Unit 2

# Forces and Structures

http://www.pbs.org/wgbh/buildingbig/educator/act_index.html

# What is a Structure?

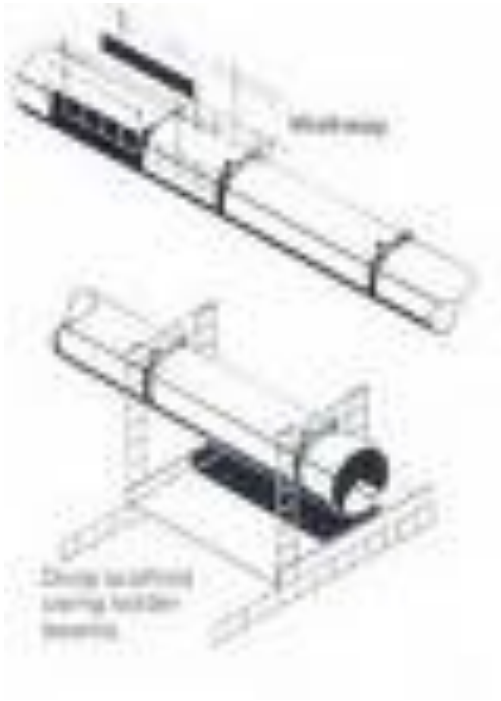
- Structures have definite size and shape, which serve a definite purpose or function
- Every part of the structure must resist forces (stress such as pushes or pulls)
- Force can potentially damage a structures stability and shape

# Natural Structures

- Not made by people
- Occur naturally in the environment

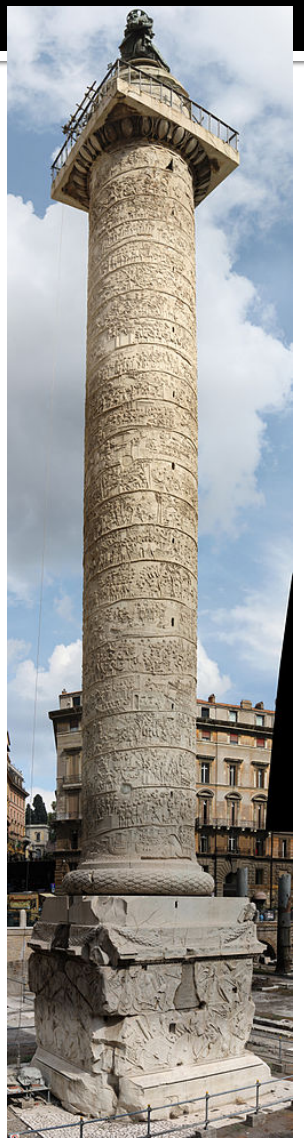
# Manufactured Structures

- Built by people
- Many are modeled after natural structures



# Mass Structures (Also Known As) Solid Structures

- Can be made by, piling up or forming similar materials into a particular shape or design.
- It is held in place by its own weight, losing small parts often has little effect on the overall strength of the structure



# Natural Mass (Solid) Structures

# Manufactured Mass (Solid) Structures

# Manufactured Mass (Solid) Structures

# A Layered Look

- Mass structures are not always solid, but are layered and have hollowed out areas for specific functions

# A Layered Look

- Sandbag Wall Structures are mass structures that are layered. They prevent flooding and have 4 key elements to avoid failure:
  - Must be heavy enough to stay in place
  - Must not be too heavy to compact the earth unevenly below it
  - Must be thick enough so it cannot be pushed out of place
  - Must be anchored firmly

# Frame Structures

- Have skeleton of strong materials, which is filled and covered with other materials, supporting the overall structure
- Most of the inside part of the structure is empty space.

