Model of Simple Axial Loading 2

Prof. Charlie Kemp

BMED 3410: Introduction to Biomechanics
September 2, 2022
Lecture 4

Outline

1. Website with PSS and lecture information
    a. https://sites.gatech.edu/intro-to-biomechanics/
    b. See my announcements on Canvas
2. Homework Quiz #1 in lecture on Wednesday
    a. Plan to send to testing center today for people with accommodations
3. Review our simple axial loading model
4. Trapeze design problem wrap up
5. Second design problem

Model of Simple Axial Loading

Geometry
L and A
length (m), area (m^2)

Material
E
Young's Modulus (Pa)

Load
P
axial load (N)

Input

→

Model of Simple Axial Loading
(deformable body)

→

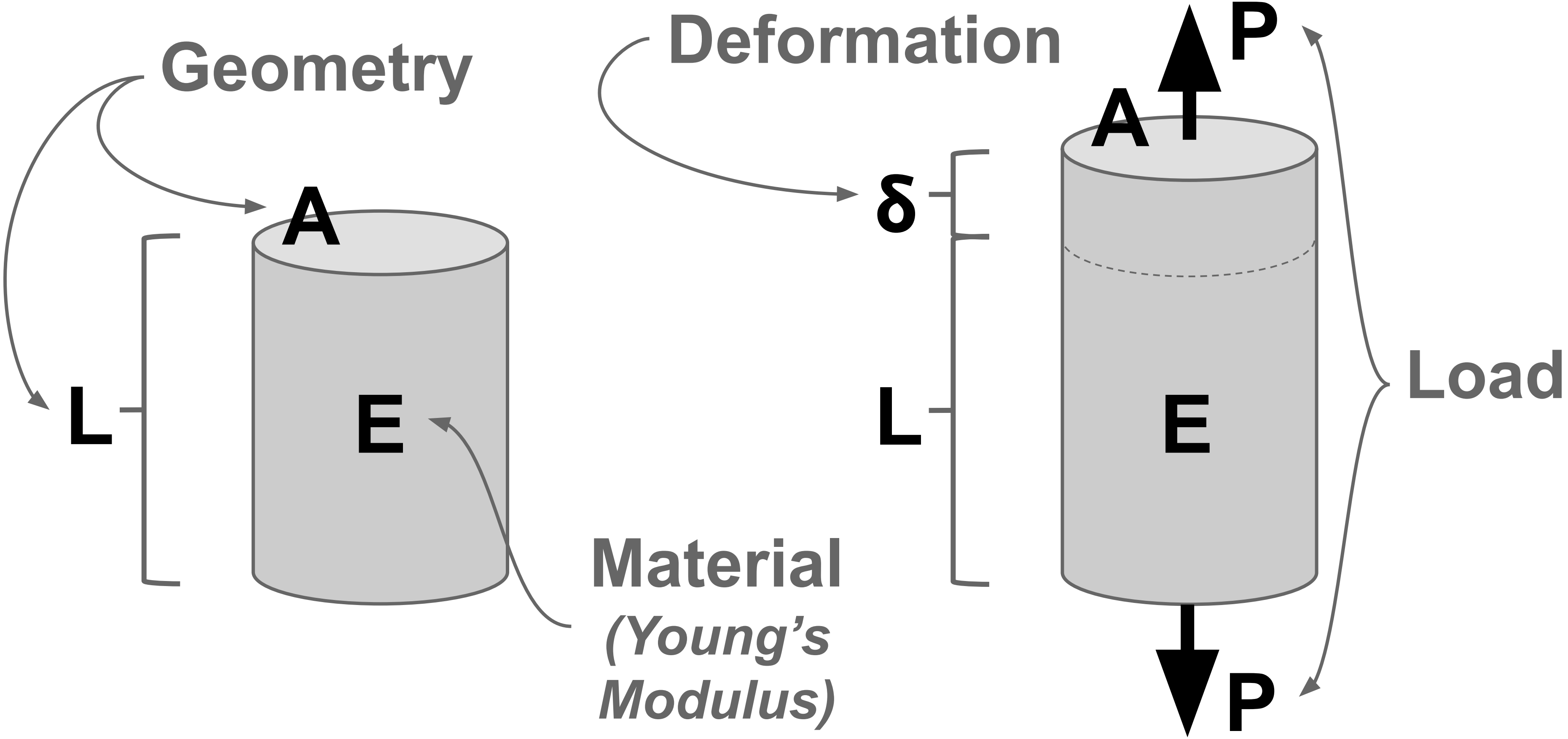
Stress
$\sigma = P/A$
normal stress (Pa)

