RoboJackets

CAT®

THE ARTHUR M. BLANK FAMILY FOUNDATION

2007 TE Sessions – Mechanical Basics

September 18, 2007

•www.robojackets.org

Mechanical Basics

Goals for this session:

- Teach the basics of successful mechanisms
- Teach material basics
- Rotational basics
- Vex applications

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Mechanical Basics

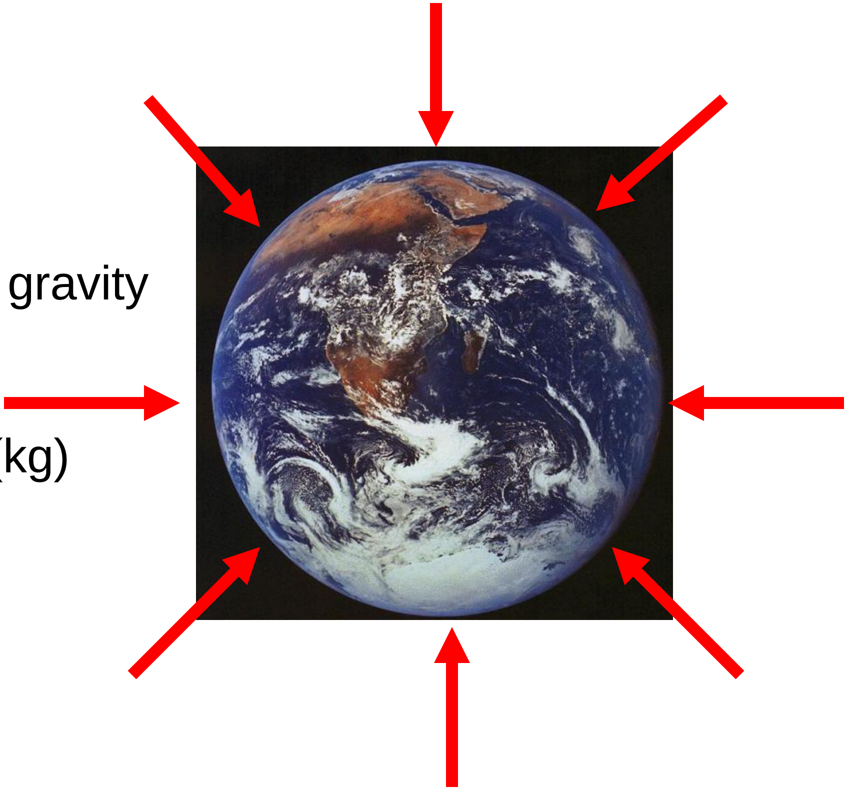
Motivation:

- Strong structures can fail catastrophically
- Geometry of design can contribute to or prevent failures
- Material selection can also be crucial

Forces

Gravity:

- Gravity is all around us, pulling toward the center of the earth



Isaac Newton:

- Newton's 2nd Law: $F=ma$
- a is the acceleration due to gravity
- 9.81 m/s^2
- m is the mass of an object (kg)
- F is the resultant force felt

Forces

Example:

- a 1kg body is 1kg on the moon, on earth or in space
- The same body weighs different amounts though

Weight:

- **Newton's 2nd Law: F=ma**
- On Earth, $a = 9.81\ m/s^2$
- $F = 1\ kg \times 9.81\ m/s^2 = 9.81\ N$
    - On the Moon, $a = 1.6\ m/s^2$
    - $F = 1\ kg \times 1.6\ m/s^2 = 1.6\ N$
        - In outer space, $a = 0\ m/s^2$
        - $F = 1\ kg \times 0\ m/s^2 = 0\ N$

Stresses

Materials Bend

- Everything stretches before it breaks
- **Elastic:**
  - Stretches a lot before it breaks
  - Rubber
- **Brittle:**
  - Doesn’t stretch much before it breaks
  - Glass
- **Stress:**
  - Defined as Force per Area
  - Pressure: pounds per square inch

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Stresses

Area

- Cross-section through force
- **Circular**
  - pi * (radius)^2
- **Rectangular**
  - L * H
- **Stress:**
  - Tension

  - Compression

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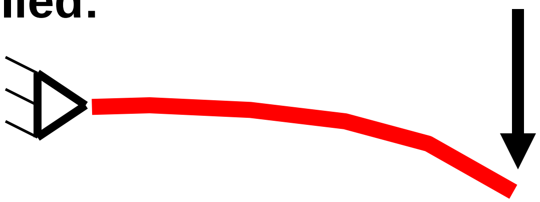
Stresses

