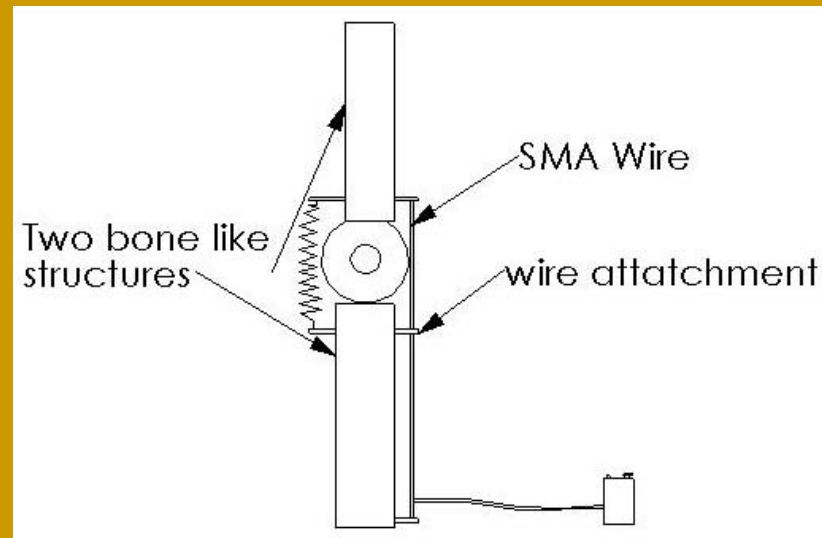
SMA Wire located in upper cross beam of intake



Prototype GM SMA Grill

Preliminary Design

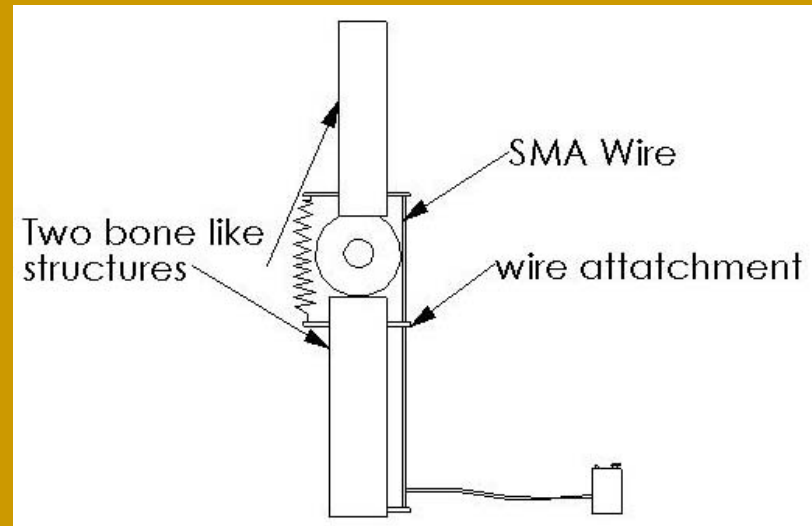
- Provides a basic idea of how the hand will work:
 - Two bone-like structures as the body of the finger
 - An SMA wire attached to both bone structures



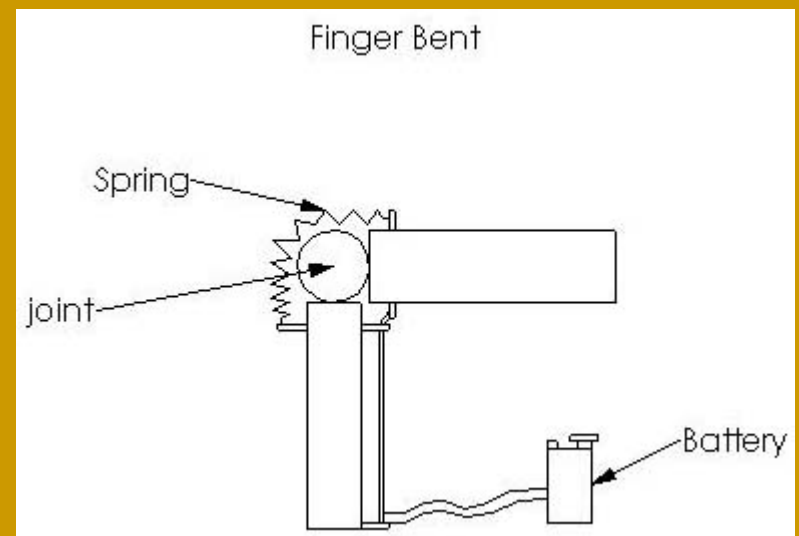
Preliminary SMA design

Preliminary Design

- A battery will heat up the wire and cause the SMA to contract, bending the joint
- A spring will be placed on the back of the finger to restore it to an upright position.



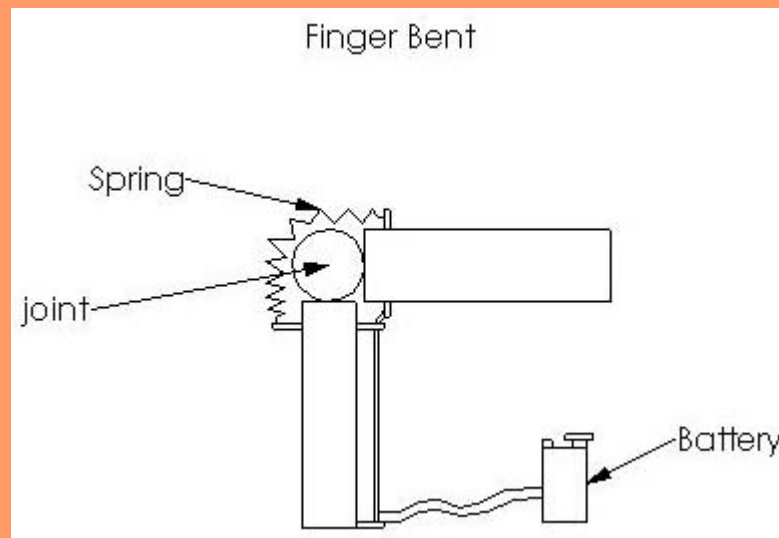
SMA Finger Extended



SMA Finger Contracted

Main Issues:

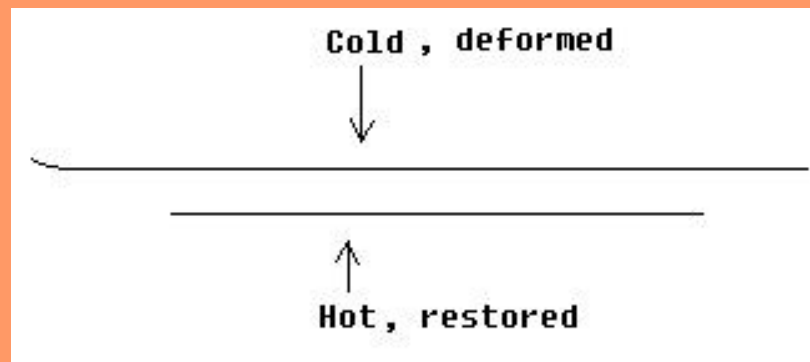
- Will the finger bend?
 - How long does the wire need to be?
 - Will it be able to reach transition temperature?
 - Will the spring be soft enough for the wire?



SMA Finger Bent

Why is the Length of Wire Important?