Strain
$\varepsilon = P/AE$
normal strain (m/m)

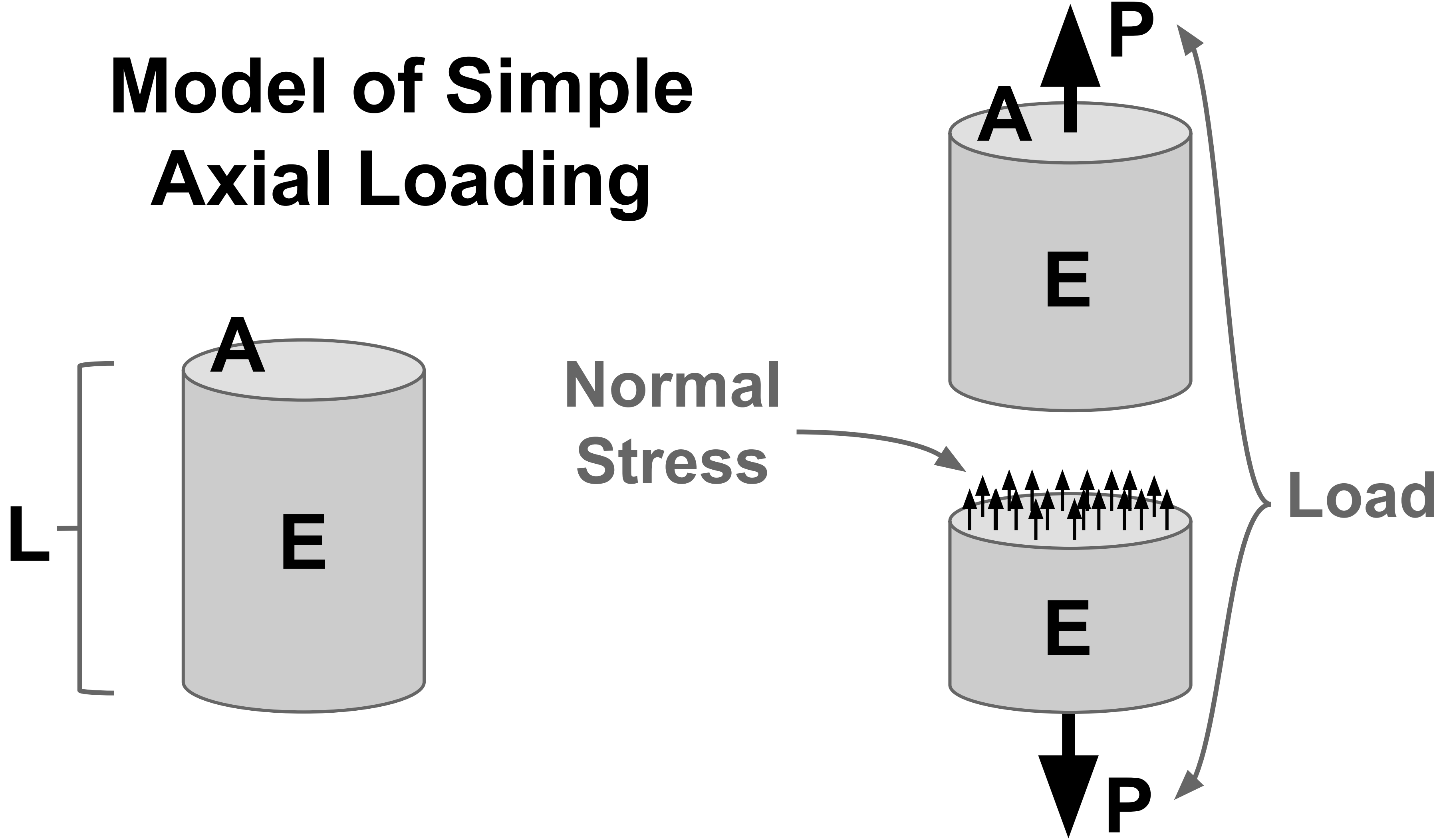
Deformation
$\delta = PL/AE$
change in length (m)