Materials Bend

- **Everything** stretches before it breaks
- **Single Point Bending**
  - **Cantilever Beam:**

  - **Force Applied:**



- **Deflection:**
  - End of beam deflects in direction of force
  - If deflection is large enough, stresses will cause beam to permanently deform

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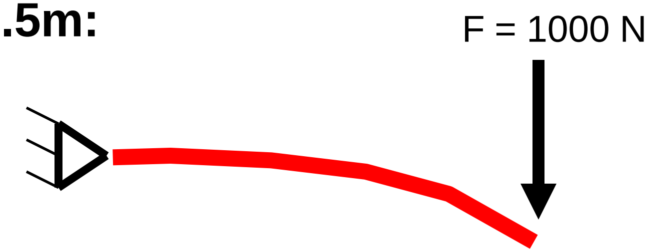
Stresses

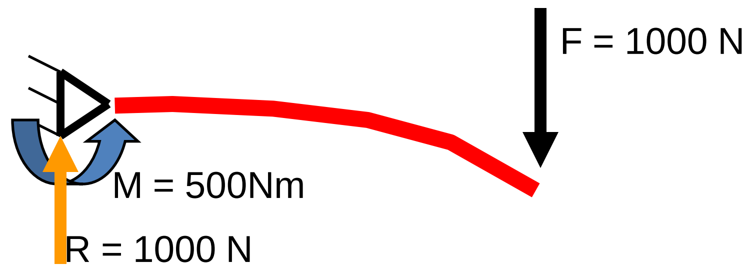
Example

- **Single Point Bending**
  - **Cantilever Beam, length of 0.5m:**

  - **Force of 1000N Applied:**



- **Reactions**
  - **Moment**
  - **Force**



- **Thoughts:**
  - Large deflections can occur without damage
  - Large moments may be difficult to resist
  - Cantilevered loads can be avoided

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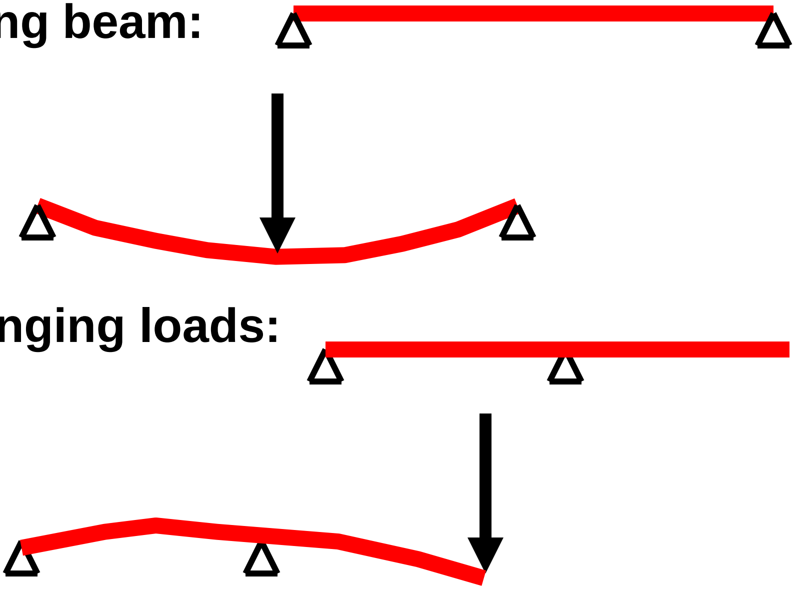
Stresses