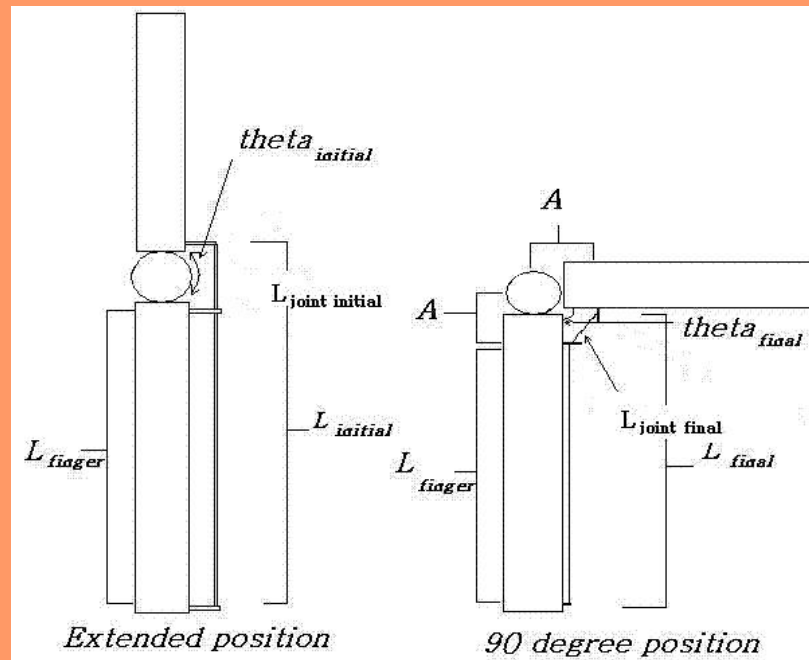
- The amount of contraction we get from the wire will determine the amount the finger rotates about the hinge.
- The amount of contraction is dependent on the total length of the wire.
- The more wire, the more the finger will bend.



SMA Wire Transitioning

How Much Length of Wire Do We Need?

- The answer to this question depends on the change in length of the wire.
- We can use our knowledge of isosceles right triangles to determine this.

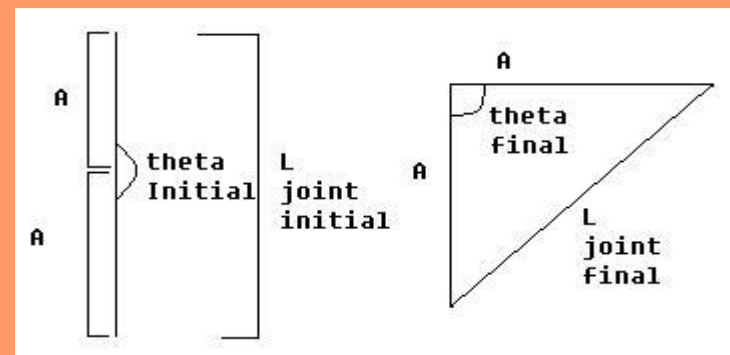
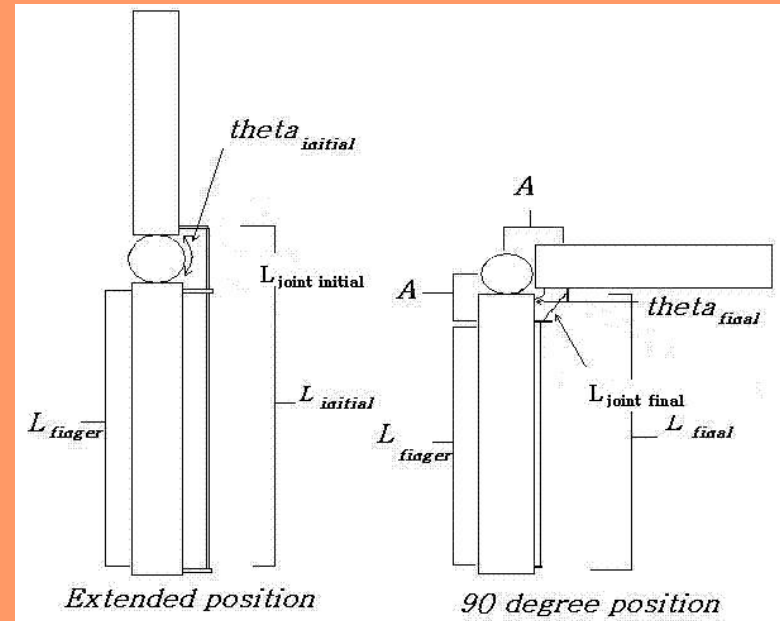


SMA Finger in Two Positions

Calculations for Length

Given: $A=1/2$ inch and Contraction amount of 4.3%:

- $L_{\text{initial}} = L_{\text{finger}} + L_{\text{joint initial}}$
 $= L_{\text{finger}} + 2A$
- $L_{\text{final}} = L_{\text{finger}} + L_{\text{joint final}}$



Magnified View of Joint (Labeled)

Calculations for Length

Given: A=1/2 inch and Contraction amount of 4.3%:

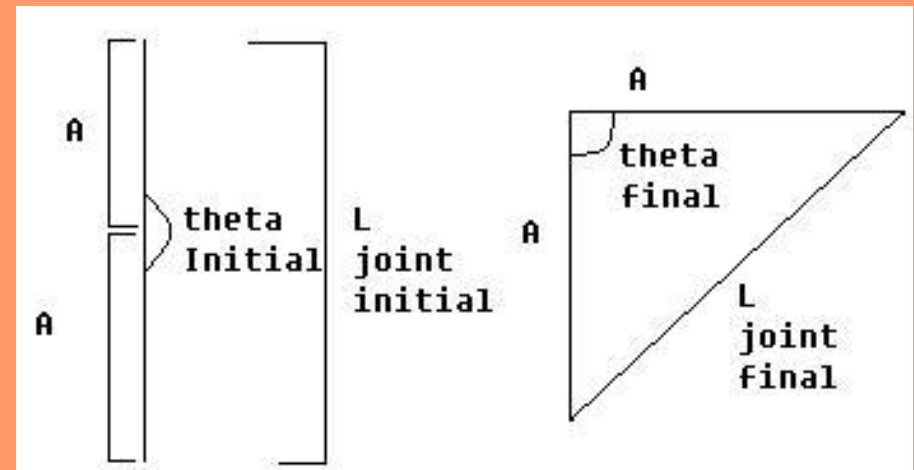
- $L_{\text{joint final}}$ is $A\sqrt{2}$ in length, which can be found by knowing isosceles right triangles.

$$=L_{\text{finger}} + A\sqrt{2}$$

- $\Delta L = L_{\text{initial}} - L_{\text{final}}$
 $= (2 - \sqrt{2})A$
 $= 0.6A$
 $= 0.3''$