Output
(predictions)

Model of Simple Axial Loading



Model of Simple Axial Loading



Example of Something our Simple Axial Loading Model Ignores

- Saint-Venant’s Principle
  - "... the difference between the effects of two different but statically equivalent loads becomes very small at sufficiently large distances from load." - Wikipedia
- Figure shows results of a finite element model (FEM)

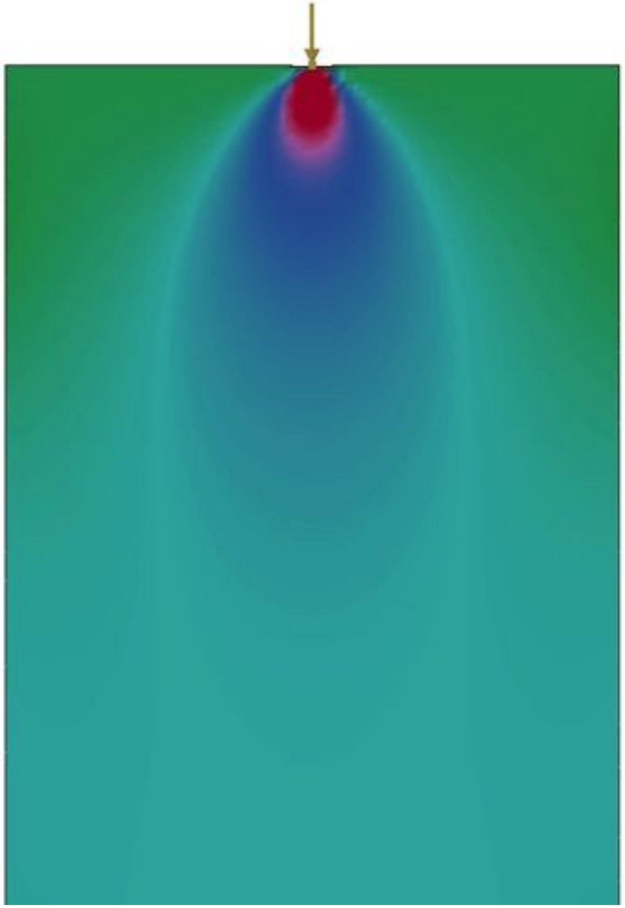


Figure from
https://alliance.seas.upenn.edu/~medesign/wiki/index.php/Courses/MEAM247-10C-P3-background