# Frame Structures

- Formed from a combination of parts
- None of the components are capable of supporting the load by itself, but when they are fastened together they support and strengthen each other
- Ex. Goal posts, skeleton, hydro towers, girders on a bridge
  - Flexible and are usually better at handling torsion and tension forces
  - Less material and lighter than solid structures
  - May require more work to construct

# Frame Structures

- Load-Bearing Walls: these are walls that support the load of the building

# Frame Structures

- Partition Walls: these are the walls that divide up the space in a building

# Frame Structures

- Most common construction choice because:
  - Easy to design
  - Easy to build
  - Inexpensive to manufacture

# Frame Structures

# Shell Structures

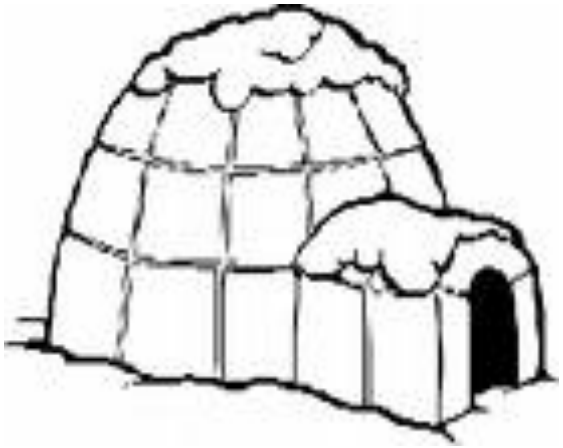
- Keep their shape and support loads, even without a frame, or solid mass material inside
- Use a thin, carefully shaped, outer layer of material, to provide their strength and rigidity
- Spreads forces throughout whole structure (every part of structure supports only a small part of the load)

# Shell Structures

- Has a solid surface and a hollow interior
- Ex. Egg shells, egg cartons, domed roofs, helmets, shoeboxes
  - Curved structure are stronger than shell structures with surfaces
  - Strong shells can be made from weak materials (ex. eggshells)

# Shell Structures

# Shell Structures



# Shell Structures

- Flexible Structures:are also shell structures but are more flexible rather than rigid

# Shell Structures

- They are completely empty so they make great containers
- Their thin outside layer means they use very little materials

# Shell Structures

- A tiny weakness or imperfection on the covering can cause the whole structure to fail
- When shell is created from hot or moist materials, uneven cooling can cause some parts to weaken other parts from pushing or pulling on nearby sections
- Flat materials are hard to form into rounded shell shape
- Assembly of flexible materials is very precise, so that seams are strong where the pieces are joined

# Mix and Match

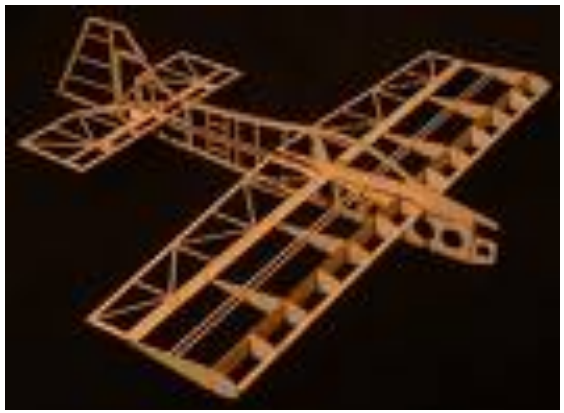
- Football Helmets
  - Shell structure (to protect head)
  - Frame structure attached in front (to protect the face)

# Mix and Match

- Hydro-electric Dams
  - Mass structures with frame structure inside to house generators

# Mix and Match

- Airplanes
  - Frame structure
  - 'skin' that acts like a shell (giving it added strength to resist stresses and making it light weight and flexible)



# Mix and Match

- Domed Buildings
  - Combines shell and frame construction

# Mix and Match

- Warehouses
  - Often built with columns to support the roof (frame) and concrete blocks (mass structure) which stay in place because of their weight