Bending

- **Two Point Bending**
  - **Spanning beam:**
  - **Overhanging loads:**

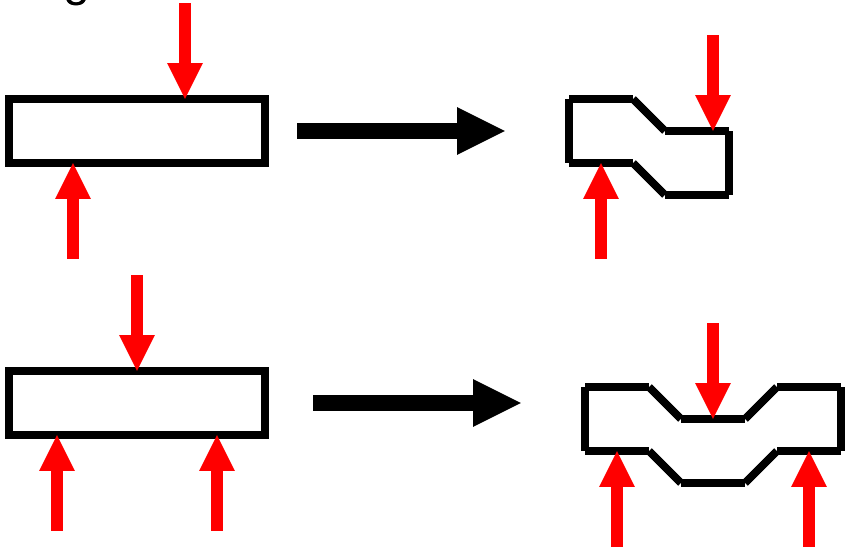


- **Deflection:**
  - End of beam deflects in direction of force
  - Middle of beam rises in direction opposite of force

Shear Stress

Shear

- While bending results in tension and compression
- Shear loads produce different stresses
- Single and double shear:



- Double shear setups reduce load on pins by 1/2

Materials

Steel vs. Aluminum

- Which should I use???
- **Steel**
  - Strong, but heavy
  - Flexible
- **Steel is an alloy of Iron and Carbon, with carbon levels varying by grade**
- **Carbon Steel or Stainless?**
  - Carbon steel comes in various grades:
    - **Low carbon:** more flexible, yields at lower stress (AISI 1006 – 1020)
    - **High carbon:** more brittle, yields less before failure (AISI 1060+)
- **Stainless Steels**
  - Stainless resists oxidation (rust)
  - Expensive, and difficult to machine
    - 304, 304L, and 316 are most common

Materials

- **Aluminum**
  - Light, but weaker than steel
  - Limited flexibility
  - Pound for pound, more expensive than steel
- **Aluminum comes in various grades based on alloy**
- **Which grade?**
  - **Most common:** 2024, 6061
    - Suitable for 99.9% of robotics uses
  - **Special grades:** 4000s 7000s
    - Ultra-light, corrosion resistant, etc.
- **Fatigue!!**
  - Aluminum **WILL BREAK!!!**
  - When repeatedly flexed & stressed, cracks will develop, and the piece WILL fail.

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Materials

- **Plastics**
    - Light
    - Flexible
    - Cheap & easy to machine
- **Many types of plastics are available**
- **Which type?**
        - **HDPE:** High Density Polyethylene
        - Flexible, white or black
        - **Polycarbonates:** Lexan, etc
        - Extremely flexible, clear sheets
        - **Acrylics:** Plexiglas, etc
        - Brittle, clear sheets
        - **Delrin:** Acetal resin
        - Slick, low friction, many colors

Material Selection

Based on component properties

- **Axles & drive components**
  - Steel can withstand fatigue and stresses
  - Aluminum or plastics will wear and fail to quickly
- **Frame**
  - Aluminum beams will be easy to cut and drill, stay lightweight
  - Steel will be very strong and easily weldable
- **Arms**
  - Aluminum is lighter than steel, and with good design, will be strong
  - Steel is strong, but too heavy to be an arm
- **Body panels**
  - Aluminum and steel are both too heavy
  - Polycarbonates or Acrylics work well

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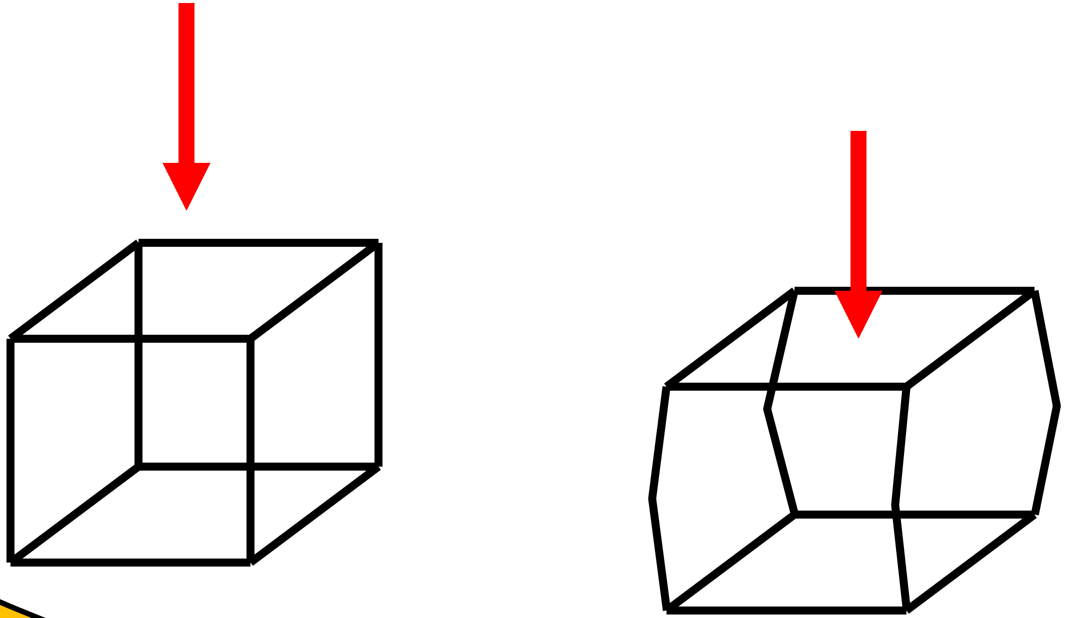
Build a Box

