MEM 435 Product Development: Final Presentation

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- Revisit stakeholder needs
  - Educational value, interactivity
- Final Design
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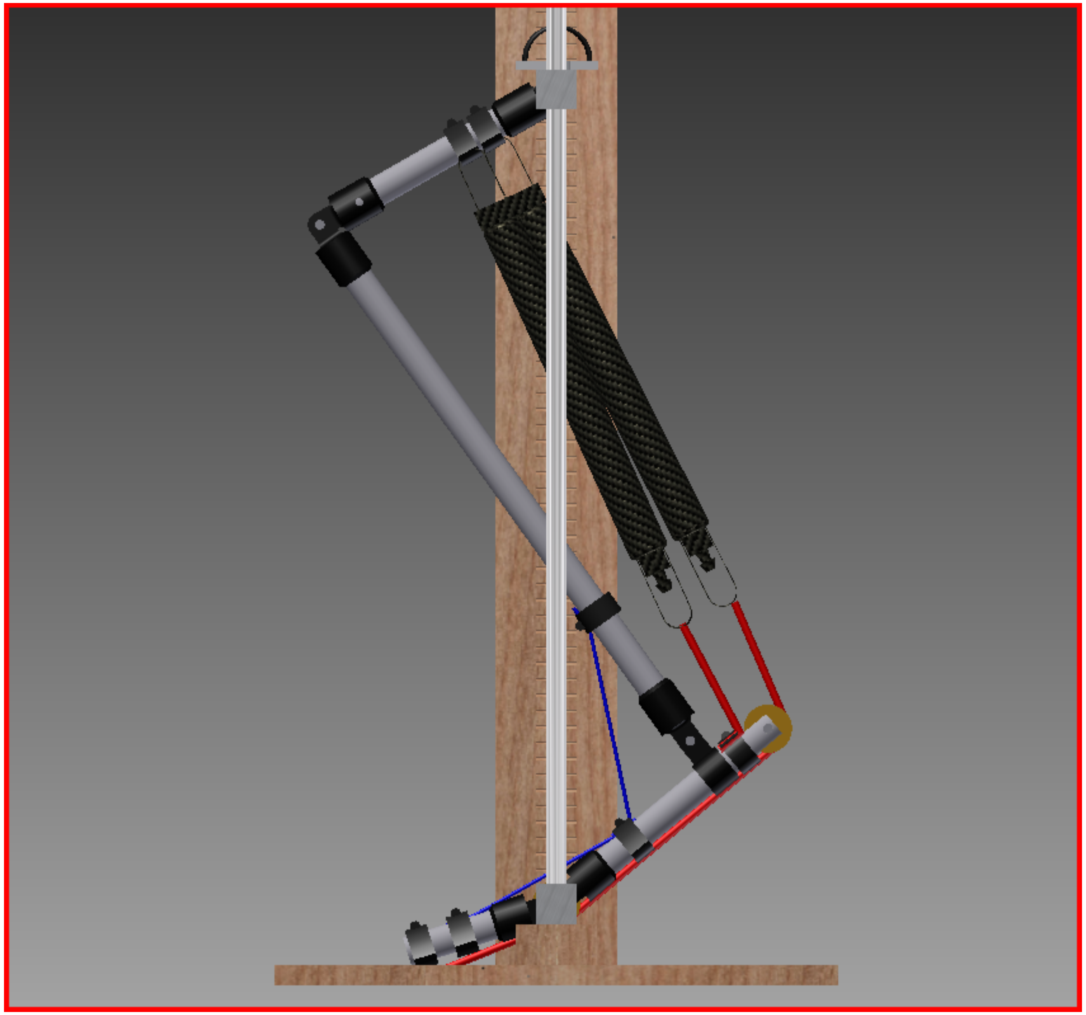
  - Critical functionalities
  - ANSYS analysis
  - Our thoughts
- Cost Analysis

Our Product

- Energy conservation model based on jumping Kangaroo leg

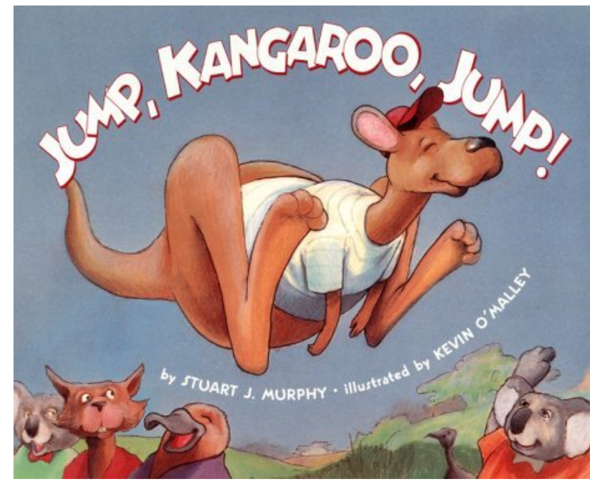


Our Process

- Stakeholder needs
- Target specifications
- Concept generation
- Concept selection
- Develop and design alpha prototype
- Create parts list
- Build prototype
- Analyze
- Learn necessary changes for final product

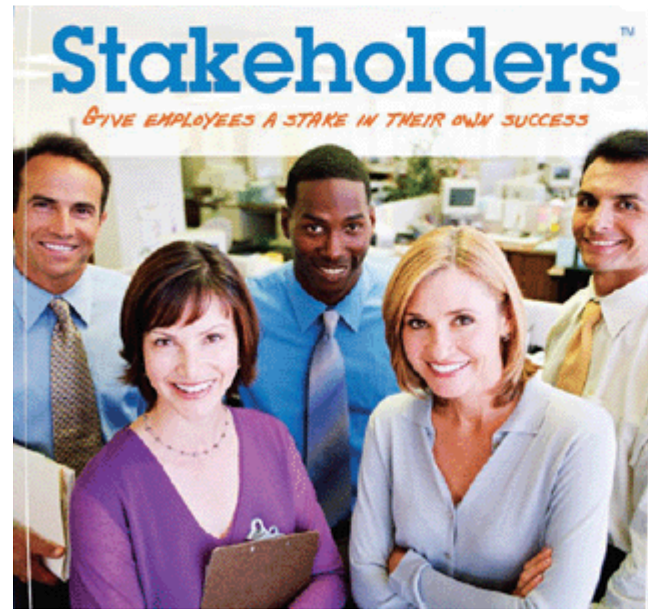
Our Concept

- Energy conservation in tendons
  - Muscles contract
  - Tendons stretch
  - Jump
  - Rebound jump
- Competing products
  - Not accurate model



Recap Stakeholder Needs

- Educational Value
- Safety
- Design
- Marketability
- Distribution
- Power
- Aesthetics
- U.I./Experience



Stakeholder Quotes

- “Don’t design a black box. The kids need to be able to see what’s going on to understand the underlying concepts”

  – Dr. Carey Inouye

- “A lot of teachers travel between classrooms. Make sure it packs up and fits on a shelf!”

  – Margaret Alspach

Educational Value

- Must demonstrate biological system or phenomenon
- Must hold attention of 14-17 yr-olds for length of lesson
- Accompanying documentation must be well-written and understood (multi-lingual, diagrams)
- Must promote analytical and experimental skills
- Must be versatile to accommodate multiple levels of students/teachers
- Demonstrate a concept with underlying math and physics