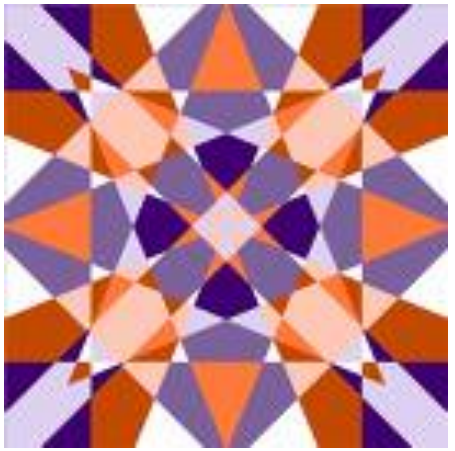
# Topic 1 Review

# Topic 2- Describing Structures

- Supporting (its own weight)
- Containing (substances)
- Transporting
- Sheltering
- Lifting
- Fastening
- Separating
- Communicating
- Breaking
- Holding

# Aesthetics

- The study of beauty in nature
  - Best structural designs 'look good' or are 'aesthetically pleasing'
  - Aesthetics are accomplished by shape, texture, colour, type of material, and simplicity of the repeated pattern in a design.



# Safety

- All structures are designed and built within an acceptable margin of safety
  - Usually, structures are designed with a built-in large margin of safety

YouTube - Construction and Building Inspectors

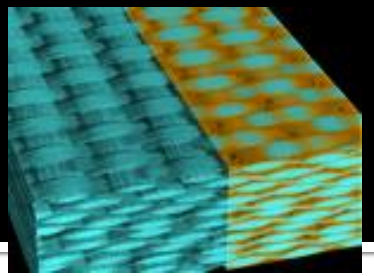
# Cost

- Adding extra strength to a structure will increase the cost, as well as using more highly skilled workers and better materials.
  - Good design is a compromise between a reasonable margin of safety and reasonable cost
  - Totally unexpected events will cause even the best (well designed) structures fail (ie. World Trade Center Towers)
    - YouTube - Moore Releases Plan to Cut School Construction Costs
    - YouTube - Shipping Containers Recycled as Homes

# Materials

- Properties or characteristics of the materials must match the purpose of the structure
  - Example: You don't want to build a boat out of paper!

# Composite Materials



- Made from more than one kind of material
- Two types of forces act on a composite material:
  - Tension (pulling)
  - Compression (pushing)

YouTube - Composite Materials

# Layered Material

- Layers of different materials are pressed and glued together, combining the properties of the different materials
  - Layers are called laminations

Examples of layered materials include: car windshields, drywall, and plywood

YouTube - Bent Plywood Manufacturing

# Woven or Knit Materials

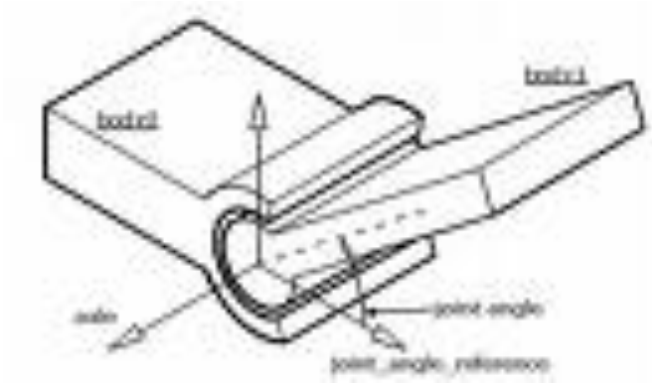
- Spinning or twisting, looping or knotting fibres together gives materials added strength.
  - Looms are used to weave two or more pieces of yarn together in a criss-cross pattern
  - Pressing, gluing, melting, and dissolving also combine materials to gain strength
  - YouTube - Weaving on Primitive Hand Loom

# Choosing Materials

- It is always important to weight the advantages and disadvantages of various materials
- Factors to consider:
  - Cost- with cheaper materials perform its function over a length of time?
  - Appearance
  - Environmental Impact
  - Energy efficiency