- $L = \Delta L / 0.043$

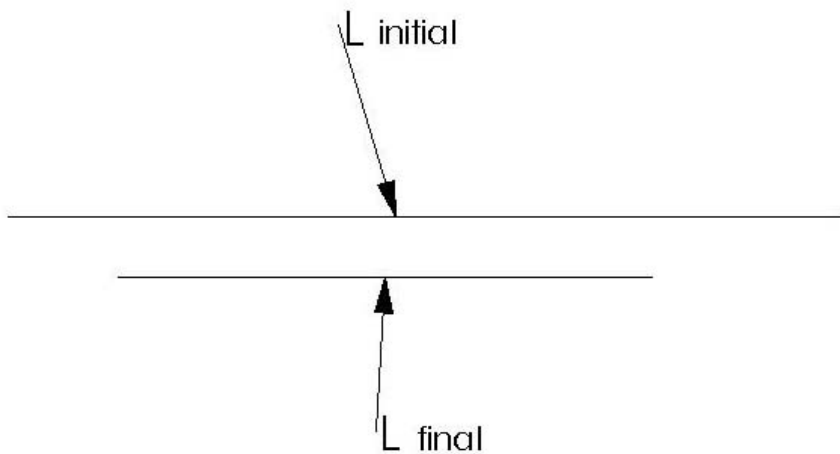
- **$L = 7''$**



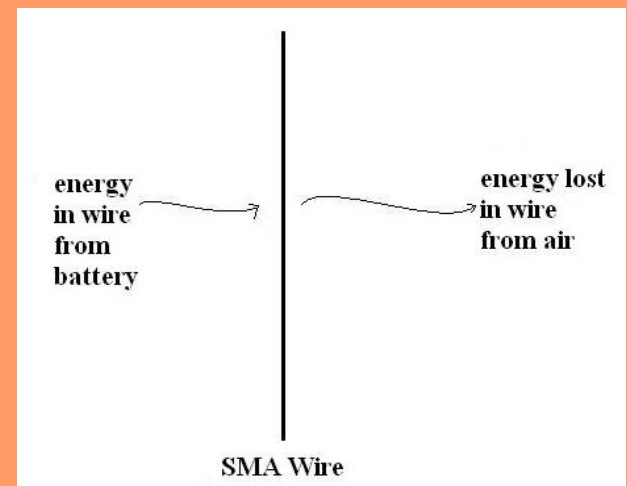
Based on these calculations, we need about 7 inches of wire to get a contraction of 0.3 inches and a rotation of 90 degrees.

Will the Wire Reach Transition Temperature (70°C)?

- Why is this important?—The transition temperature needs to be hit in order to get the change in length we want.
- When the wire reaches an equilibrium, the temperature at that point will be the maximum temperature.
- If this maximum temperature is greater than 70°C , then the transition temperature will be reached.



Wire before and after power



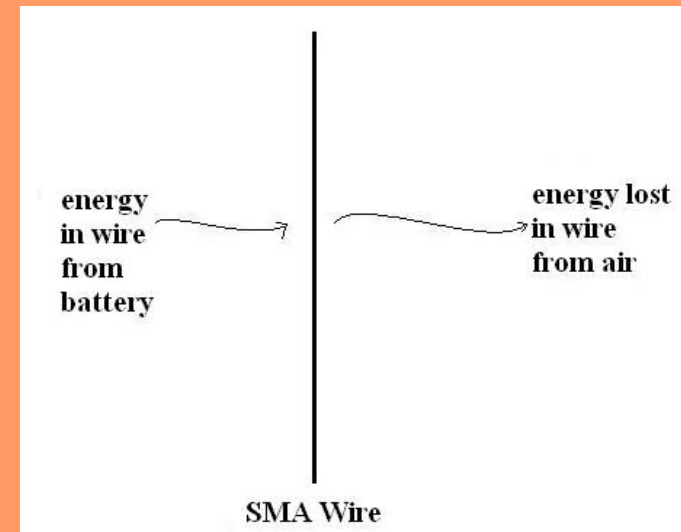
Energy in Wire

What Will the Maximum Temperature of the Wire Be?

- We need two formulas to aid us in finding the maximum temperature: $P=V^2/R$ and $Q_{\text{convection}}=h*S_{\text{wire}}(T-T_0)$
- $P=V^2/R$ is used to figure out the power being put into the wire by the battery, and $Q_{\text{convection}}=h*S_{\text{wire}}(T-T_0)$ is the rate of energy taken away from the wire from the air.
- We know that at the point when $Q_{\text{convection}}=P$, the system will be in thermal equilibrium and at the highest temperature it can reach.

Key

- P is rate of energy gained by the SMA wire supplied by the battery (J/s)
- V is the voltage across the battery (V)
- R is the total resistance in the wire (Ω)
- $Q_{\text{convection}}$ is rate of energy lost to air (J/s)
- h is the heat transfer coefficient ($J/(s*m^2*^{\circ}C)$)
- S_{wire} is the surface area of the wire (m^2)
- T is the current temperature in the wire ($^{\circ}C$)
- T_0 is room temperature, or the initial temperature of the wire ($^{\circ}C$)



SMA Energy Flow

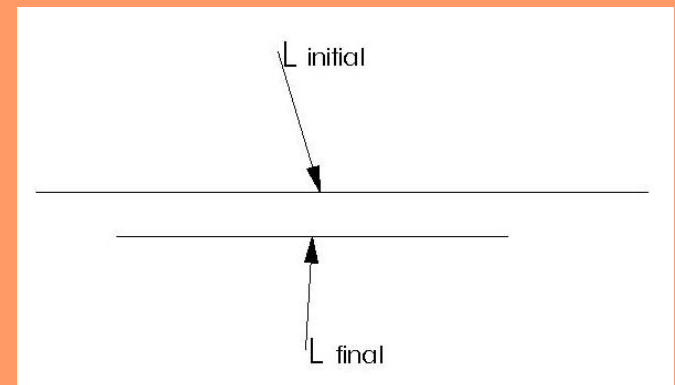
Calculations for Maximum Temperature (with 0.006" thick wire)

- $P=V^2/R$
 $=9V^2/9.1\Omega$
 $=1 \text{ J/s}$ (this value remains constant)
- $Q_{\text{convection}}=h*S_{\text{wire}}(T-T_0)$
 $=8 \text{ J/(s*m}^2*\text{°C)}*8.5*10^{-5} \text{ meters}^2*(T-T_0)$
- At equilibrium, $Q_{\text{convection}}=P$, Therefore:
- $9V^2/9.1\Omega=8 \text{ J/(s*m}^2*\text{°C)}*8.5*10^{-5} \text{ meters}^2*(T-T_0)$
- $T-T_0=(9V/9.1\Omega)/(8 \text{ J/(s*m}^2*\text{°C)}*8.5*10^{-5} \text{ meters}^2)$
- $T=T_0+(9V/9.1\Omega)/(8 \text{ J/(s*m}^2*\text{°C)}*8.5*10^{-5} \text{ meters}^2)$
 $=1450\text{°C}$, which is an exceptionally high temperature that fits one criterion but adds more problems.
- For a heat transfer coefficient of $18 \text{ J/(s*m}^2*\text{°C)}$,
 $T=645 \text{ °C}$, which certainly still fits the minimum temperature to pass.

These calculations show that the wire will be able to reach the transition temperature but is in potential danger of being too hot.

Given:

- $V=3V$
- $R=9.1\Omega$
- h is an experimentally attained value that should lie somewhere between 8 and $18 \text{ J/(s*m}^2*\text{°C)}$ based on test values by other groups.
- d is $1.52*10^{-4}$ meters
- L is $7''=0.1778$ meters
- $S_{\text{wire}}=\pi*d*L=8.5*10^{-5} \text{ meters}^2$
- $T_0=22\text{°C}$



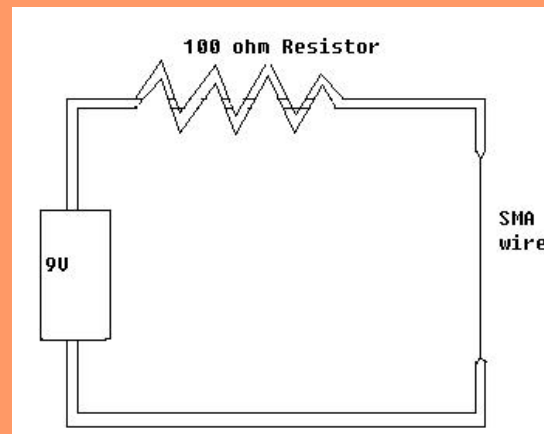
SMA Before and After Heating

How Do We Lower Maximum Temperature?