(A good one)

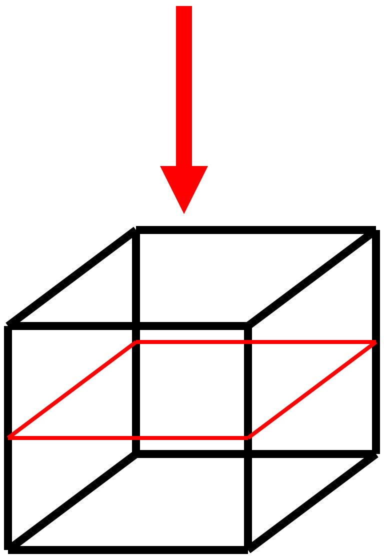
- **What makes a box good?**
  - Should be able to support weight
  - Should be light
  - Shouldn’t flex too much under loads



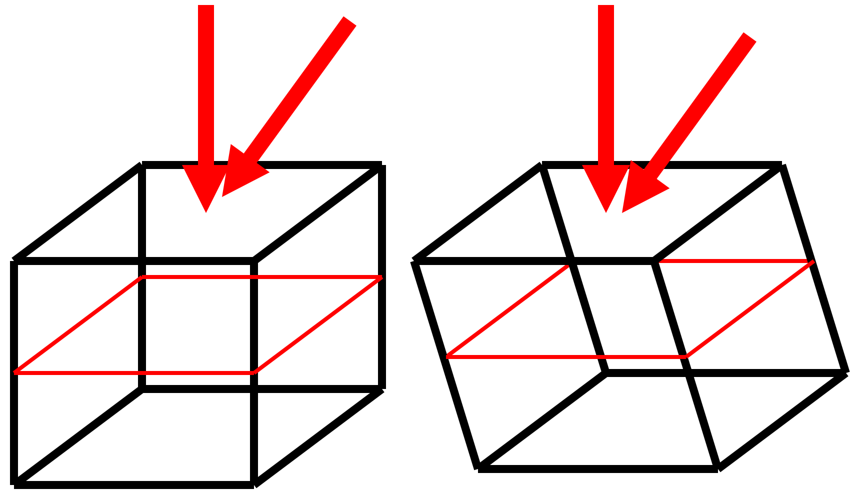
Build a Box

(A better one)

- **What makes a box better?**
  - Members spanning sides can prevent buckling
  - Shouldn't flex too much under side loads



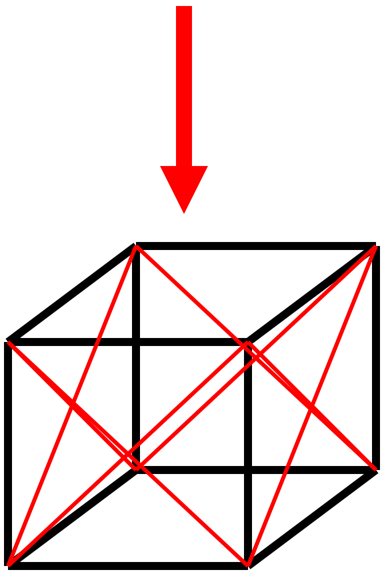
- **Looks good, but what if….?**



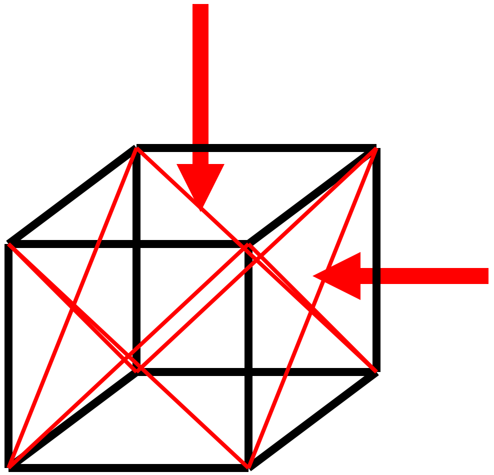
Build a Box

(An even better one)