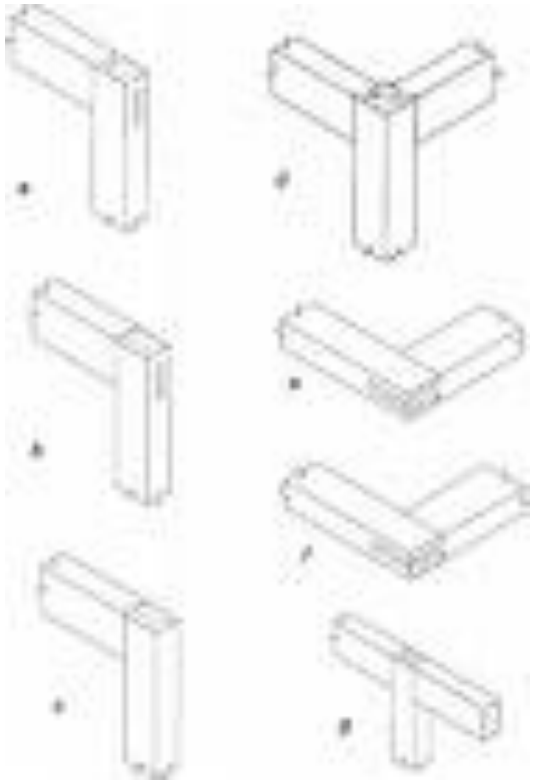

# Joints: Fastening Structures

- Mobile Joints: joints that allow movement




# Rigid Joints

- Rigid joints do not allow movement.



# ints

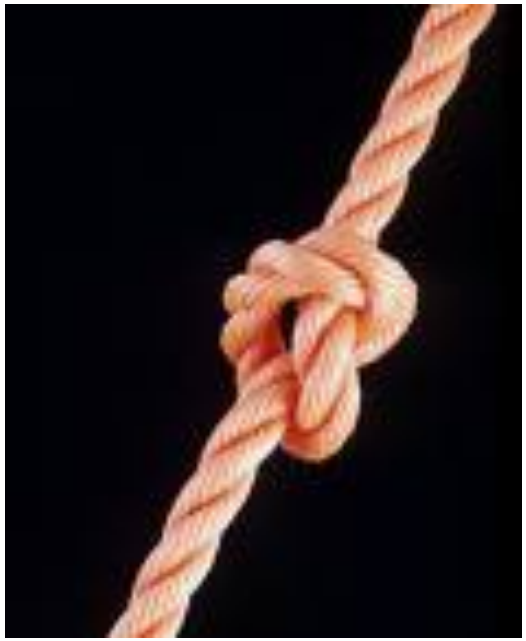
- **Fasteners**
  - Ie. Nails, staples, bolts, screws, rivets, and dowels
  - Holes made in structure actually weaken the structure
  - One fastener allows movement when parts are pushed or pulled
  - More than one fastener will make a more rigid joint (but will also weaken it more)

# Rigid Joints

- **Interlocking Shapes**
  - Fit together because of their shape
  - Ie. Lego, dovetail joints, and dental fillings

# Rigid Joints

- **Ties:**
  - Fasten things together
  - Ie. Thread, string, and rope



# Rigid Joints


- **<u>Adhesives:</u>**
  - Sticky substances hold things together
  - Ie. Hot glue, drying glue, and epoxy resin

# Rigid Joints

- **Melting:**
  - Pieces of metal or plastic can be melted together
  - Ie. Welding, soldering, and brazing

# Topic 2 Review

# Topic #3

## Mass versus Weight
### How are weight and mass different?

To understand the differences we need to compare a few points:

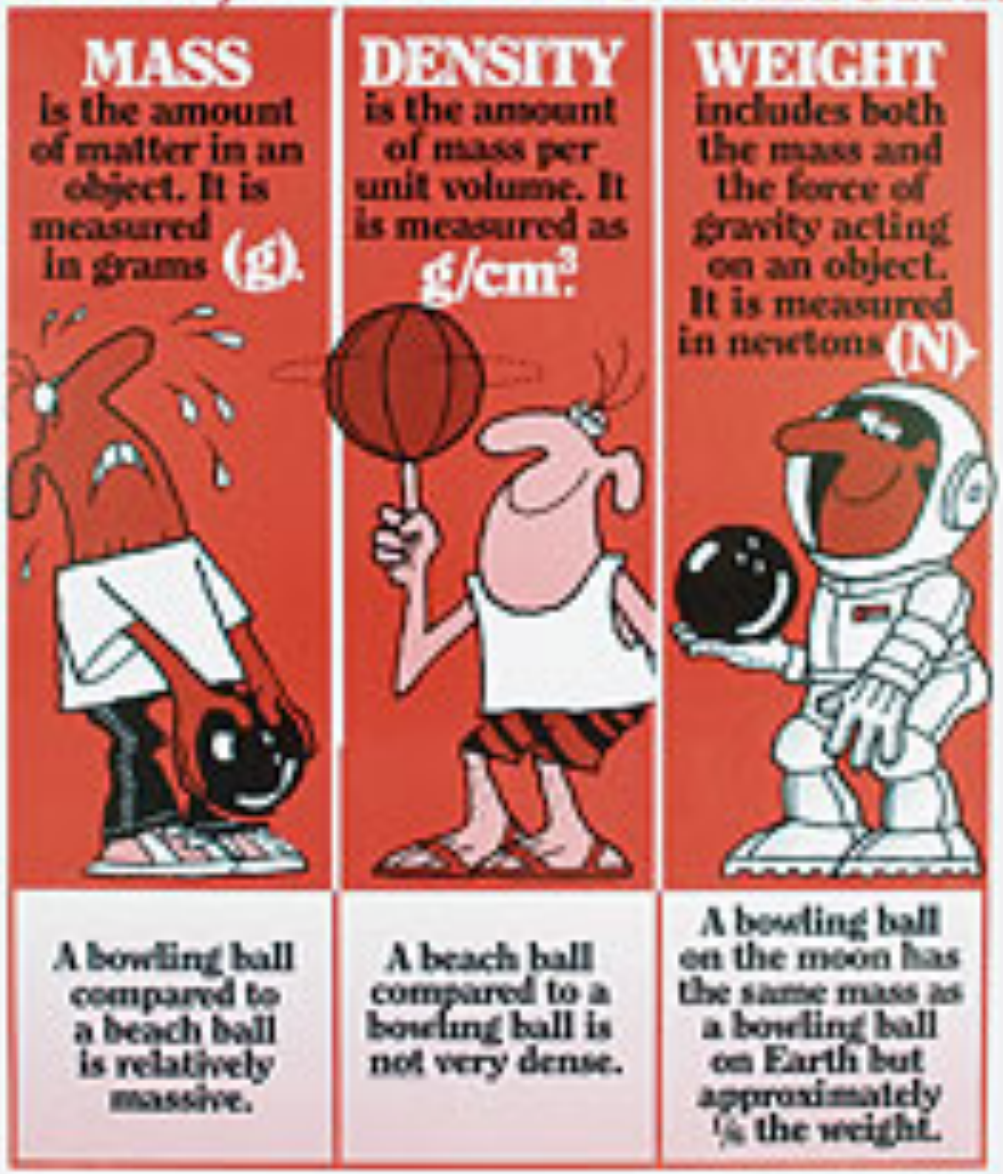
1) Mass is a measurement of the amount of matter something contains, while Weight is the measurement of the pull of gravity on an object.

2) Mass is measured by using a balance comparing a known amount of matter to an unknown amount of matter. Weight is measured on a scale.