Simple Normal Stress is Average Stress

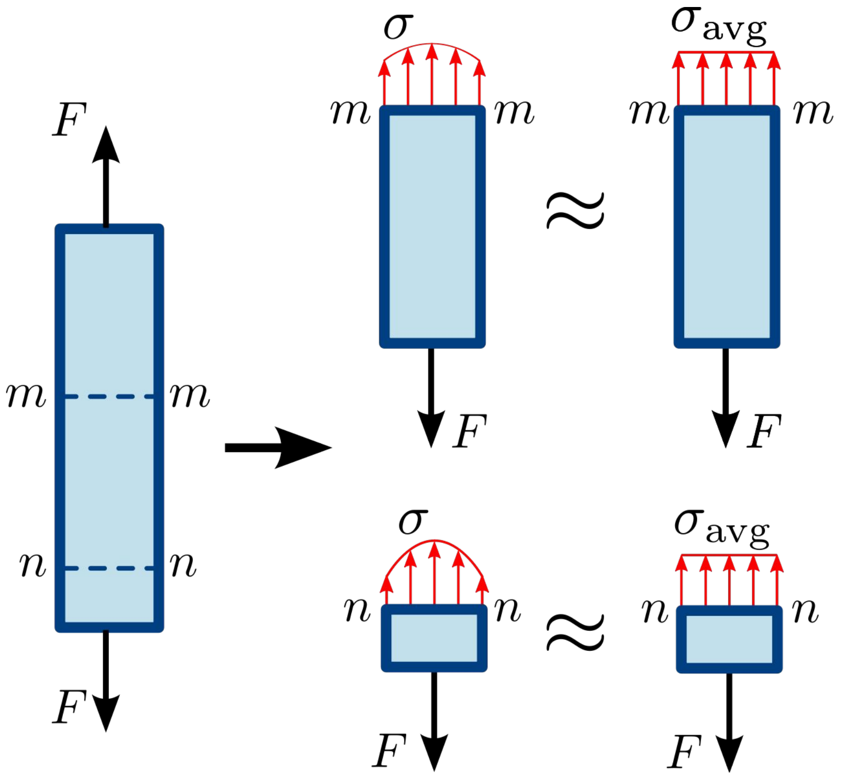
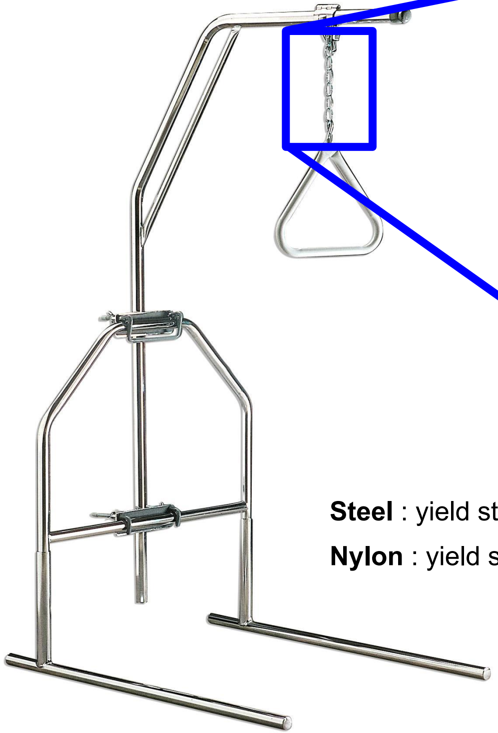