Because the projected temperature of the wire is too hot we need to find a way to lower the temperature.

- Of the two equations $P=V^2/R$ and $Q_{\text{convection}}=h*S_{\text{wire}}(T-T_0)$, increasing the resistance R is the easiest way to decrease maximum temperature.
- By adding a resistor of 100 ohms, the amount of power going into the SMA wire will be reduced, lowering the final temperature.
- When we insert the additional 100 ohm resistor into the previous data, we find that the heat transfer coefficients of 8 and 18 give final temperatures of **143** and **76** degrees Celsius, respectively.

This resistor will lower the final temperature significantly but still keep it above the transition temperature.



Circuit Diagram
With Resistor

Why is Knowing the Stiffness of the Spring Important?

- The SMA wire needs to have a greater pull force than the spring's restoring force when it has finished contracting.
- Otherwise, when the SMA attempts to contract, it will be unable to pull the foam finger along with it.
- Therefore, we need to use a formula to determine the stiffness of the spring.



Spring Relaxed



Spring Extended

Calculations for Maximum Stiffness the Wire Can Take

We want to know how stiff a spring the wire is able to handle when trying to pull 0.3 inches.

Given:

- To determine the maximum stiffness, we must know the maximum force the wire can pull with, and the change in length expected from the wire.
- From the Dynalloy website and we know that the wire can pull with a maximum force of 3.2N
- $F_s = kx$, and both the maximum F_s and x are known.
- $3.2\text{N} = k * 0.00762\text{m}$
- $k = 3.2\text{N} / 0.00762\text{m}$
 $= 420 \text{ N/m}$
- F_s is the restoring/pulling force of the spring
- k is the spring constant, which determines the spring's stiffness.
- m is the mass of the testing object
- x is the displacement from the relaxed position of the spring, discovered by knowing the necessary change in length of the wire.
- The wire is able to pull against a maximum force of 3.2N.
- 0.3 inches = 0.00762 m.

We now know that the spring constant must be less than 420 N/m for the wire to be able to bend the finger.

How Do We Determine the Stiffness of the Spring?

By hanging a known mass from one end of the spring and attaching the other to a firm surface, we can determine stiffness of the spring.

- $F_s = kx$ is the upwards restoring force of the spring
- $F_g = mg$ is the downwards force pulling the mass and spring down.
- When the mass is neither moving down nor the spring pulling the mass up, we know that $F_s = F_g$.
- Next, we measure x , which is the displacement of the spring from its resting state.
- Knowing x , m , and g , we can solve for k .



Spring
Test

Calculations for Spring Stiffness

Using two masses, we approximated a range for the possible stiffness of the spring.

- We used a 33 gram mass first and a 230 gram mass second to give two tests for the spring constant.
- With $kx=mg$, we measured the displacements of the spring, and solved for k .
- $k*0.8\text{cm}=33\text{g}*9.8\text{m/s}^2$ [for the first test with a 0.8 cm. displacement]
 $k=(33\text{g}*1\text{kg}/1000\text{g}*9.8\text{m/s}^2)/(0.8\text{ cm}*1\text{m}/100\text{cm})=40\text{ N/m}$
- Repeating the test for the 230 gram mass, we got **18 N/m** when the displacement was 12.0 cm.

Since the spring constant lies well beneath what the wire is able to pull, we are assured that the wire will be able to bend the finger.



Spring
Test 1



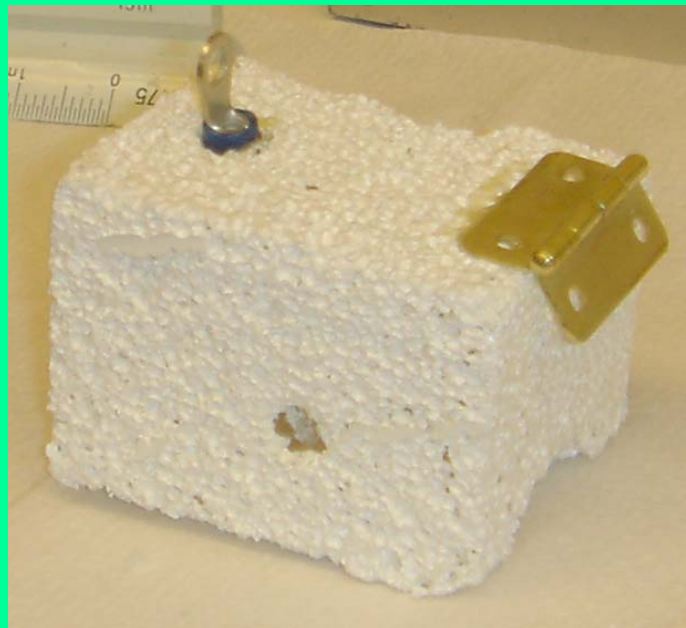
Spring
Test 2

Preliminary Design

- Using the results from the calculations we will design and build a test finger to determine the accuracy of our calculations.
- This will allow us to change any errors we may have made.

Preliminary Test

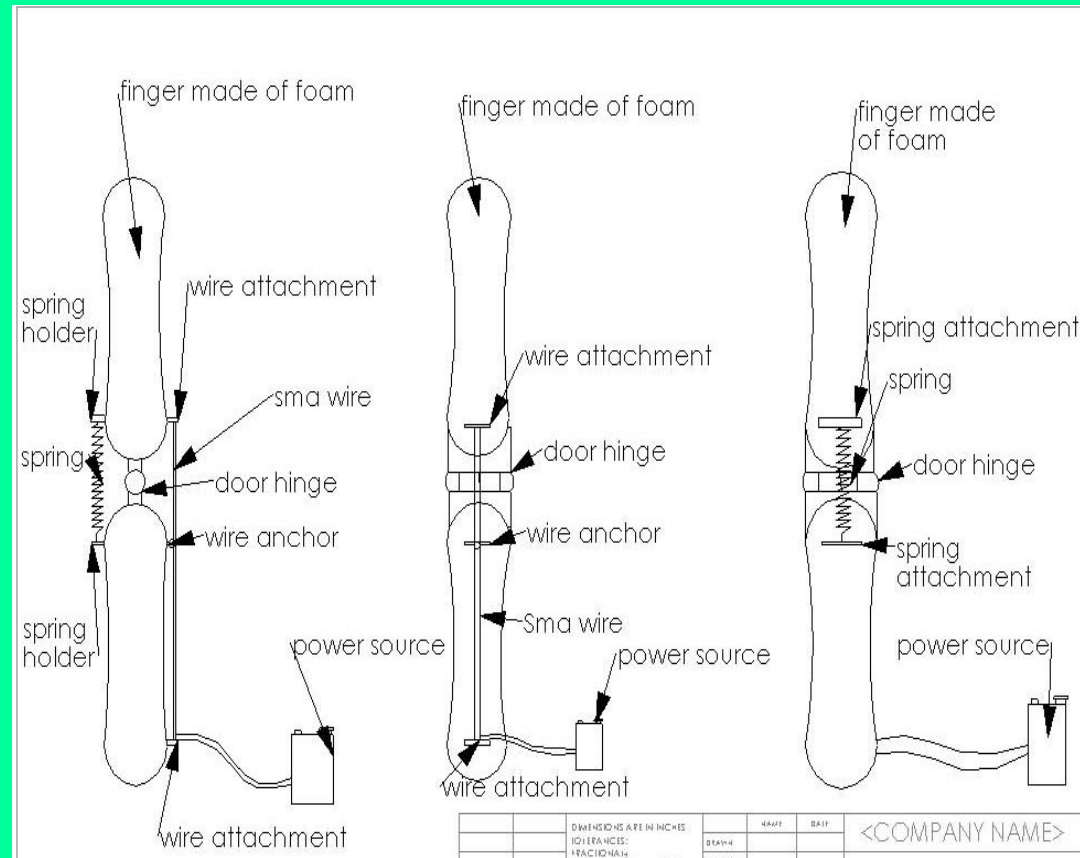
- To test foam strength, ring terminal and hinge security we attached them to a block of foam coated with primer.