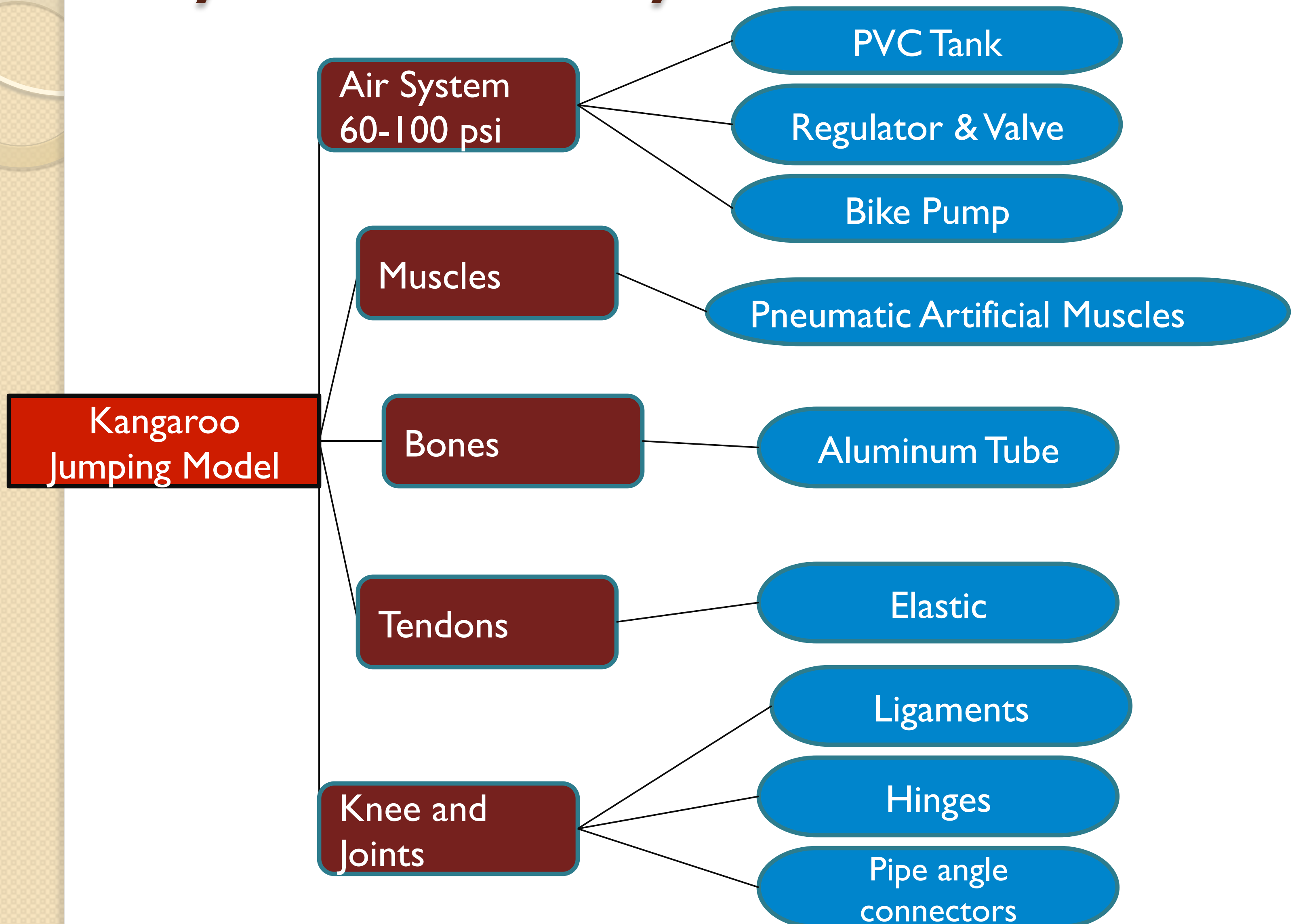
Final Design

Final Design Differences

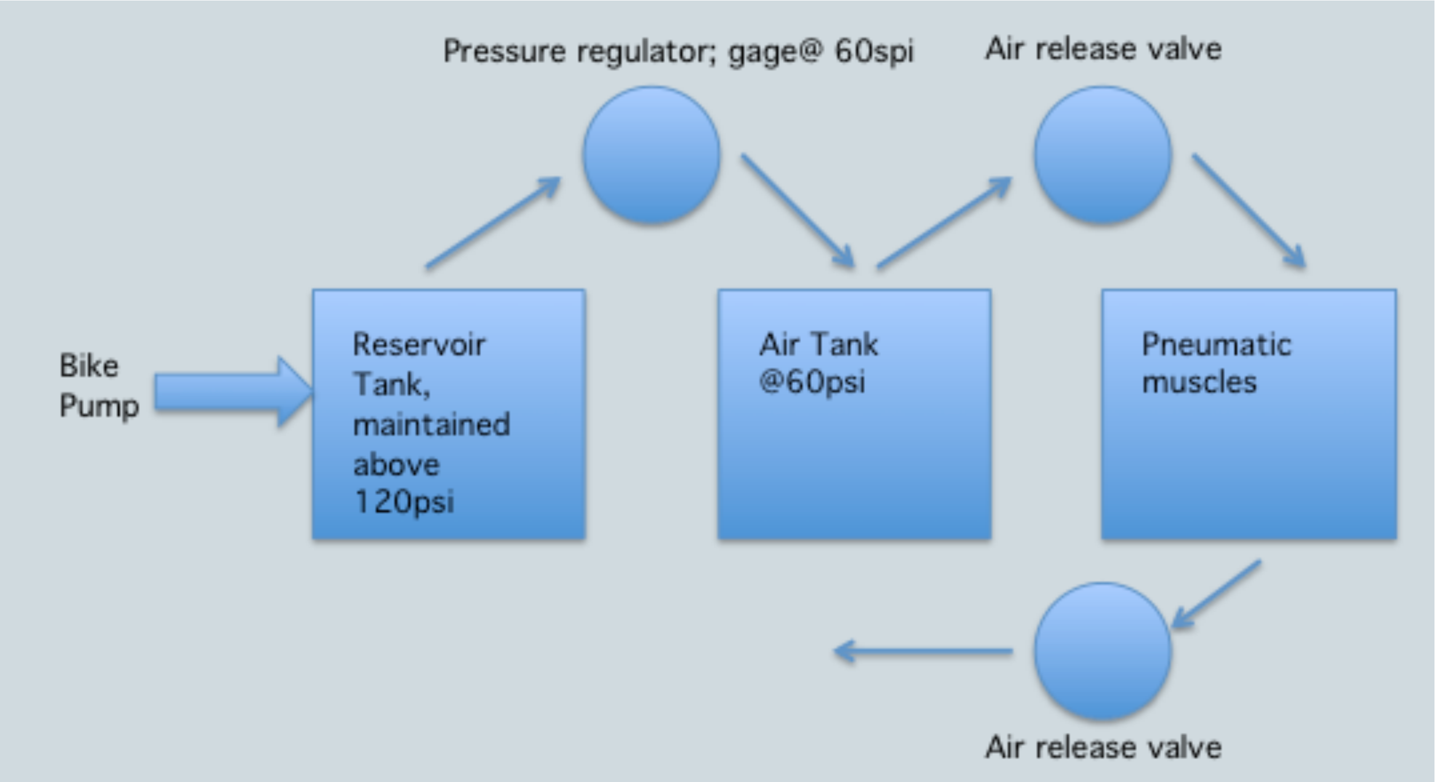
- Loose wooden bushings
- Solenoid valve
- Birch dowel bones (1"OD)
- Fence knuckle hinges
- A lot of play in the joints and bushings
- PVC heel and pulleys beside toe hinge
- Thumb drive hose clamps
- Bolts through hinges
- Runs at 100PSI
- Includes mass tray for preloading at COM
- Runs at less than 80PSI

- Brass bushings on precision ground rods
- Push button valve (no elec.)
- Aluminum tube bones (3/4"OD)
- Custom, minimal hinges
- Precision manufacturing allows for tighter fits, less binding
- Central pulley on heel and ankle
- Quick release hose clamps
- Press fit shafts in hinges
- Includes gradations for measuring travel (cm)