Diagram from https://en.wikipedia.org/wiki/Stress_(mechanics)#Simple_stress

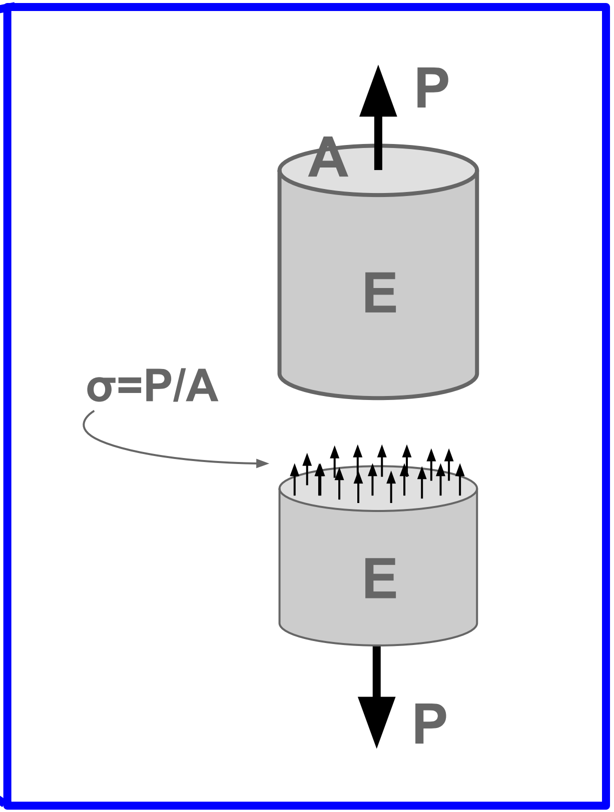
Trapeze Design Problem Wrap Up

[Video of tensile test]()



Steel : yield strength ~200 MPa

Nylon : yield strength ~40 MPa



Invacare Trapeze, Trapeze Bar, and Floor Stand
http://www.invacare.com/cgi-bin/imhqprd/inv_catalog/prod_cat_detail.jsp?s=0&prodID=7740A
http://www.invacare.com/cgi-bin/imhqprd/inv_catalog/prod_cat_detail.jsp?s=0&prodID=7714P
image from http://www.ojmedical.com/invacare/inv7714pxz/trapeze_floor_stand

Design Problem

You are a member of a team designing a new surgical robot. The gripper (see image) at the end of the robotic arm will be controlled with two cables, one for opening it and one for closing it. You have been given a sample of a novel material and tasked with evaluating the potential to fabricate suitable cables with it.

Image from Intuitive Surgical website:
http://www.intuitivesurgical.com/products/instruments/

Design Problem

You are a member of a team designing a new surgical robot. The gripper (see image) at the end of the robotic arm will be controlled with two cables, one for opening it and one for closing it. **You have been given a sample of a novel material** and tasked with evaluating the potential to fabricate suitable cables with it.

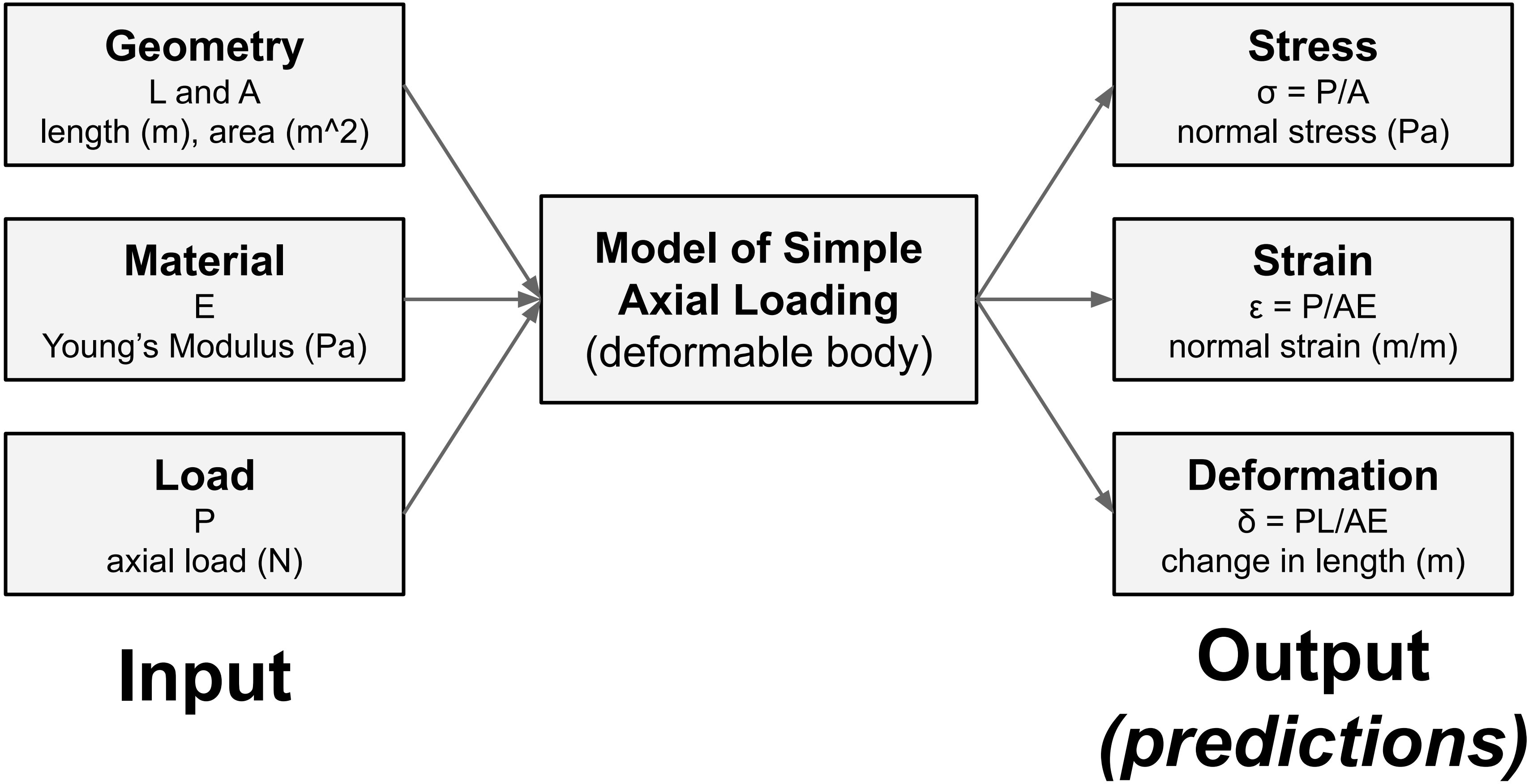
Image from Intuitive Surgical website:
http://www.intuitivesurgical.com/products/instruments/