Test Piece

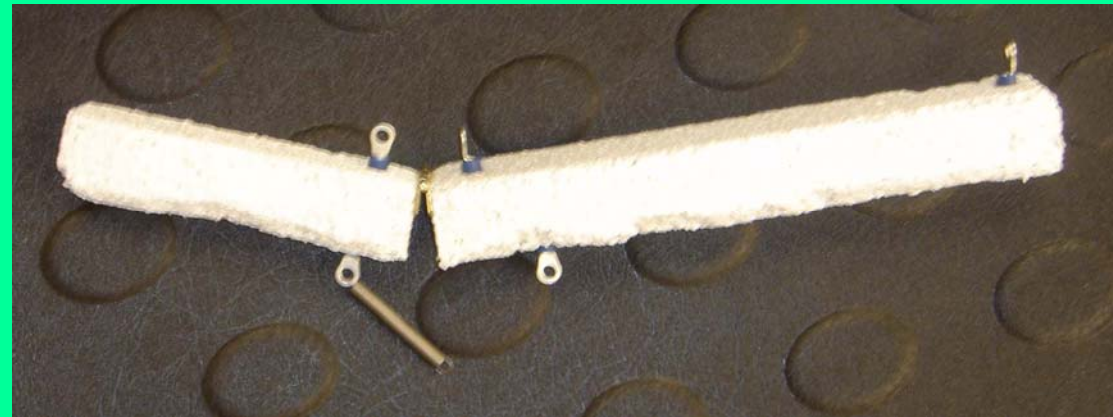
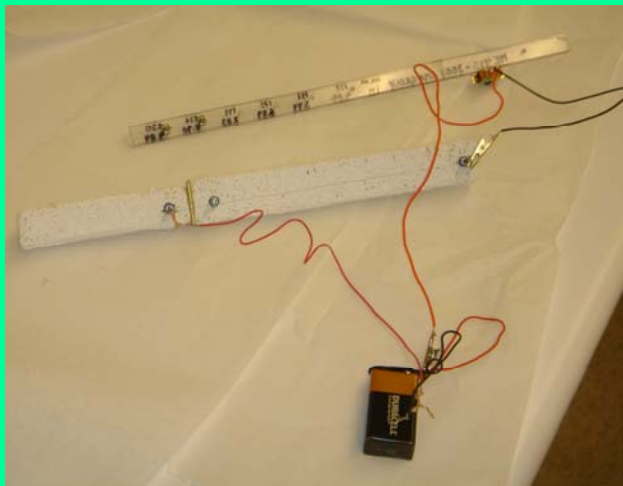
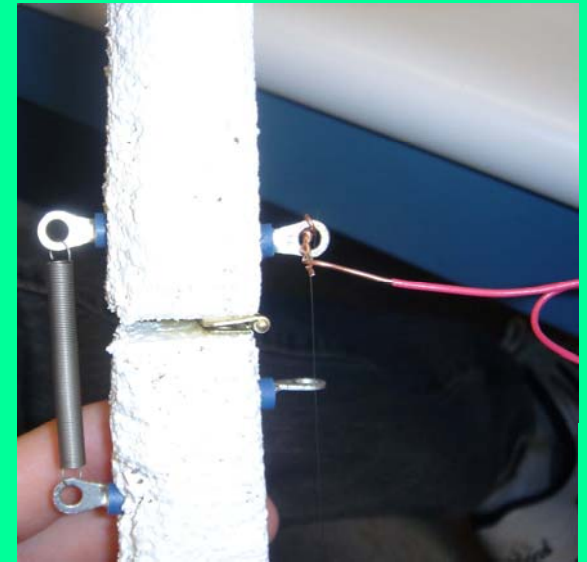
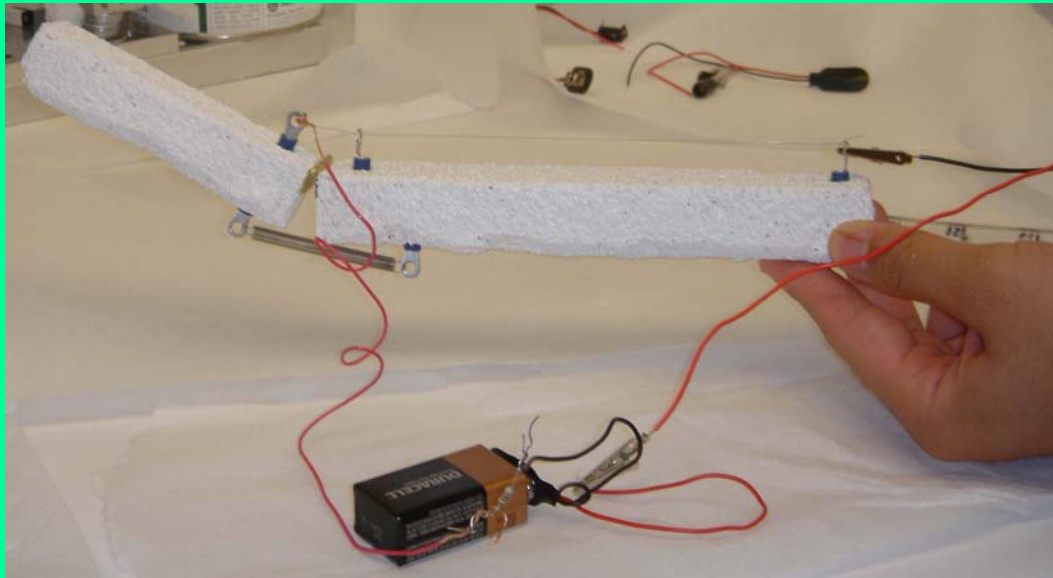
Preliminary Test Design

- Finger will be made of Styrofoam
- Foam will be coated with a primer
- Joint will be a door hinge joint
- Wire attachments will be ring terminals
- Batteries will be two AA batteries
- Batteries will be attached to the SMA at both ends using electrical wire.