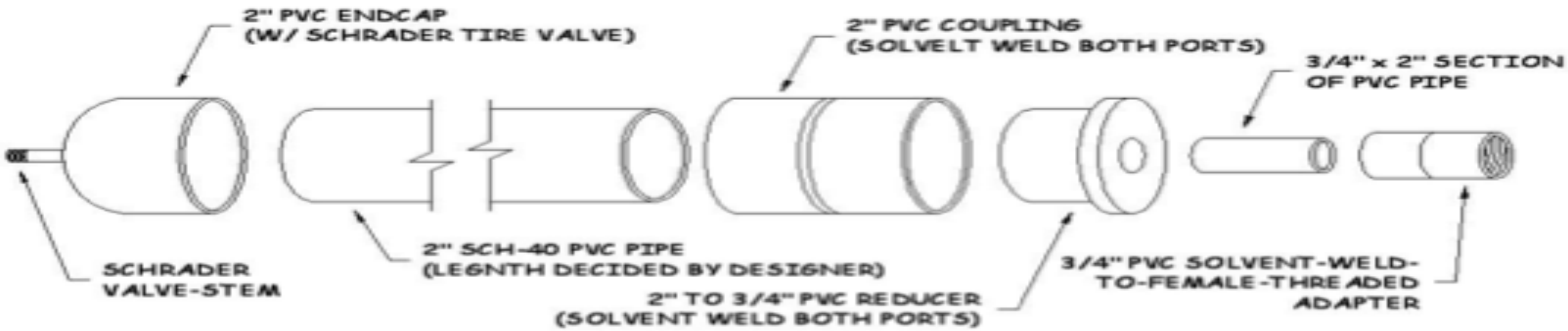
Systems/Subsystems



Subsystem – Air System



Subsystem – Air System



Design concept for Reservoir Tanks

Pressure Regulator with gage

Push button valve

Bike pump with gage

Subsystem – Air System

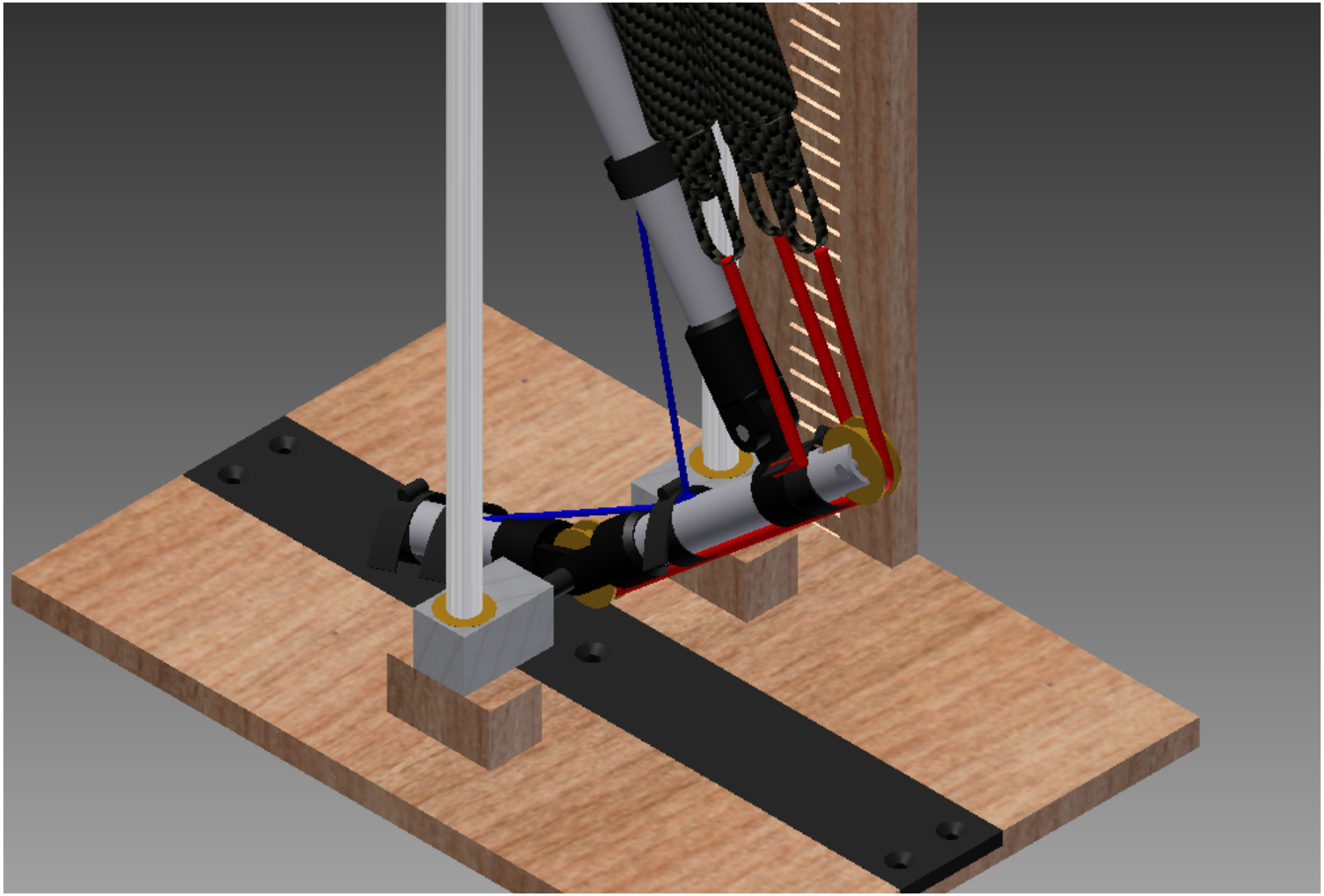
- Pros
  - Portable and does not require electricity for use
  - All parts are easily replaceable
- Cons
  - Pressure regulators with gages are expensive

Subsystems – Tendons

1/8" Elastic Chord, bundled

- Pros
  - Cheap
  - Biologically representative
- Cons
  - Difficult to attach to bones

Subsystems – Tendons

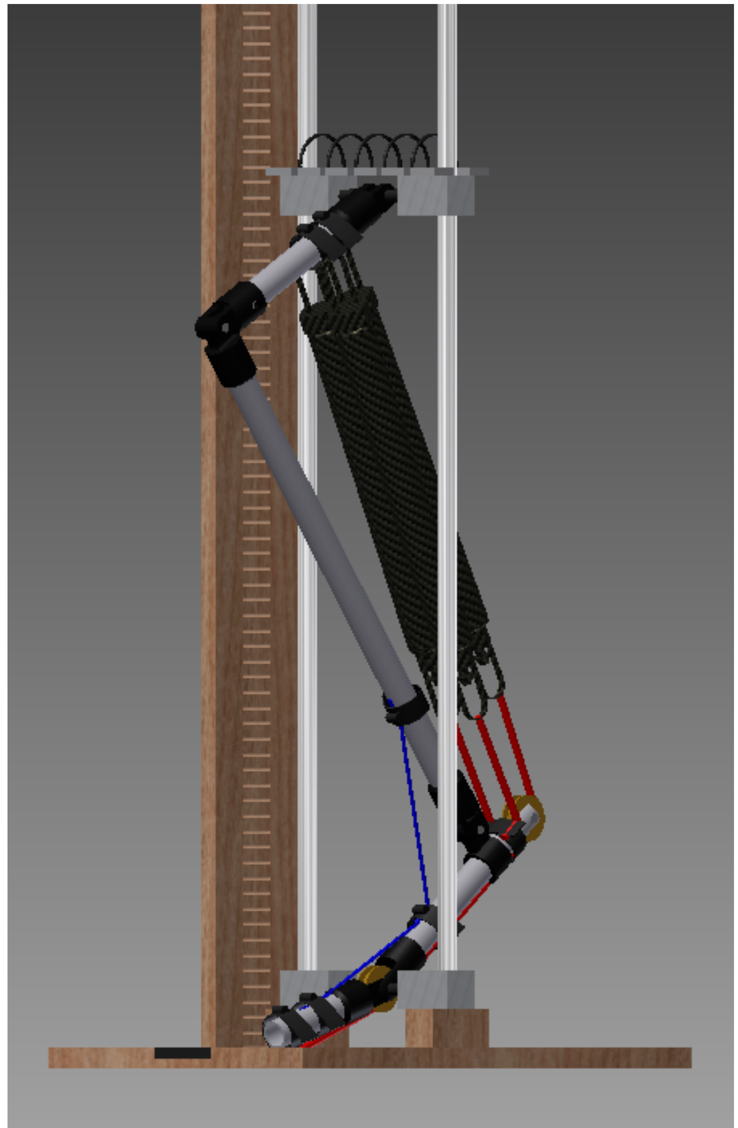


Subsystems – Muscles

8” Pneumatic muscles

- Pros
  - Do not need electricity
  - Biologically representative
- Cons
  - Needs air system (Expensive/Bulky)
  - Slow actuation and release when bundled

Subsystems – Muscles



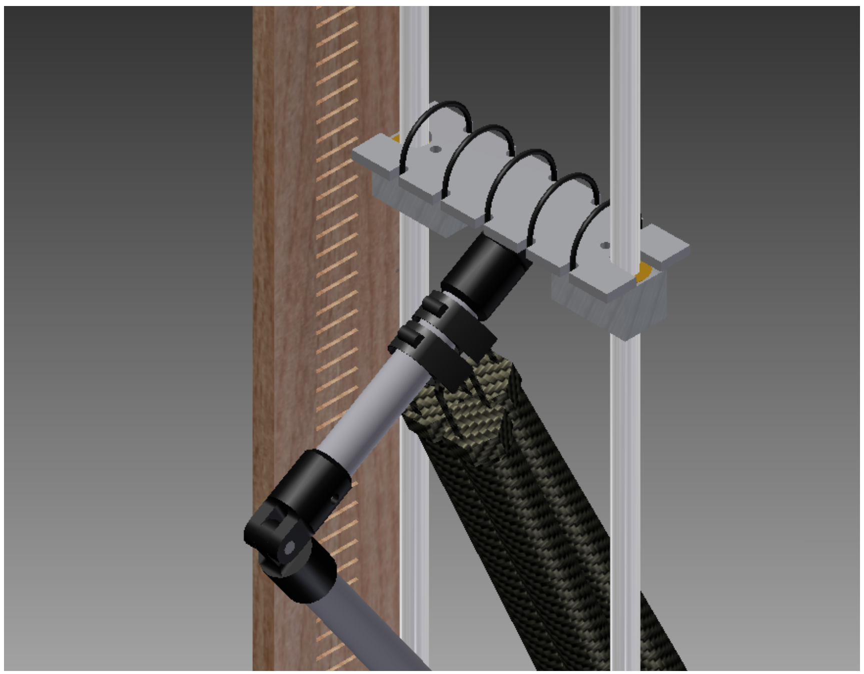
Subsystems – Bones

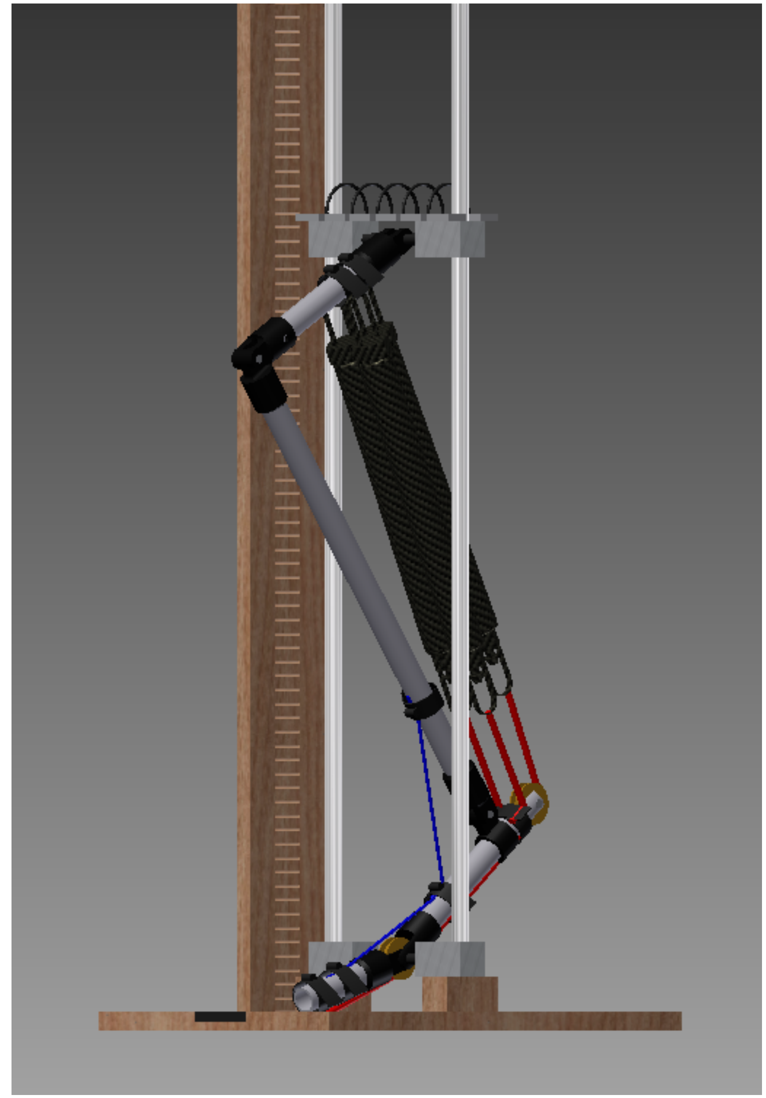
Aluminum Tube

- Pros
  - Cheap
  - Lightweight
  - Easily machined
  - Conveniently recycled
- Cons
  - Not as easy to modify as wood