Understand the Problem

- https://youtu.be/0VGgDT-IzFs
- https://youtu.be/0XdC1HUp-rU

Image from Intuitive Surgical website:
http://www.intuitivesurgical.com/products/instruments/

Model of Simple Axial Loading



Predict the Elongation of the Cable

- Geometry
- Material
- Load

Predict the Elongation of the Cable

- **Geometry**
- Material
- Load

Predict the Elongation of the Cable

- Geometry
- Material
- **Load**

How can we characterize the load (P)?

“The grasping mechanics of 31 different surgeons performing 3 surgical tasks involving tool tissue interaction have been measured. The results indicate that surgeons, for the tasks and tools under study, grasp tissue with less than 10 N of force, for durations 10 s or less, and at frequencies less than 2 Hz.”

Brown J. D., J. Rosen, L. Chang, M. Sinanan, B. Hannaford, *Quantifying Surgeon Grasping Mechanics in Laparoscopy Using the Blue DRAGON System*, Studies in Health Technology and Informatics - Medicine Meets Virtual Reality, vol. 98, pp. 34-36, IOS Press, January 2004.

Predict the Elongation of the Cable

- Geometry
- **Material**
- Load

Characterize the Material Sample

Creating a Model for a Material Sample: The Problem of Generalizing

- Problem: Our material sample differs from the part we're trying to design
  - the geometry is different
  - the load is different
- Need to put into a form that we can generalize to novel geometries and novel loads.

Stress and Strain

- Solution: Model a very small (infinitesimal) volume of the material and create a function of how it behaves under a wide range of loads.
  - Continuum Mechanics
  - Novel geometry: fill the geometry up with small boxes
  - Novel load: distribute the load across the boxes
- Stress
  - infinitesimal load
  - ratio of force to area
    - N/m^2 : pascal
- Strain
  - infinitesimal deformation
  - ratio of change in length to original length
    - m/m : unitless