Design

Preliminary Test Pictures



Results of Preliminary test

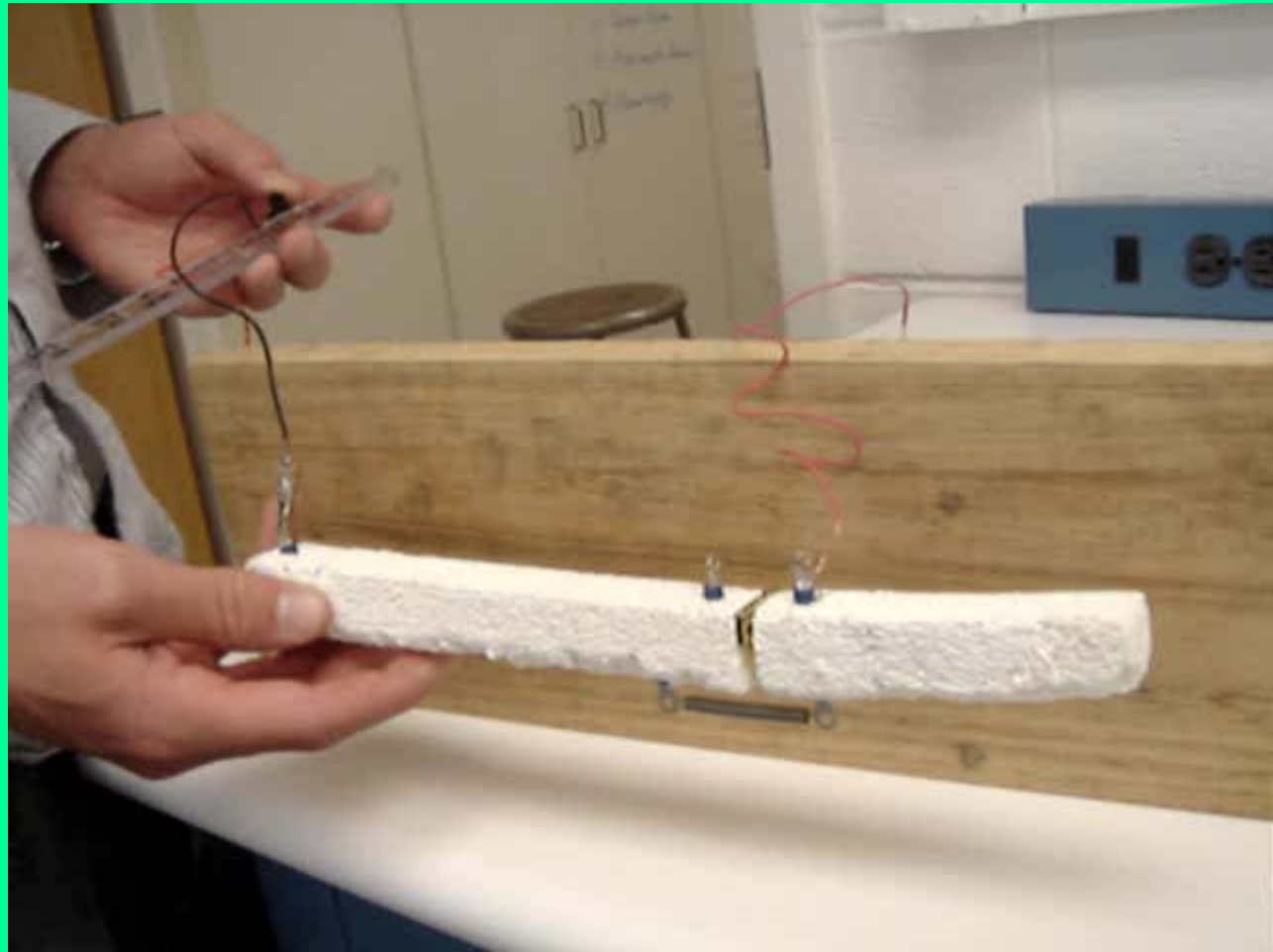
- Wire was not able to reach the transition temperature and finger did not bend.
- Two problems may exist: Heat transfer coefficient may be much larger than expected, and batteries may not be able to supply enough power.
- From here we added a 9V battery that succeeded in providing enough power to reach the transition temperature.



9V Battery

Secondary Test Movie

- With the 9V battery, the finger was able to move, although it was not able to reach 90 degrees
- The wire attachments need to be closer and/or the wire needs to be extended.



Why Did the First Test Fail?

[Estimating the Heat Transfer Coefficient]

Using a power supply with adjustable voltage and sufficient current, we can determine the minimum energy it takes to heat the wire to 70 degrees.

- The AA batteries were unable to get the SMA to reach transition temperature, so the heat transfer coefficient value might be very high.
- With two different known voltage and resistor values that just reach the minimum threshold for transition, we can approximate the value of the heat transfer coefficient within a decent range.
- Thus, applying $P = V^2 * R_{\text{wire}} / (R_{\text{total}})^2$ and $Q_{\text{convection}} = h * S_{\text{wire}} * (T - T_0)$, we can assume that we know the final temperature now, and set that equal to 70 degrees.



Power Supply



Resistors

Calculating the Heat Transfer Coefficient

- We know the different values of V and the added resistor while the resistance of the wire remains the same, and we assume that it is in thermal equilibrium at 70 degrees.

- Therefore we can once again set P equal to $Q_{\text{convection}}$ and we only have the one unknown, h , which can be solved with one equation:

$$V^2 * R_{\text{wire}} / (R_{\text{total}})^2 = h * S_{\text{wire}} (T - T_0)$$

- Example 1:

$$(4.72)^2 * (9.4) / (21.4)^2 = h * 8.5 * 10^{-5} * (70 \text{ }^\circ\text{C} - 22 \text{ }^\circ\text{C})$$

$$h = 106 \text{ W/m}^2 * \text{ }^\circ\text{C}$$

- From this we learn that the value of h is actually between 86 and 106, very different from our expected values of 8 to 18.

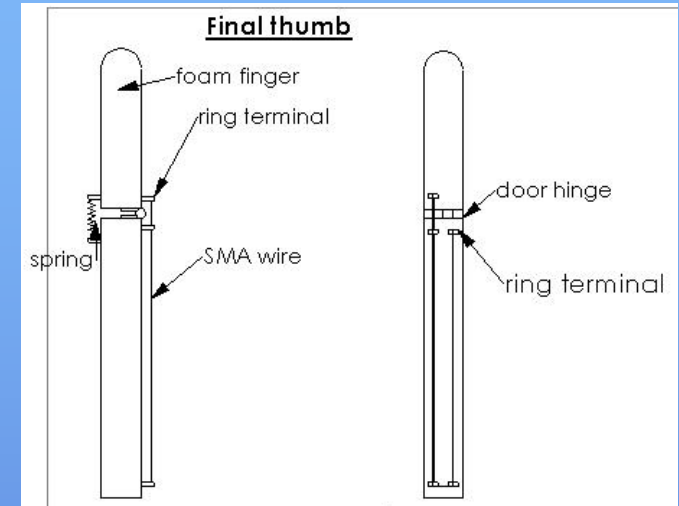
Given:

- $V_1 = 4.7 \text{ V}$
- $R_1 = 12 \text{ } \Omega$
- $V_2 = 7.2 \text{ V}$
- $R_2 = 27 \text{ } \Omega$
- $R_{\text{total1}} = 21.4 \text{ } \Omega$
- $R_{\text{total2}} = 36.4 \text{ } \Omega$
- $T = 70 \text{ }^\circ\text{C}$
- $T_0 = 22 \text{ }^\circ\text{C}$
- $S_{\text{wire}} = 8.5 * 10^{-5} \text{ meters}^2$