Chose Aluminum Tube over Birch for the final product

Subsystems – Bones



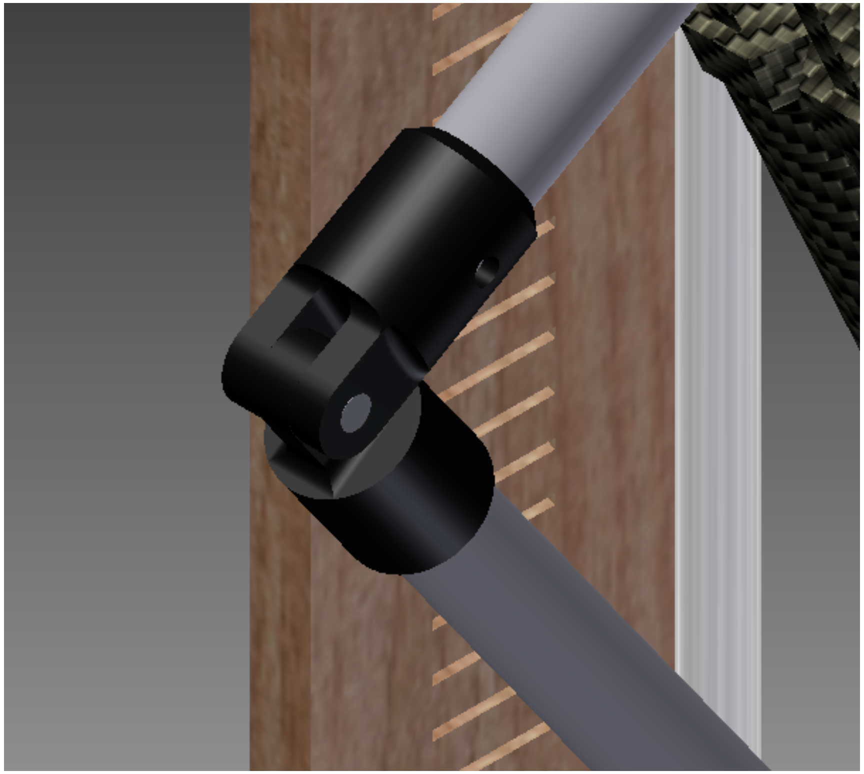


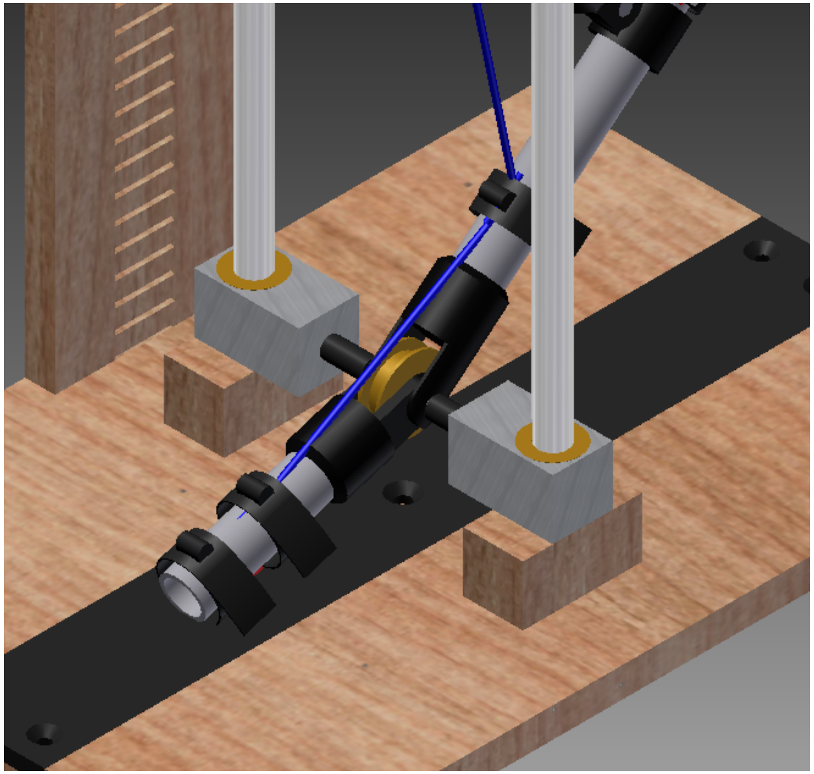
Subsystems – Knee & Joints

Custom Aluminum joints

- Pros
  - Can accommodate joint internal pulleys
  - Rigid
  - Low cost in bulk
- Cons
  - Not off-the-shelf

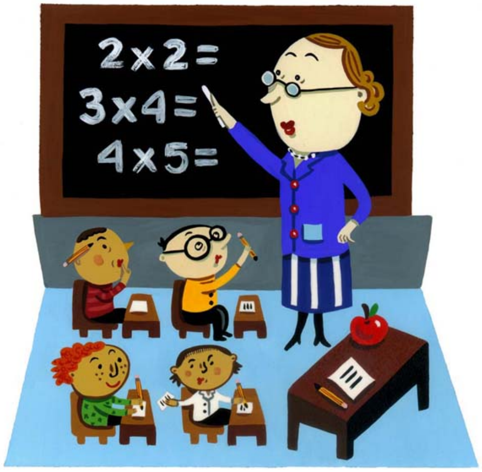
Subsystems – Knee & Joints





Lab/Classroom Use

- Interactivity
  - Student and teachers can use together
  - Variables to change
    - Bone length
    - Mass at COM
    - Ligament length
    - Tendon length and elasticity
    - Tendon/muscle placement on bone
    - Air pressure



Labs and Homework

- **Pre-Lab:** Review Potential Energy and force due to a spring
- **Lab 1:** Conservation of Energy, 2 Jumps
- **HW 1:** Calculating stored potential energy
- **Lab 2:** Manipulating tendon configuration, measuring second jump
- **HW 2:** Discovering differences when components are moved and explaining why

Meeting Educational Needs

- Demonstrates biological system or phenomenon
  - Kangaroo leg structure and movement
- Hold attention of 14-17 yr olds for lesson
  - Hands on, exciting and engaging
- Accompanying documentation must be well-written and universally understood (multi-lingual, diagrams)
  - Lab manual will be packaged with final product
- Promotes analytical and experimental skills
  - Lab reports and pre-labs, experimentation
- Demonstrates a concept with underlying math and physics
  - Conservation of energy, losses due to friction

Important Needs/Target Specs

- Must cost less than $50 to consumer
- Must cost less than $200 to develop/manufacture
- Safe material for use by humans (non-toxic)
- Should fit on a closet shelf when packed away

Performance Challenges

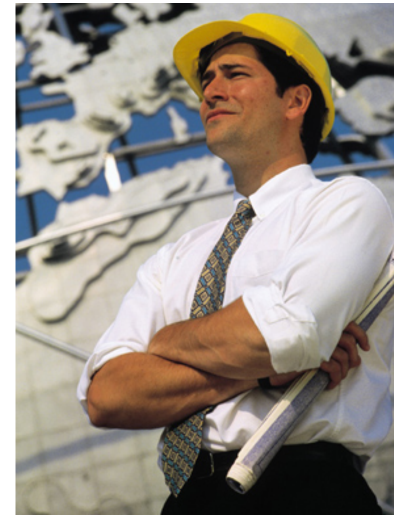
- Height of jump
- Rebound height

Solutions

- Variables for height
  - Tendon elasticity/length
  - Muscle/tendon placement
  - Mass change at COM
  - Ligament location/length
  - Actuation pressure

- Variables for rebound jump
  - Tendon elasticity/length
  - Mass change at COM
  - Muscle relaxation pressure

Engineering Challenges



- Air system regulation
- Reducing friction/binding
- Jump landing – toe retraction
- Optimal tendon placement
- Tendon connection to toe (routing)
- Sturdy guide rails
- Joint ranges of motion
- Weight/power