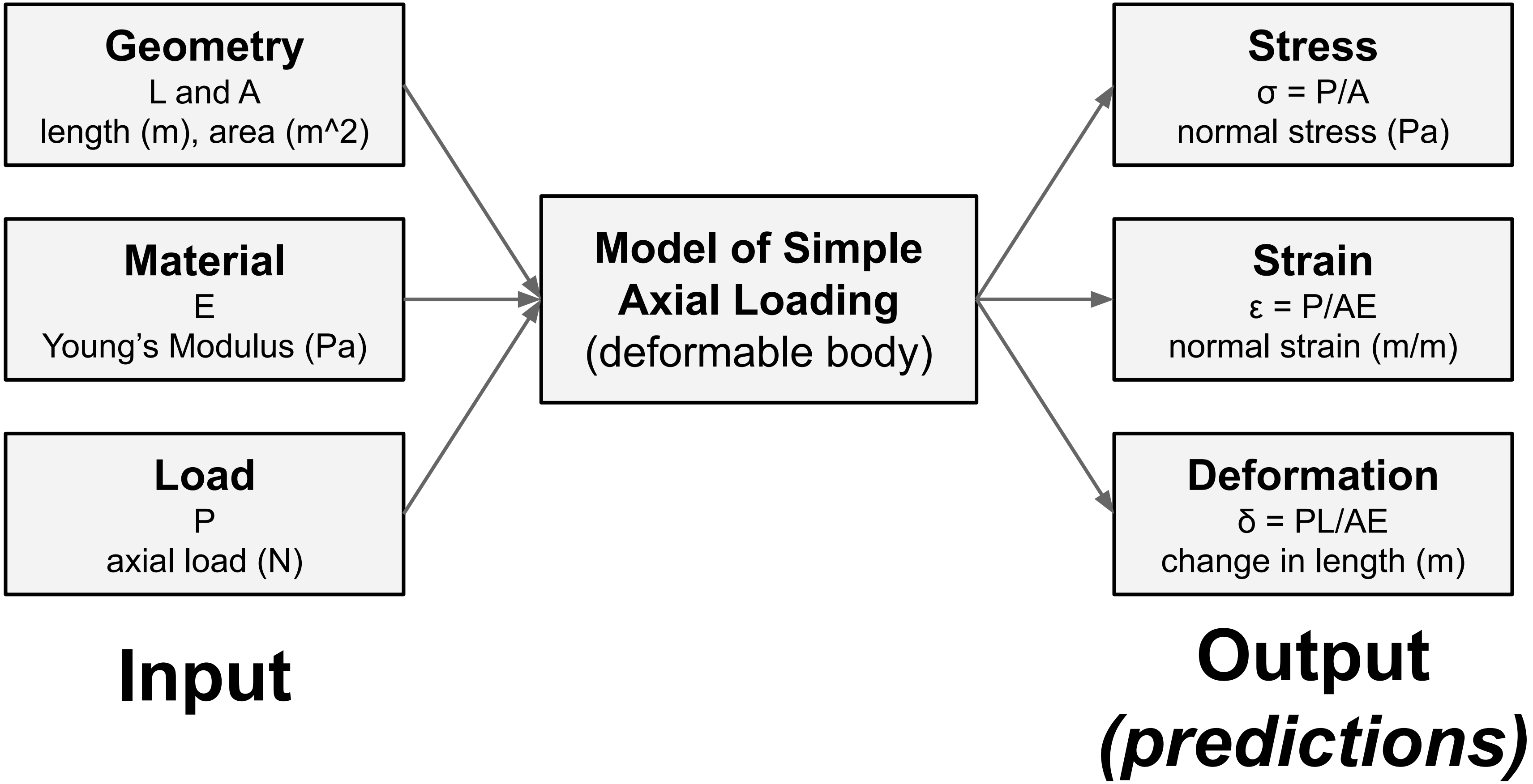
Use Our Model of Simple Axial Loading to Estimate Stress and Strain

- Measuring properties of infinitesimal boxes is hard!
- Instead, measure easily observable macroscopic properties.
- Has the advantage of effectively averaging the behavior of all the infinitesimal boxes in the material sample.