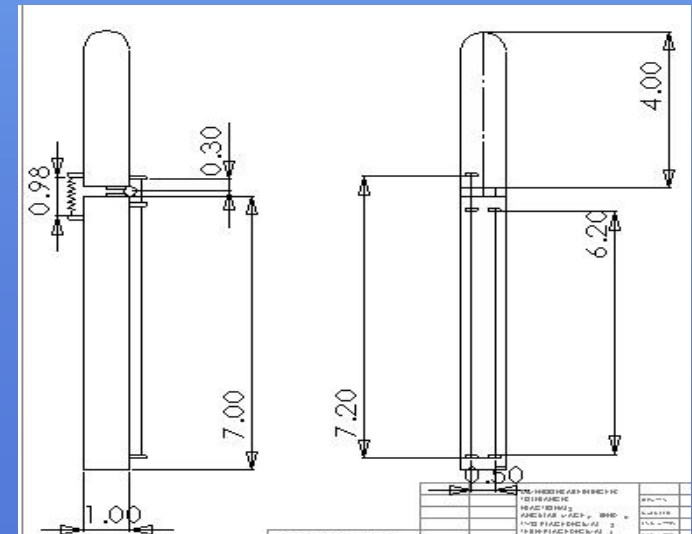
The heat transfer coefficient turned out to be about 7 times greater than expected, so by our calculations we would not have had sufficient power to reach transition temperature with the AA batteries

Changes in the Final Design (Thumb)

- SMA will be wrapped around the bottom to get double the contraction of the previous design.
- Ring terminals will be placed 0.3 inches away from the joint to obtain more bend in the finger



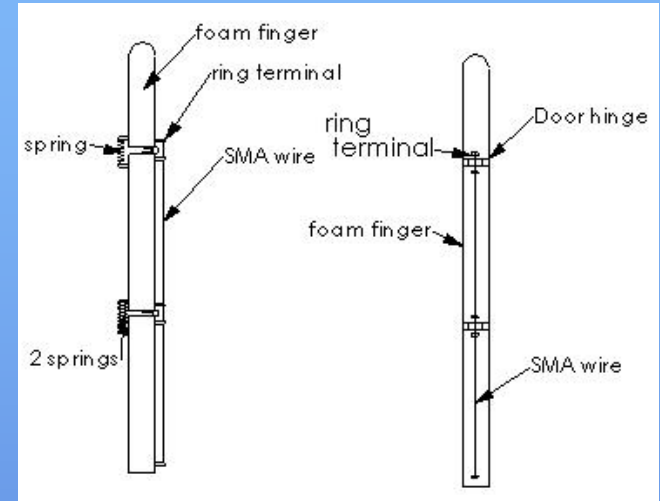
SMA Thumb



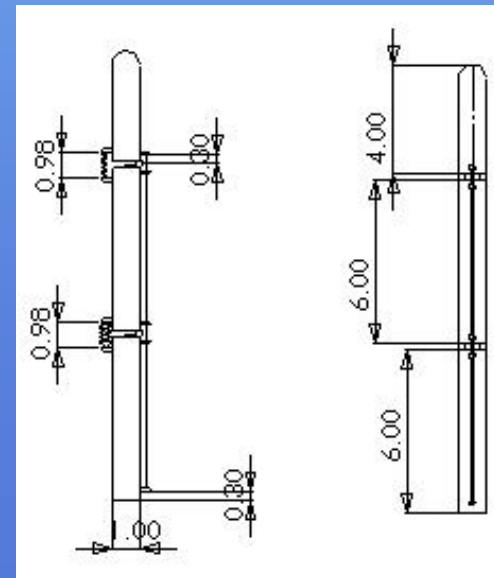
SMA Thumb Dimensions (in inches)

Changes in the Final Design (index)

- The index finger will have two joints.
- Each ring terminal will be placed 0.3 inches away from the joint.
- The bottom joint will have two springs to restore the finger to its upright position more easily.



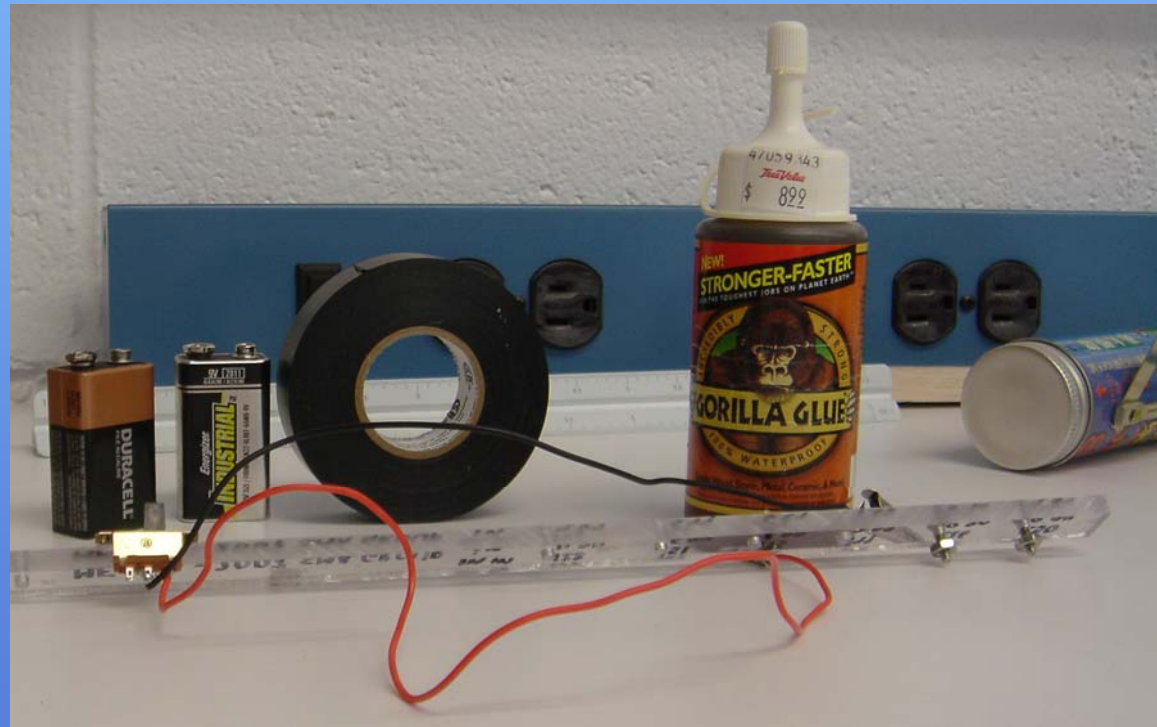
SMA Index Finger



SMA Index Finger Dimensions (in inches)

List of Parts and Costs

Gorilla glue	8.99
Electrical tape	2.99
Paint Primer	8.97
9V Batteries	5.00
9V Battery Connectors	0.90
Switch	2.30
AA Batteries	10.47
Wire terminals	6.90
Electrical wire	2.40
3 Styrofoam Blocks	10.47
2 Balsa wood rods	4.58
Resistors	0.00
4 hinges	3.96
SMA wire	28.00
Springs	0.00
Mounting Wood	0.00
Paint	0.00
Subtotal	95.93
Tax	7.20
Total Cost Not Counting Labor	103.13