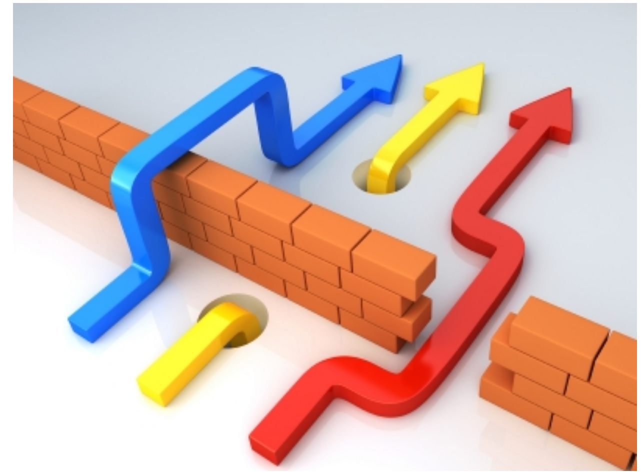
Solutions

- Air system regulation
  - Regulate using solenoid with blow-off valves (later to be push button valve, no elec.)
- Reducing friction
  - Use lubricant between guide rail and bushings
  - Slop in joints and bushing was actually helpful
  - Plastic landing track added to help toe slip
  - Pulleys at joints/protrusions around which tendons must travel
- Jump landing – toe
  - Prevent toe from flipping completely back after jump by altering the ligament
- Tendon placement
  - Tendon guide on heel (PVC, pulley) and bone attachment

Solutions

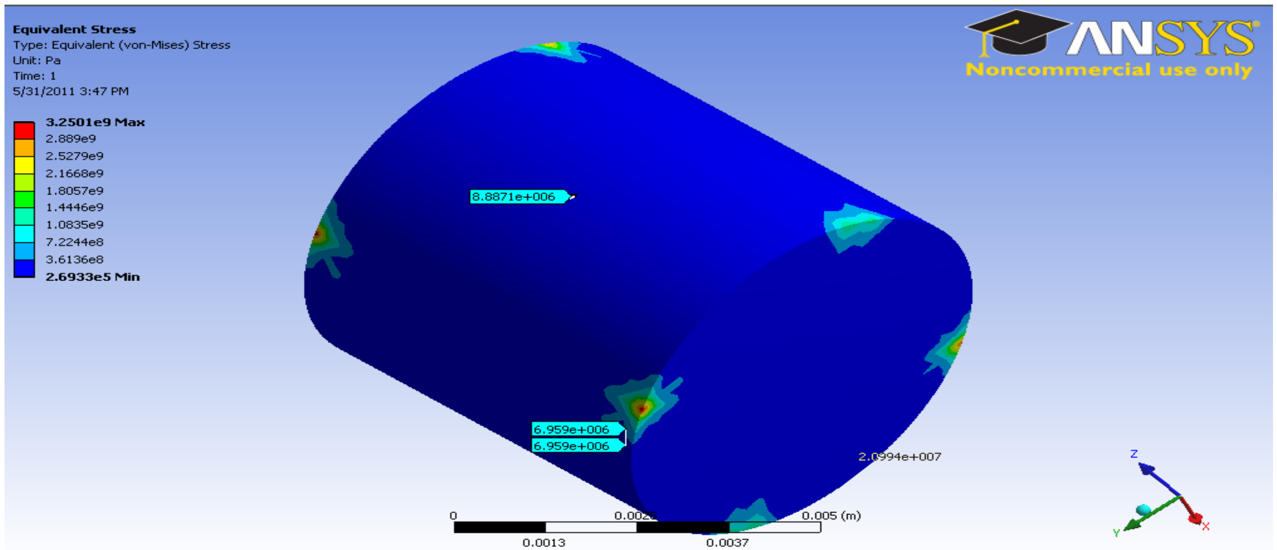
- Tendon connection to toe
  - Hose clamp
- Number of guide poles
  - Two poles, ½"OD
- Joint range of motion
  - Joints grinded down to allow for a larger ROM and ligaments added to constrain motion
- Weight
  - Lighter, smaller material (possibly weaker) will hold up to the forces involved

Critical Elements



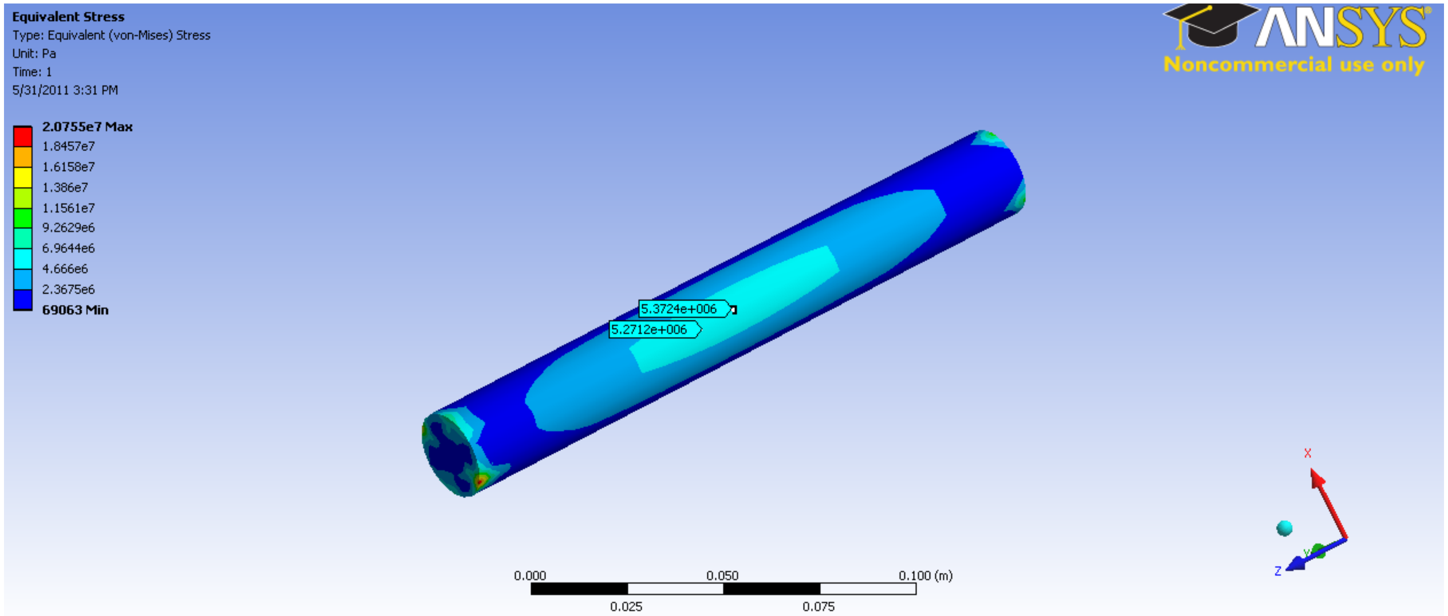
- Air system
  - Solenoid valve assembly
  - PVC pipe assembly
  - Bike pump
- Muscles & Tendons
  - Hose clamps
  - Tendon routing around joints, low friction
- Bones
  - Anatomical approximation, weight
- Joints
  - Friction, stability, binding

ANSYS Analysis



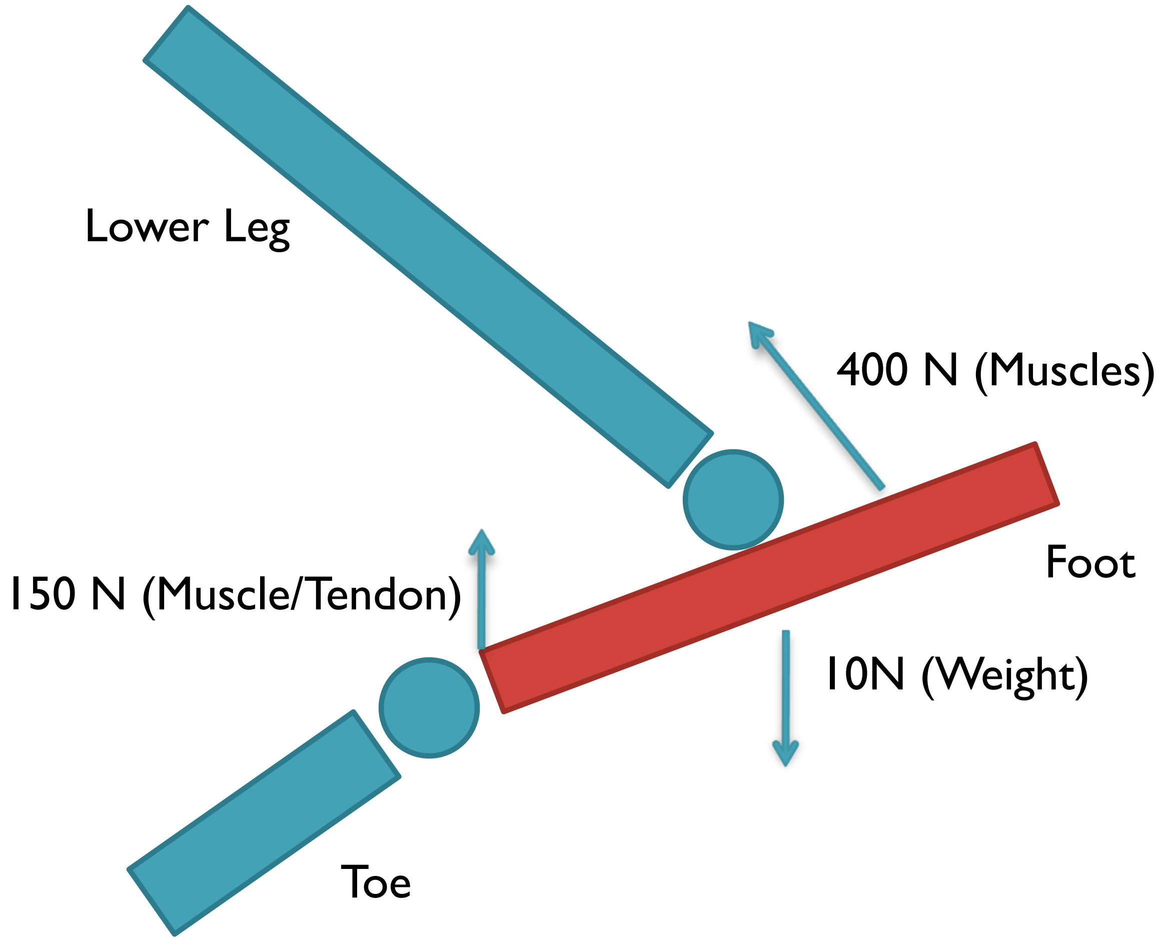
- Max Stress on Joints – 8.89 MPa
- Yield Strength (Steel) – 448 Mpa
- Factor of Safety: 50.4