- **What makes a box even better?**
  - Members spanning corners are best
  - An X shape is preferable, but not always an option due to weight



- **Much stronger**

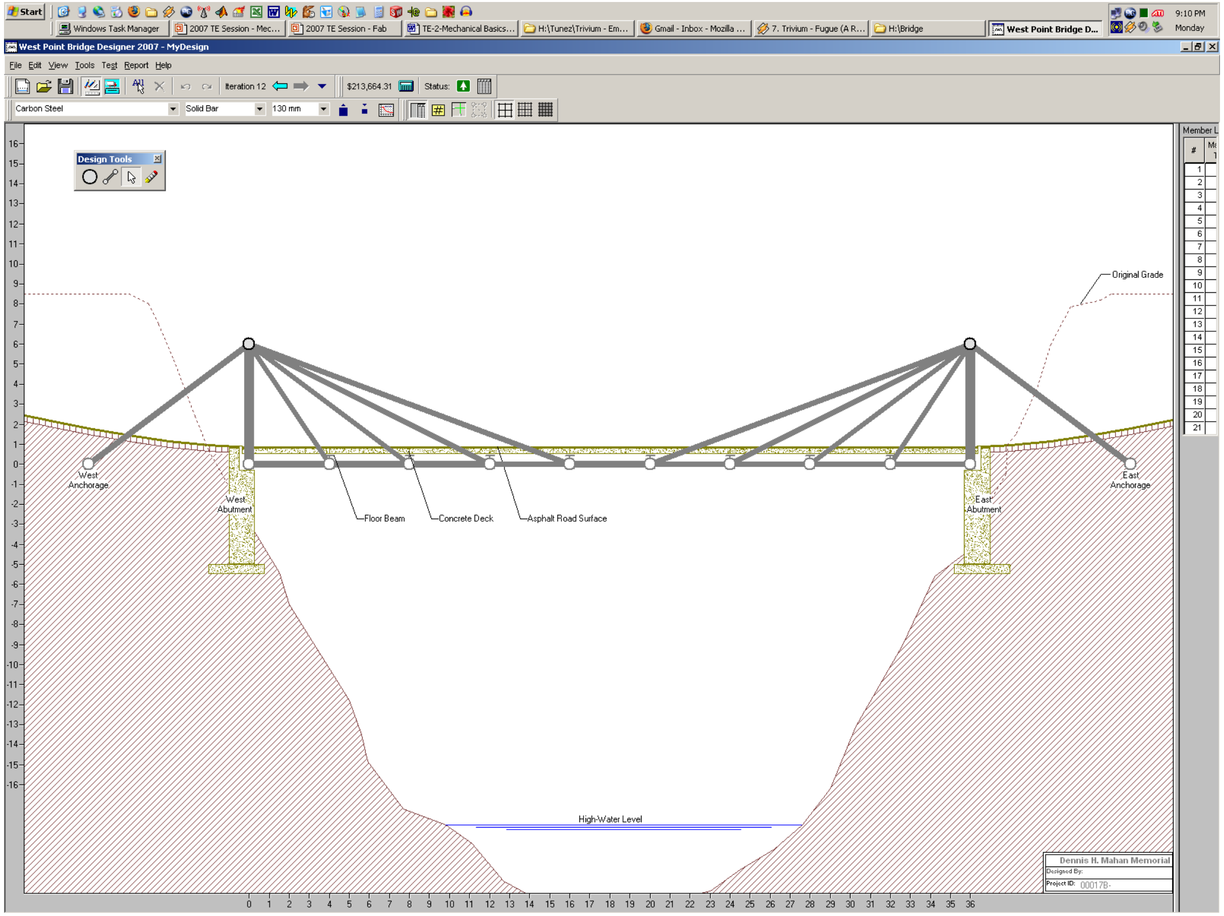


Your Turn

- **Use your Vex kits to assemble a simple box**
    - Make it as large as possible
    - The box must be strong enough to hold your whole Vex kit
    - Make it as **LIGHT** as you can (less material is better)