A Few Materials We Used

Labor Cost

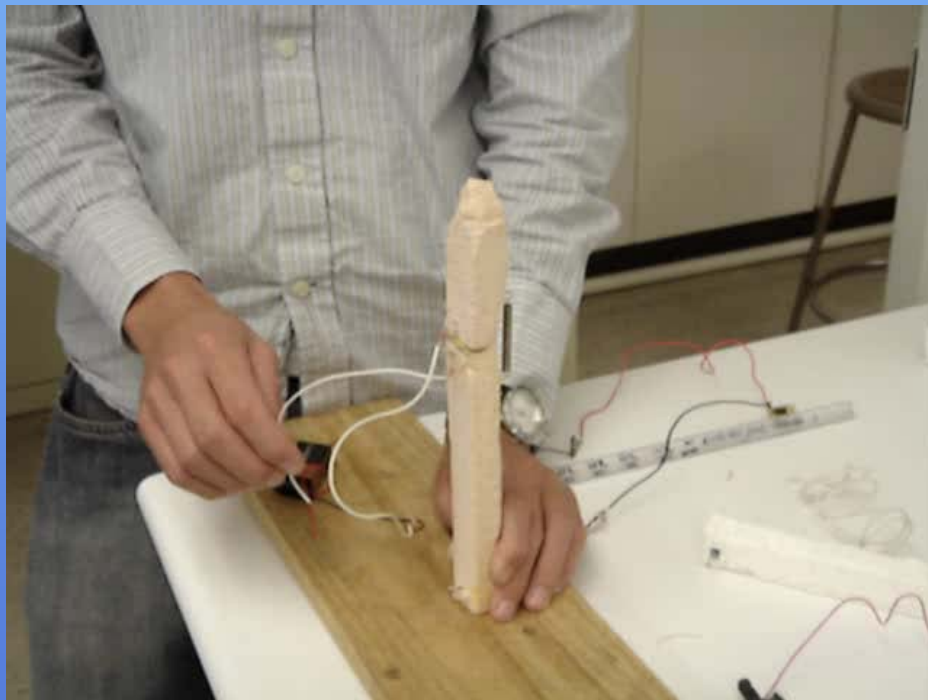
Total Cost Not Counting Labor	\$103.13
Labor Cost @ \$8.00/hour for 6.5 hours/day for 25 days for 2 people	\$2600.00
Total Cost	\$2703.13

Schedule

- Research
 - Artificial hand uses (7/19-7/23)
 - How a human hand works (7/19-7/23)
 - Possible actuators (7/19-7/23)
 - Materials for an artificial hand (7/23-7/27)
 - Determine goals (7/26)
- Design
 - Basic idea, Hydraulic hand, Motor hand, SMA hand (7/24-7/25)
 - Ideal dimensions of hand (7/25-7/30)
 - Search for materials (7/31-8/1)
 - Type of wire needed and how much (7/27-8/3)
 - Amount of energy needed (8/1-8/2)
 - Determine spring needed (8/7-8/8)
 - Buy products (8/3-8/6)
- Preliminary test
 - Design preliminary hand (8/3-8/6)
 - Begin construction of preliminary hand (8/7-8/10)
 - Use test wire to first test (8/7-8/8)
 - Use .006 inch wire for second test (8/8-8/9)
 - Collect results (8/9-8/10)
 - Analyze and find solutions to any problems (8/10-8/13)
- Design final hand
 - Create a design for the hand (8/10-8/13)
 - Paint hand (8/13-8/14)
 - Test to make sure fingers bend (8/13-8/14)
 - Finish construction (8/14-8/17)
- Create presentation
 - Create outline to slide show (8/15-8/28)
 - Present slide (8/29)

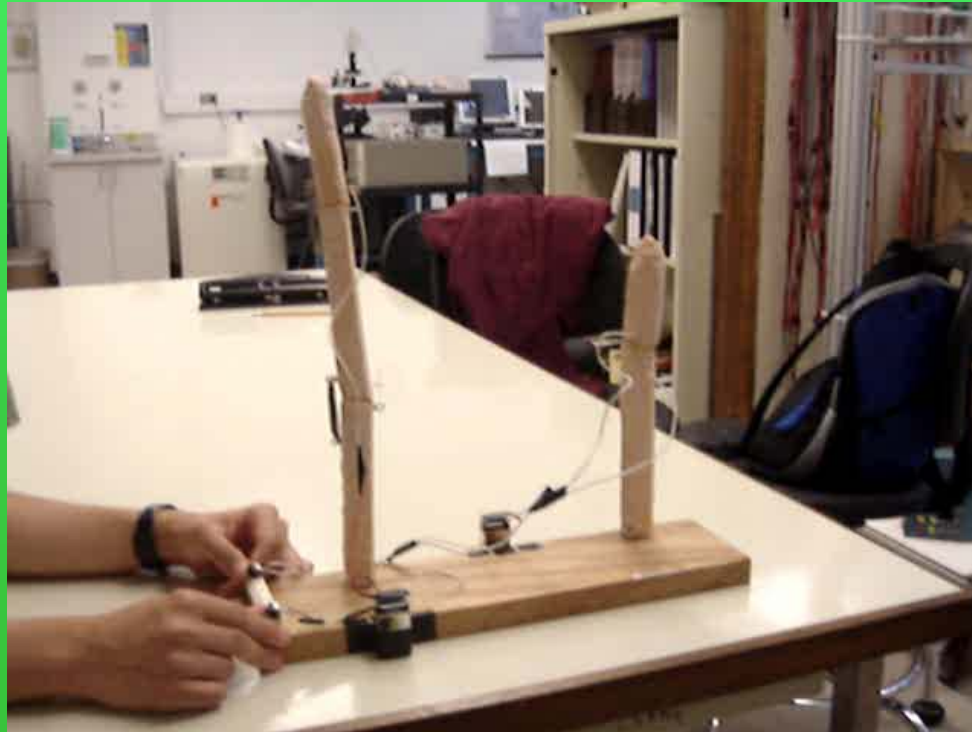
Results

- Both fingers were colored to look like human finger.
- Both fingers were able to bend much more than the preliminary design.



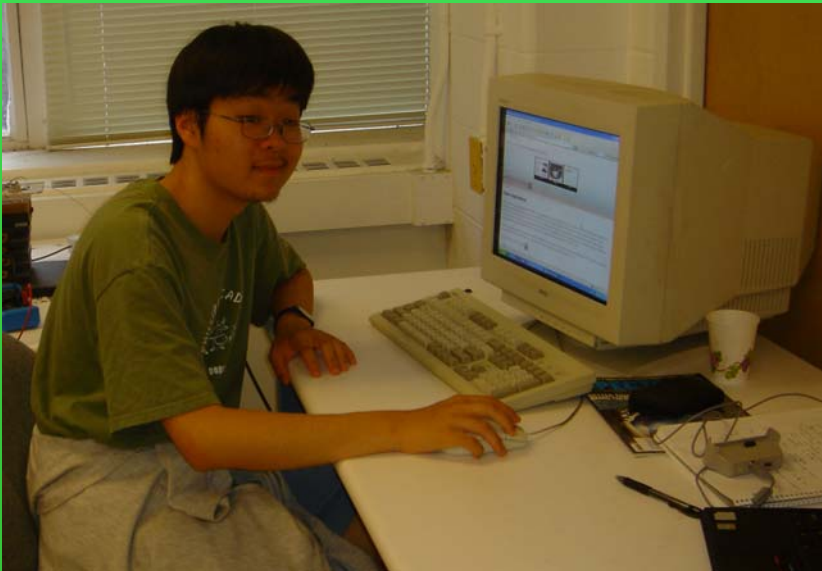
Conclusion

- Both fingers had no problem with reaching the 70 degree transition temperature
- The index finger met the goal of bending 90 degrees.
- The thumb did not quite make the 90 degree bend, but was very close.



What We Learned

- We learned how to research, design, and create an experiment.
- We learned how to present the information that we obtained through the experiment.



Sources (images)

- <http://www.abdn.ac.uk/zoologymuseum/images/hand.jpg> (slide 2)
- http://www.touchbionics.com/images/professionalscontent/sm1184528847Index_Point_Small.jpg (slide 3)
- http://www.societyofrobots.com/images/actuators_smamusclewire.jpg (slide 8)
- http://www.stoneycreeknews.com/scn/graphics/news/ston791829_1.jpg (slide 10)

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