ANSYS Analysis

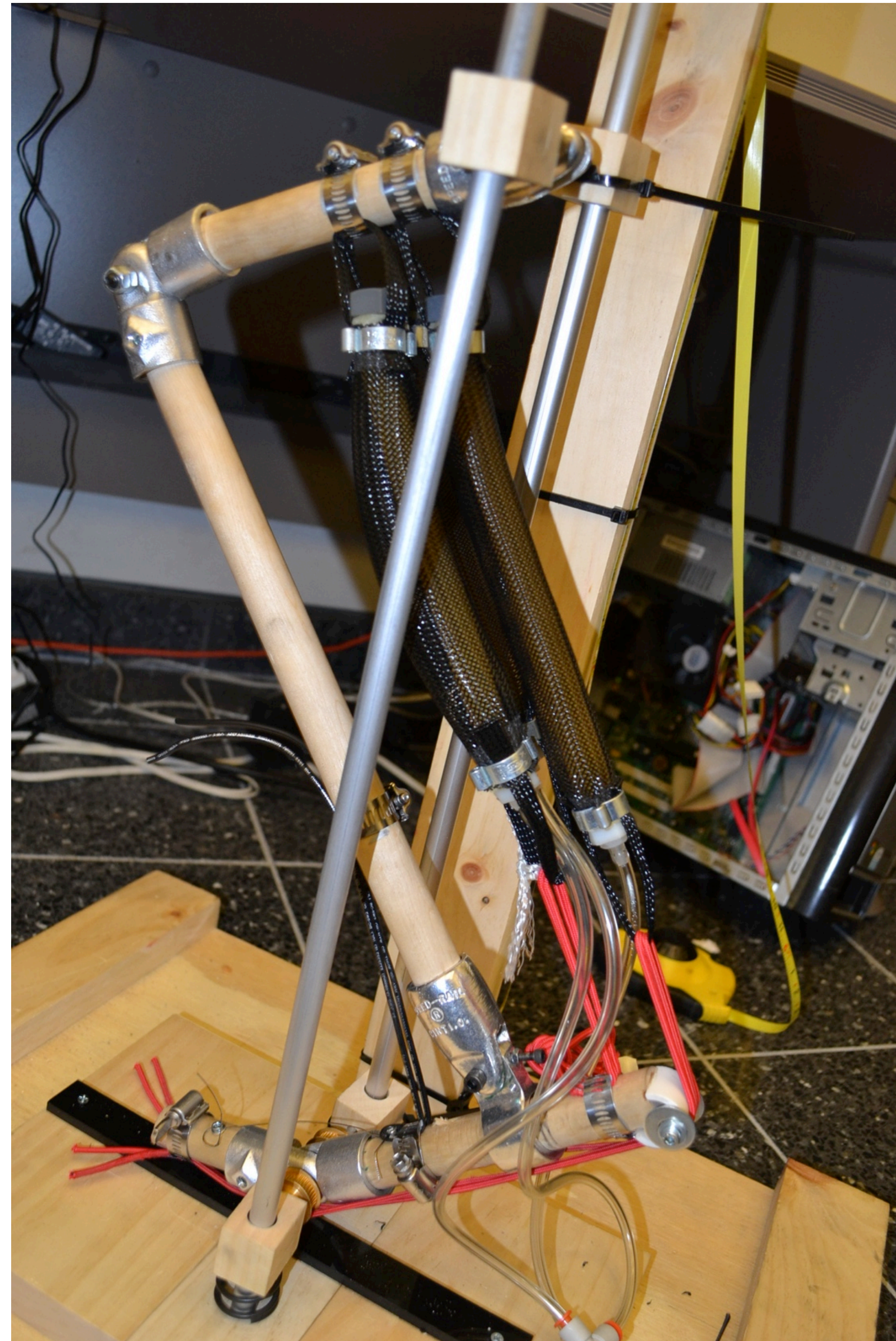


- Max Stress on Foot – 5.37 MPa
- Yield Strength (Wood) – 40 Mpa
- Factor of Safety: 7.49

Free-Body Diagram



Prototype



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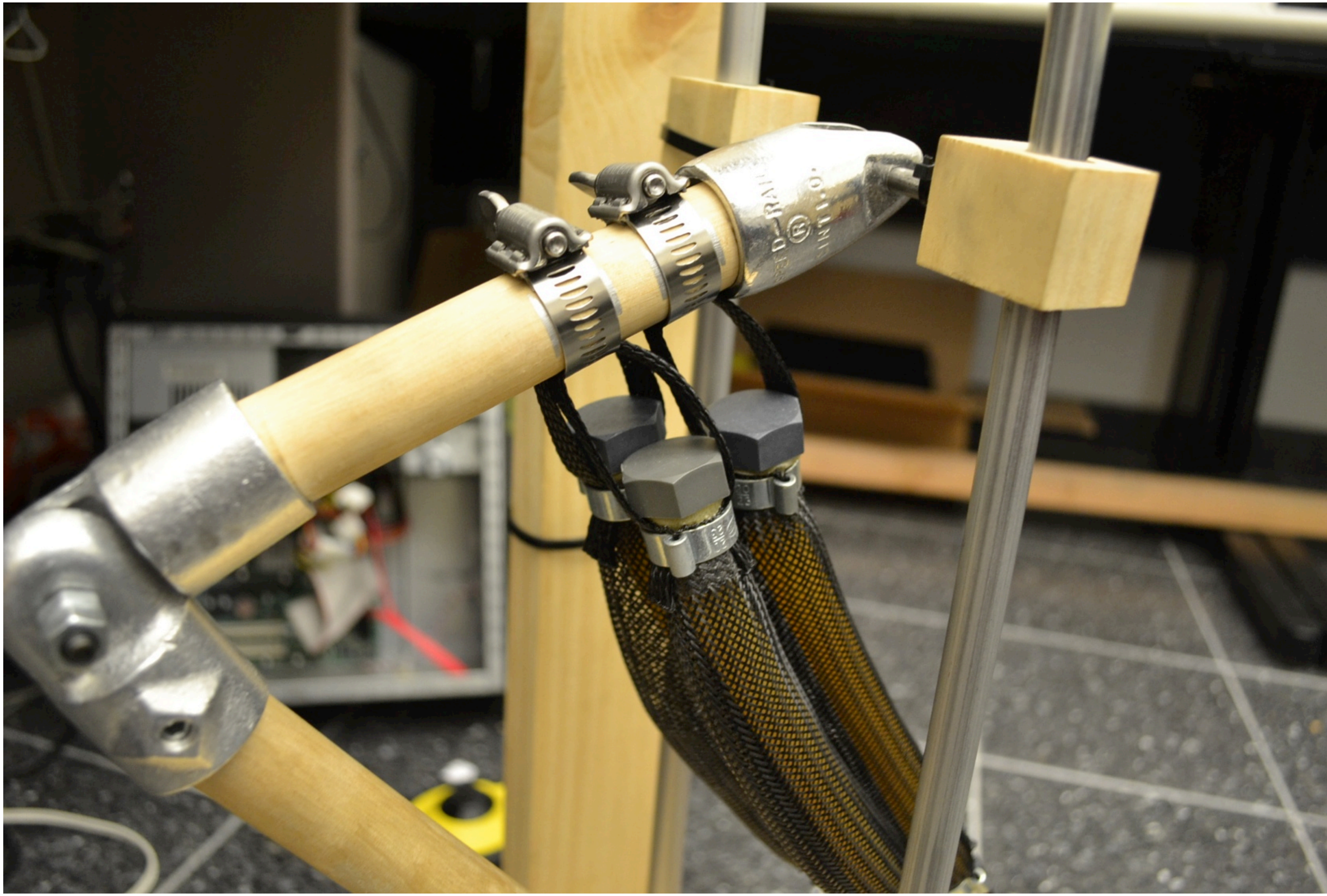