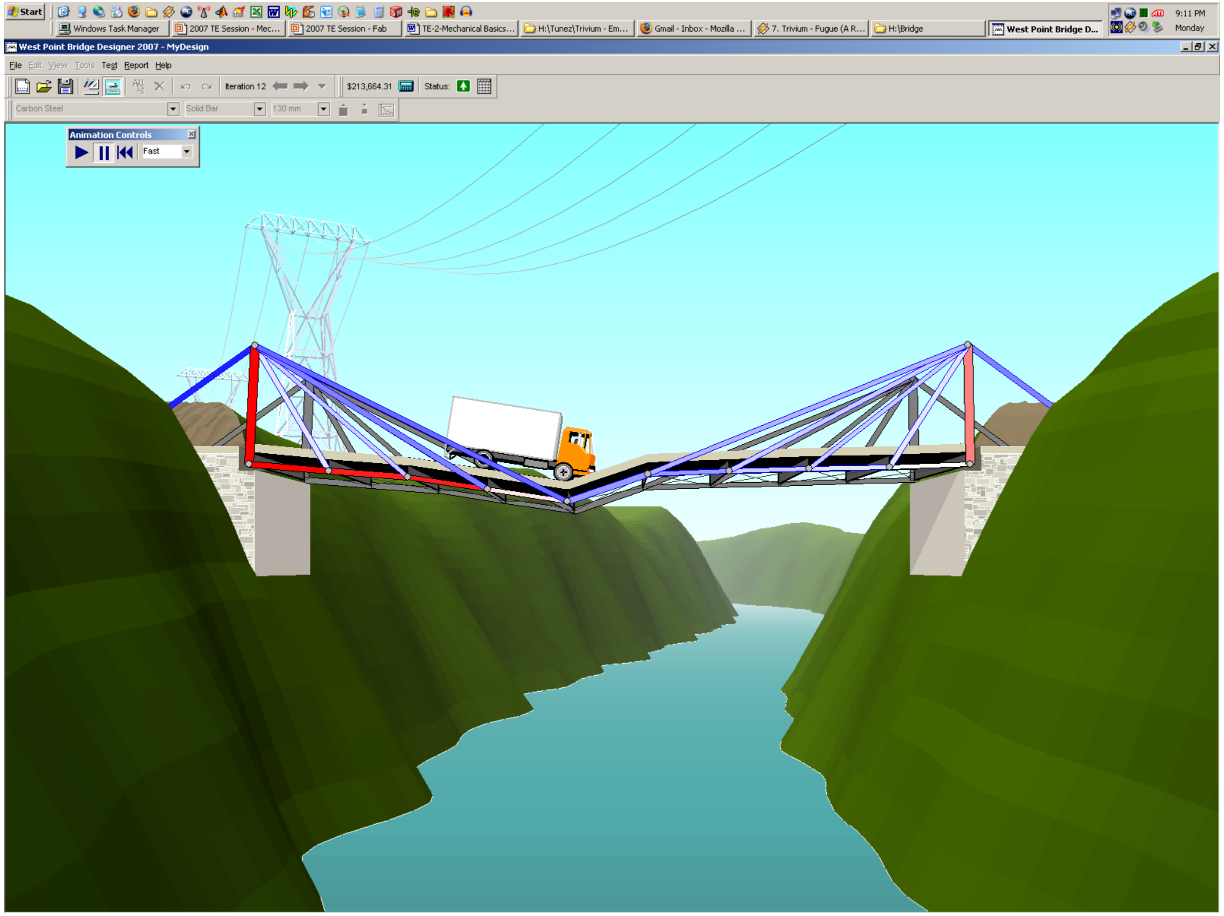
Try This

- **West Point Bridge Designer®**
  - Free download
- Design a bridge or watch it fail



Try This

- **West Point Bridge Designer®**
  - Run a real simulation on it
  - Watch the beams stretch and compress



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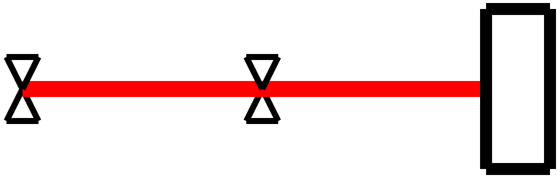
Rotation