Characterize the Material Sample by Modeling Our Material Sample

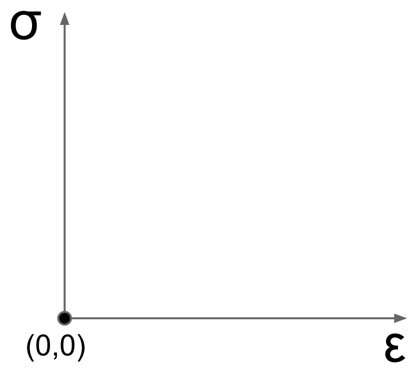
(Rubber Band)

Model of Simple Axial Loading



How can we use our model to estimate material properties?

- Method 1: Directly estimate E
  - $\delta = PL/AE$
  - $E = PL/A\delta$
- Method 2: Create a stress-strain curve
  - $\sigma = P/A$
  - $\varepsilon = \delta/L$
  - E = slope of line at (0,0) = σ/ε near (0,0)



Is this a good material to use for the cable in the surgical robot?

Supplementary Materials

These slides were not presented but might be useful.

It is important to recognize when a model is useful.

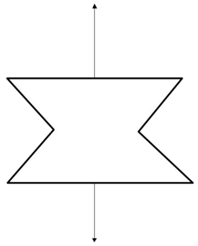
- Models represent a narrow part of the world
    - Idealizations, approximations, limited ranges of values, consider limited phenomena, etc.
- Pick the right tool for the right job
    - Can the model answer your question?
        - Does it predict what you want to predict?
    - Is the model a good match?
        - Does it represent important properties?
        - Does it ignore negligible properties?
        - Does it work well over the range of values required?
        - Do its assumptions fit the situation?
    - Do you have the information needed by the model?
    - Is the model too complex to produce a solution?

Augment our Model with Poisson's Ratio

- simple linear model relating transverse strain and axial strain

$$\nu = -\frac{\varepsilon_{transverse}}{\varepsilon_{axial}}$$

- “Most materials have Poisson's ratio values ranging between 0.0 and 0.5” - Wikipedia
    - What would nu = 0.0 mean?
        - cork
    - What would nu = ½ mean?
        - rubber
        - ideal incompressible material
    - auxetic materials
        - nu < 0
        - Figure from http://en.wikipedia.org/wiki/Auxetics



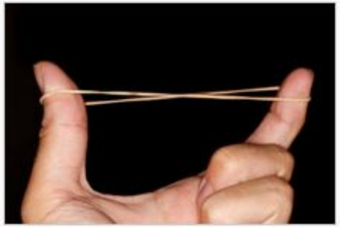
Do you believe this value?

Young's modulus

From Wikipedia, the free encyclopedia

Young's modulus, which is also known as the elastic modulus, is a mechanical property of linear elastic solid materials. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material. Young's modulus is named after the 19th-century British scientist Thomas Young. However, the concept was developed in 1727 by Leonhard Euler, and the first experiments that used the concept of Young's modulus in its current form were performed by the Italian scientist Giordano Riccati in 1782, pre-dating Young's work by 25 years.[1] The term modulus is the diminutive of the Latin term *modus* which means *measure*.

A solid body deforms when a load is applied to it. If the material is elastic, the body returns to its original shape after the load is removed. The material is linear if the ratio of load to deformation remains



Rubber, a material with an extremely low Young's modulus

Approximate Young's modulus for various materials

Material	GPa	Mpsi
Rubber (small strain)	0.01–0.1[4]	$1.45–14.5 \times 10^{-3}$

4. ^ a b c d e f g h i j k l m n o p q r s t "Elastic Properties and Young Modulus for some Materials". The Engineering ToolBox. Retrieved 2012-01-06.

screenshots from https://en.wikipedia.org/wiki/Young%27s_modulus on January 21, 2016