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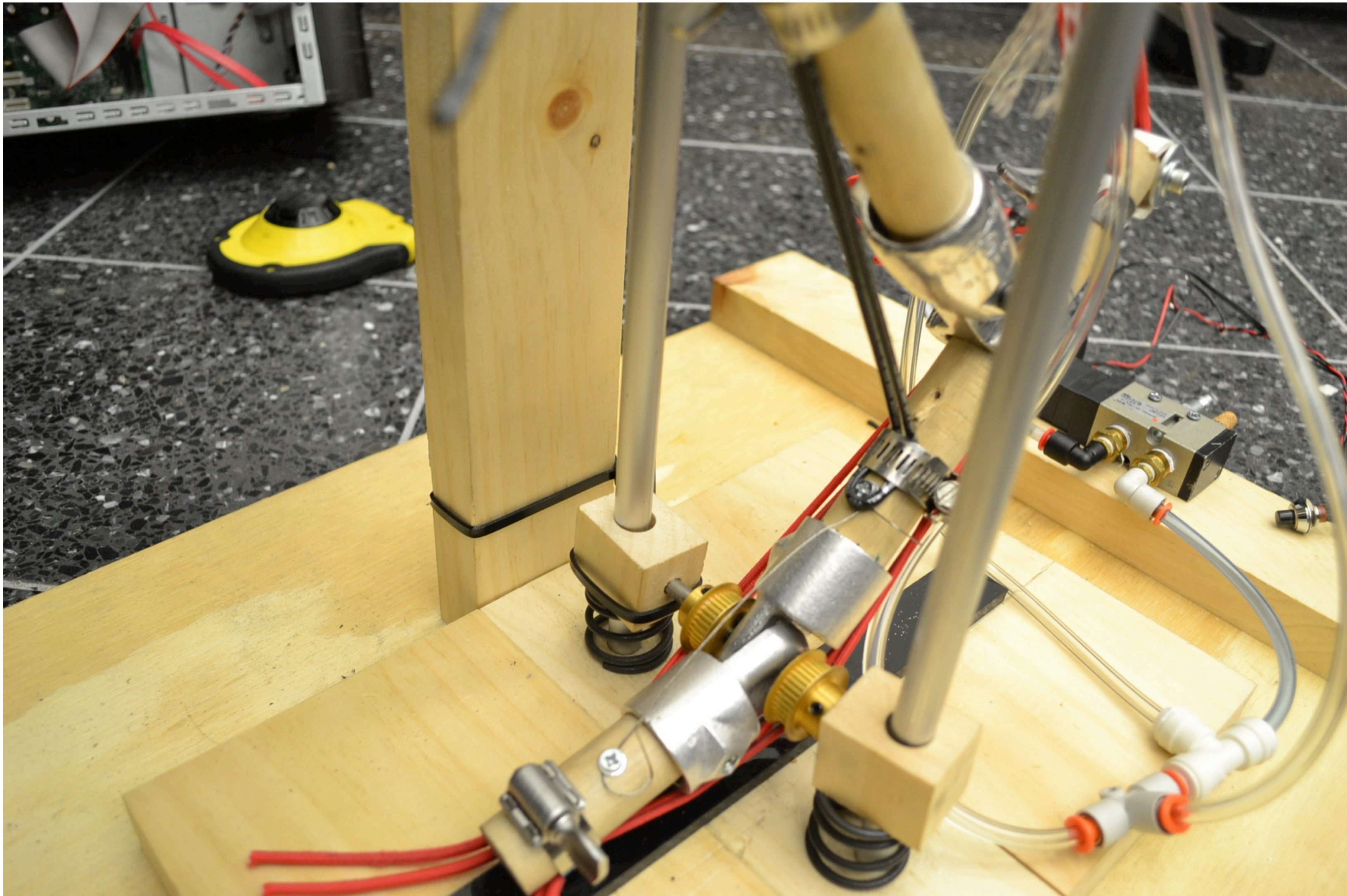

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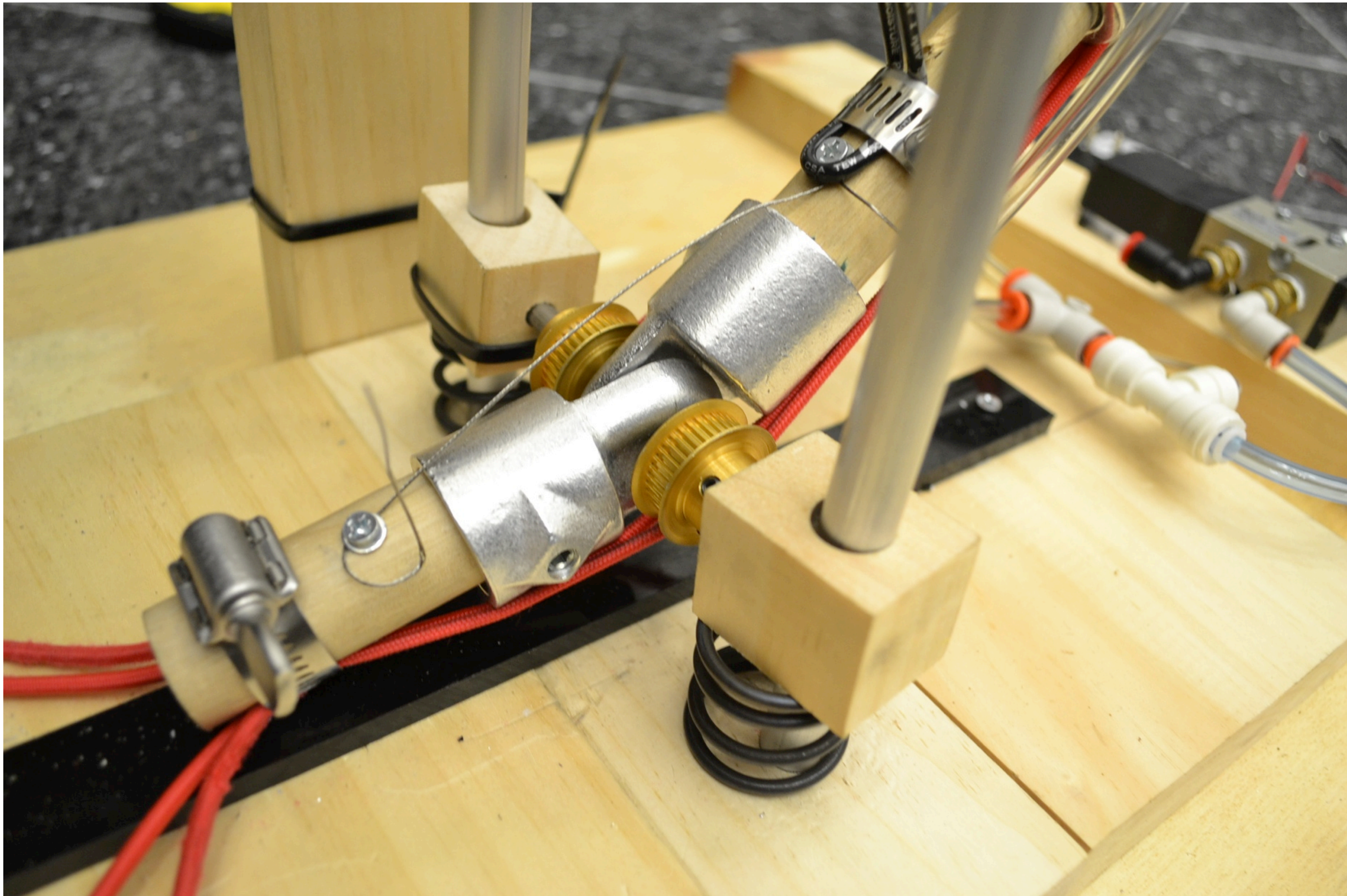