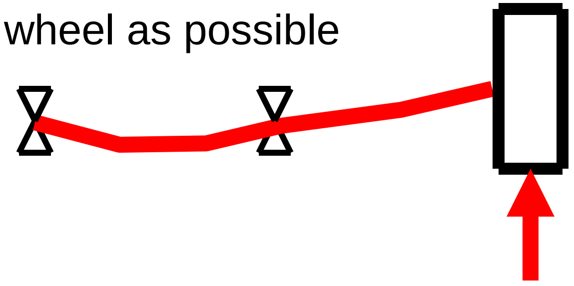
- **Rotary motion is key to most machines**
  - **Torque**
    - Motors transmit torque to gears
    - Gears transmit torque to wheels
    - Wheels transmit torque to the ground

Wheel Setups

- **Overhanging Loads**
  - **Analog to beam bending**
    - Wheels can be placed on the end of a shaft
    - Shaft **MUST** be supported in two places
    - Shaft **MUST** be supported in two places
- **Overhanging wheels:**

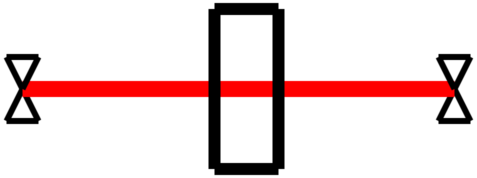


  - Put bearings as close to wheel as possible

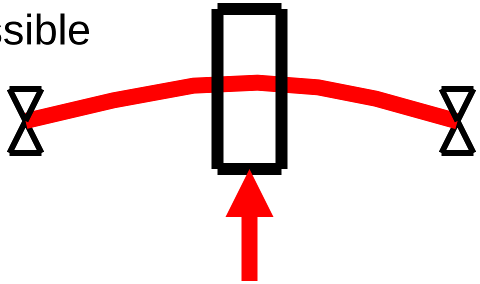


Wheel Setups

- **Centered Loads**
  - **Analog to beam bending**
    - Wheels can be placed at the center of shaft
    - Shaft **MUST** be still supported in two places
    - Shaft is supported on both sides of wheel
- **Centered wheels:**



  - Put bearings as close to wheel as possible



Wheel Setups

- **Wheels spinning on shaft**
  - **Advantages:**
    - Wheels are passive components
    - Useful for unpowered wheels
    - Simple for unpowered applications
  - **Disadvantages:**
    - Wheels must have bearings inside hub

Wheel Setups

- **Wheels spinning with shaft**
  - **Advantages:**
    - Wheels are actively driving the vehicle
    - Wheels can be mounted directly to gearbox
    - Or driven by chains or belts at a distance
  - **Considerations**
    - Wheels must be coupled to shaft
    - Keyed shafts are most effective way to couple

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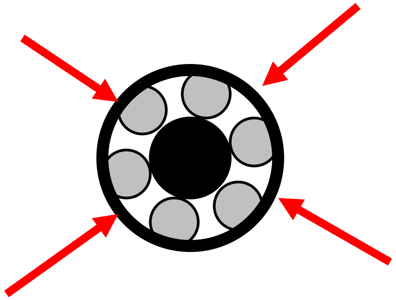
Bearings

- **Radial Load bearings**
  - Radial bearings handle loads in the radial direction



  - Radial loads are applied from wheels to shaft

- **Why even use bearings?**
  - Bearings are essential in rotating machines
  - Bearings reduce drag and handle forces
  - Without bearings, the shaft would heat up so much that it would swell and seize in its housing

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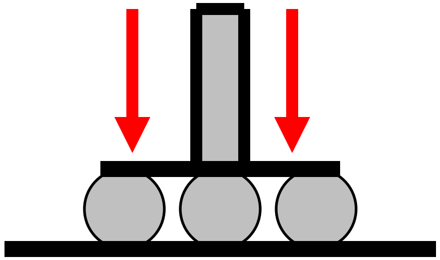
Bearings

- **Thrust Load bearings**
  - Thrust bearings handle loads in the axial direction



  - Radial loads are applied from shaft to housing or support

- **Why even use bearings?**
  - Thrust bearings are good for supporting a rotating arm assembly…
  - Cars use combination radial/thrust bearings to handle cornering loads

Bushings

- **What's the difference?**
  - Bushings act like bearings
  - No moving parts except shaft
  - Used for low speed applications
  - Less $$$

Ratings & Terminology

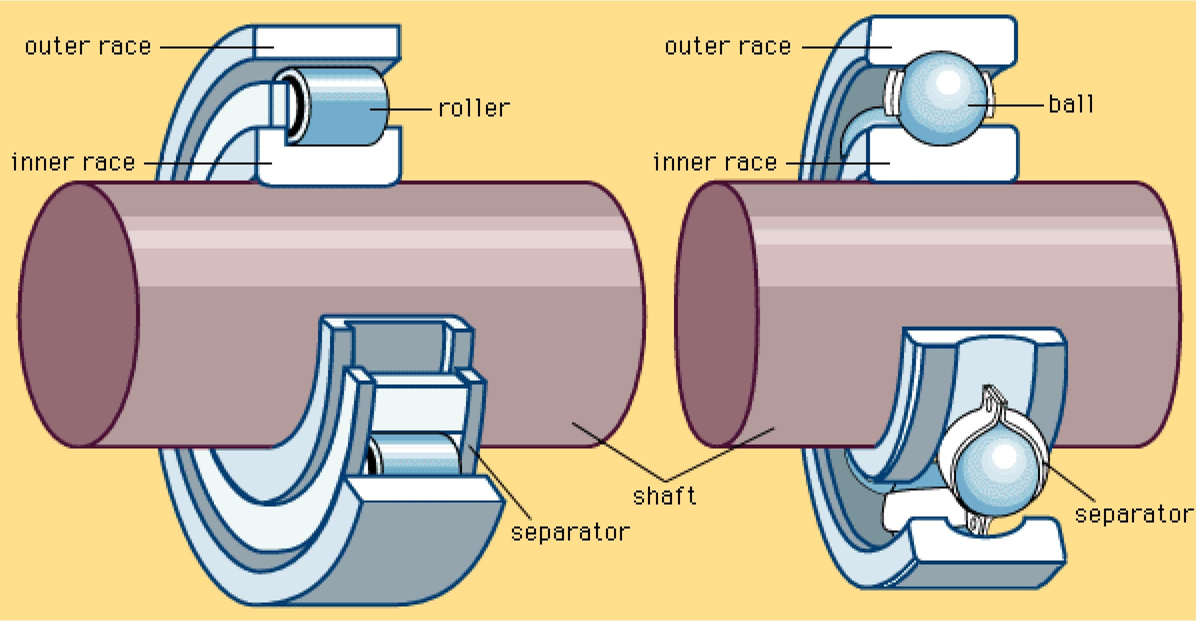
- **Bearings**
  Shaft speed (rpm)

  > 10,000 rpm
- **Roller**
  Higher radial loads

Bushings

< 1,000 rpm

Ball
Higher shaft speeds



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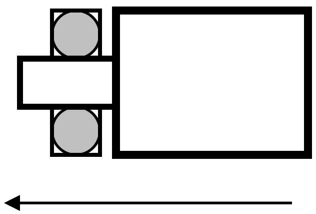
Shaft Restraints

- **Reasons**
    - Shafts can still move axially within bearings
    - Solutions:
- **Shoulders**

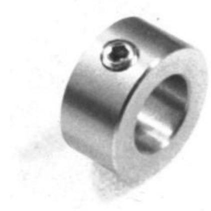


- Prevents motion in one direction

- **Snap Rings & E-Clips**

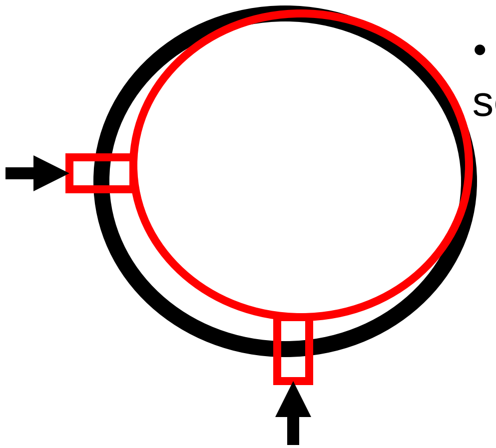
- Clip onto grooves in shaft to prevent motion

- **Shaft Collars**
- Grip onto shaft by friction or set screws



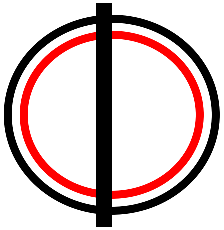
Shaft Restraints

- **Set Screws**
  - Set screws seize the shaft onto a hub
  - Set screws work best when applied at 90 degrees
- **Application**



- Even though the shaft is off-centered, the set screw clamping force is effective

- **Pinning**



- Pinning is simple but can shear

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Your Turn

- **Put some wheels on your box!**
  - Wheel setup should be strong enough to support weight
  - Make sure your wheels don't move around on the shaft
  - Make sure the shafts can spin freely in the Vex frame
- **Box should still be strong enough to hold your Vex Kit**
- **If you have time, put the wheels on the side of your box and see how robust the design really is**

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