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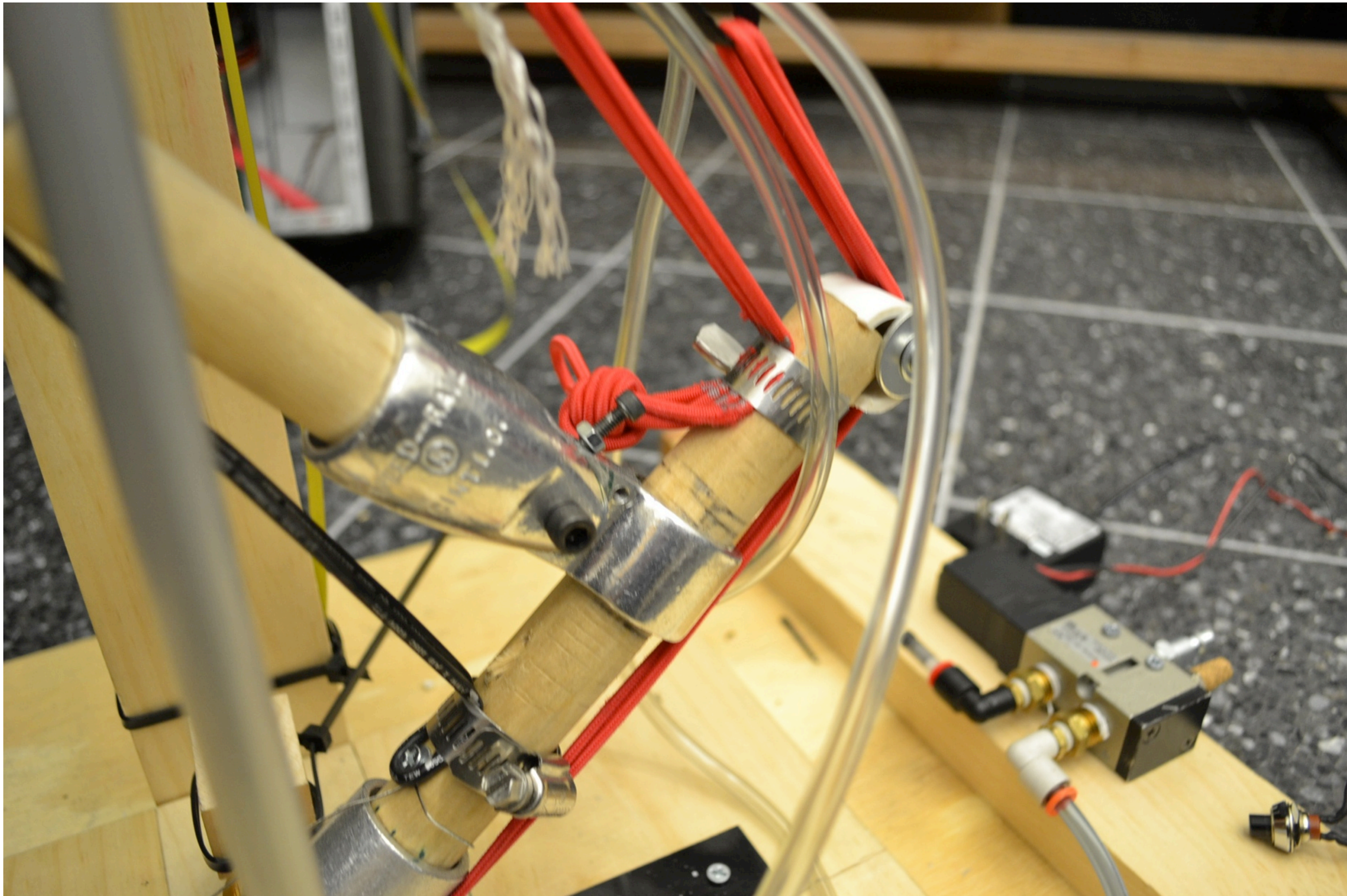
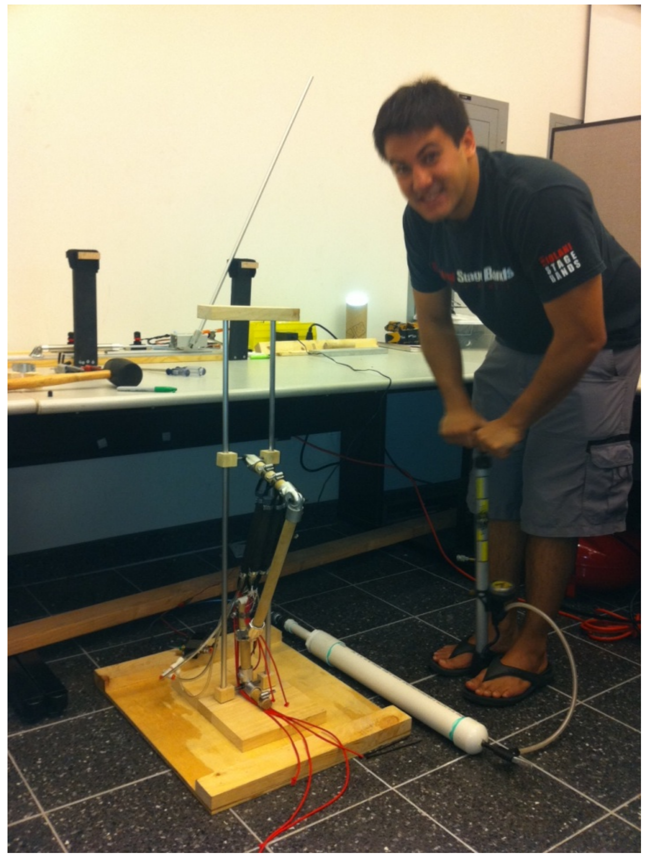
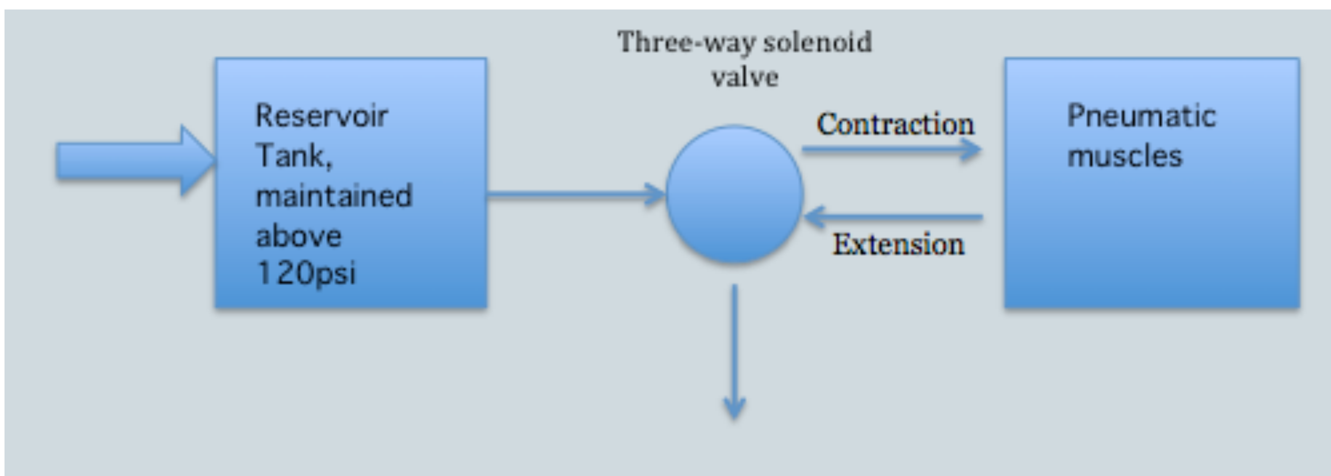


Design and Development



Prototype – Air System

- Concept
  - Bicycle Pump
  - PVC Air tank
  - Solenoid valve



Prototype – Air System

PVC Air reservoir tank

3-way solenoid valve

Bike pump with gage

Prototype – Air System

- Pros
  - Cheap to construct
  - Fully functional

- Cons
  - Electricity controlled

Assembled Air System

Critical Functionality

- Jumps!
- Stores energy for next bound when landing (Final design)
- Low cost pressurized air system
- Ligament, tendon and muscle placement affect jump
- Can be broken down and stored in a classroom

Prototype Critical Analysis

- Air system
  - Able to fill with bike pump
  - Held pressure and released when needed
  - May not be able to have enough pressure for many jumps
- Tendons
  - Stretched and applied forces well
  - Did not work when loosened
- Muscles
  - Applied reasonable force

Prototype Critical Analysis

- Bones
  - Could have been smaller/lighter, but worked well
- Joints and joint screws
  - Worked well mechanically
  - Too much friction
  - Heavy
  - Did not always provide complete Range of Motion
  - Too much play in torsion, caused binding

Meeting Educational Needs: Prototype

- Demonstrates biological system or phenomenon
  - Kangaroo leg structure and movement
- Hold attention of 14-17 yr olds for lesson
  - Hands on
- Accompanying documentation must be well-written and universally understood (multi-lingual, diagrams)
  - Lab manual
- Promotes analytical and experimental skills
  - Lab reports and pre-labs, experimental data

Other Needs Met: Final Design

- Should fit on a closet shelf when packed away
- Safe material for use by humans (non-toxic)

Needs Not Met:

- Must cost less than $50 to consumer

Lessons Learned for our Final Product

- Brass bushings on precision ground rods
- Aluminum tube bones (3/4"OD)
- Custom, minimal hinges are only option
- Precision manufacturing of bushing followers allows for tighter fits, less binding
- Central pulley on heel and ankle for tendon routing
- Quick release hose clamps for ease when changing the variables
- Press fit shafts in hinges, not screws
- Include mass tray for preloading at COM

Costing – Pneumatic Muscles

High-Temperature Silicone Rubber Tubing	$1.31 per foot
Heavy Duty Polyester Expandable Mesh Sleeving	$3.83 each
Standard Brass Compression Tube Fitting Adapter, Female	$2.86 each
Standard Brass Compression Tube Fitting Long Nut	$2.36 each
Moisture-Resistant Acetal Push-to-Connect Adapter	$1.45each
Standard Brass Compression Tube Fitting Tube Support	$7.37 for a pack of 10
Low-Pressure Brass Threaded Pipe Fitting , Female	$1.78 each
Brass Yor-Lok Tube Fitting Cap for Tubing	$2.70 each
Choose-A-Color Flexible Nylon 11	$0.21 per foot
Cost per muscle	**$18.53 per muscle**

Costing – Leg Assembly

Pneumatic muscles	$18.53 per muscle
Dowels	$7.49 per 10 feet
Elastic	$.11 per 20 feet
Joints	approx. $ 6 per joint
Clamps	$1.83 per part
Aluminum Rod	$3.68 per 3 feet
Misc. Wood	$0.53 per sq. ft.

Approximate cost: $90

(3 muscles, 3 joints, 3 feet of elastic, 4 clamps, 2 rods, wood)

Costing – Air System

2” PVC Straight Coupler	\$0.62 per part
2” PVC Cap (Solvent Weld)	\$0.57 per part
¾” Solvent Weld to Threaded Adapter	\$0.29 per part
2” to ¾” PVC Pipe Reducer	\$0.76 per part
3/4” to 1/2” Pipe Reducer	\$1.58 per part
1/2” to 1/4” Pipe Reduced	\$1.43 per part
2” x 10’ SCH-40 PVC Pipe	\$8.48 per 10 feet
¾” x 10’ SCH-40 PVC Pipe	\$2.93 per 10 feet
Schrader Valve Stems	\$1.98 per part
Cost per Tank	**\$12.14 per tank**
Pressure Regulator	\$60.14 per part
Release valve	\$2.50 per part

Air System Cost(2 tanks, 1 regulator and 2 release valves)
\$77.28 per system

Cost Analysis

- Total cost of product (including Air system) is approx $160
- After cost analysis it was realized that it would be extremely hard to keep the complete product under the $50 limit.
- However the product should be marketable to higher education institutions like colleges and university