3) The Mass of an object doesn't change when an object's location changes. Weight, on the other hand does change with location.

http://www.youtube.com/watch?v=grWG_U4sgS8

# GET A GRIP ON MASS, DENSITY & WEIGHT.



## Mass is measured in kg
## Weight in measured in newtons (N)

1 kg = 10N
(actually it's 9.8N, but 10 is an easier number to estimate)

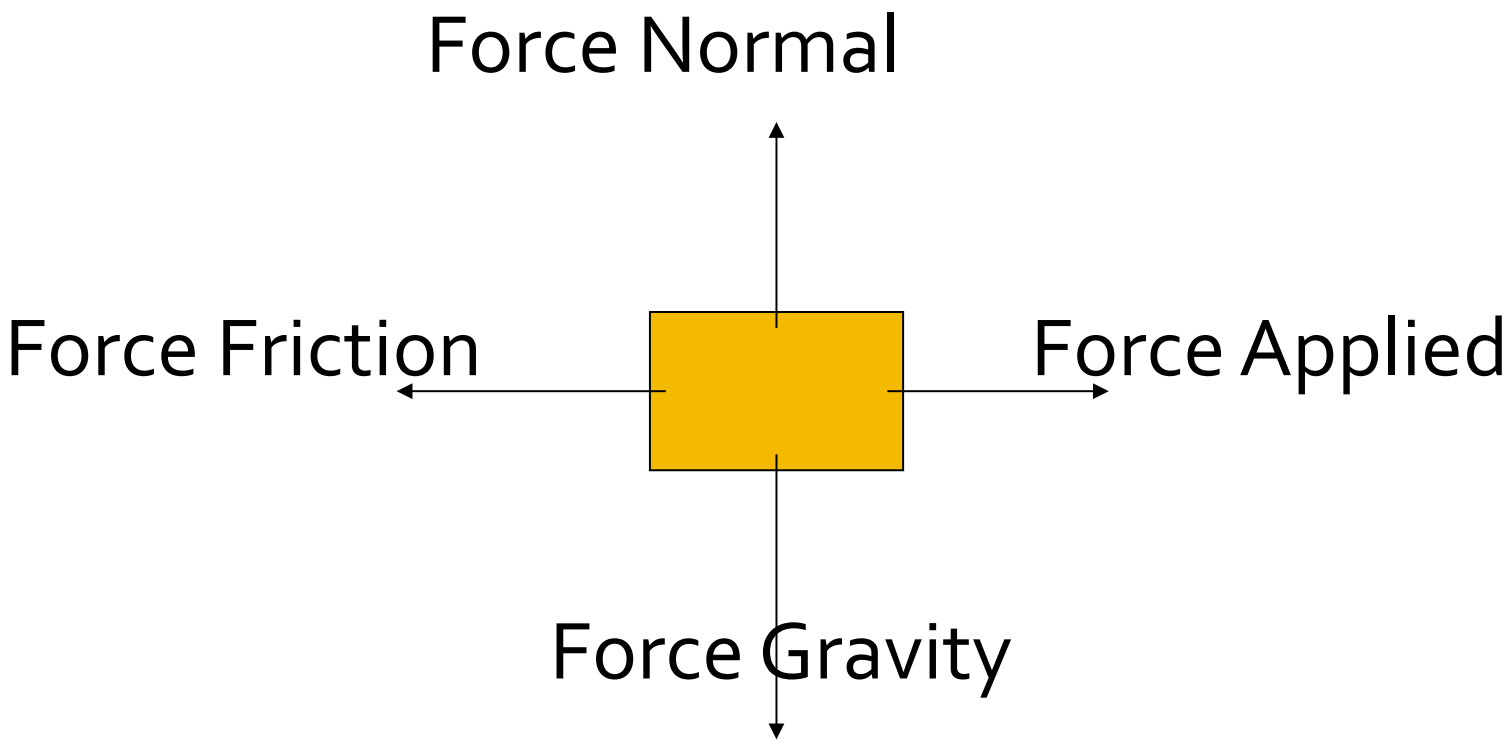
# Force and Weight

- An elephant has a mass of 5000 kg.
- On the moon would the mass of an elephant change?
- What does change?
- When does the mass change?

# Types of Forces

- Fg = force of gravity (determine Fg = mg)
- Fa = Force applied (Force pushing or pulling the object)
- FN =Force Normal
- Ff = force friction (resistance on object)

# Force Diagram



# Describing Force

- To describe a force you need **direction** and its size.
- You lift a 50 N box upward.
- A 15 N book falls down on your foot.

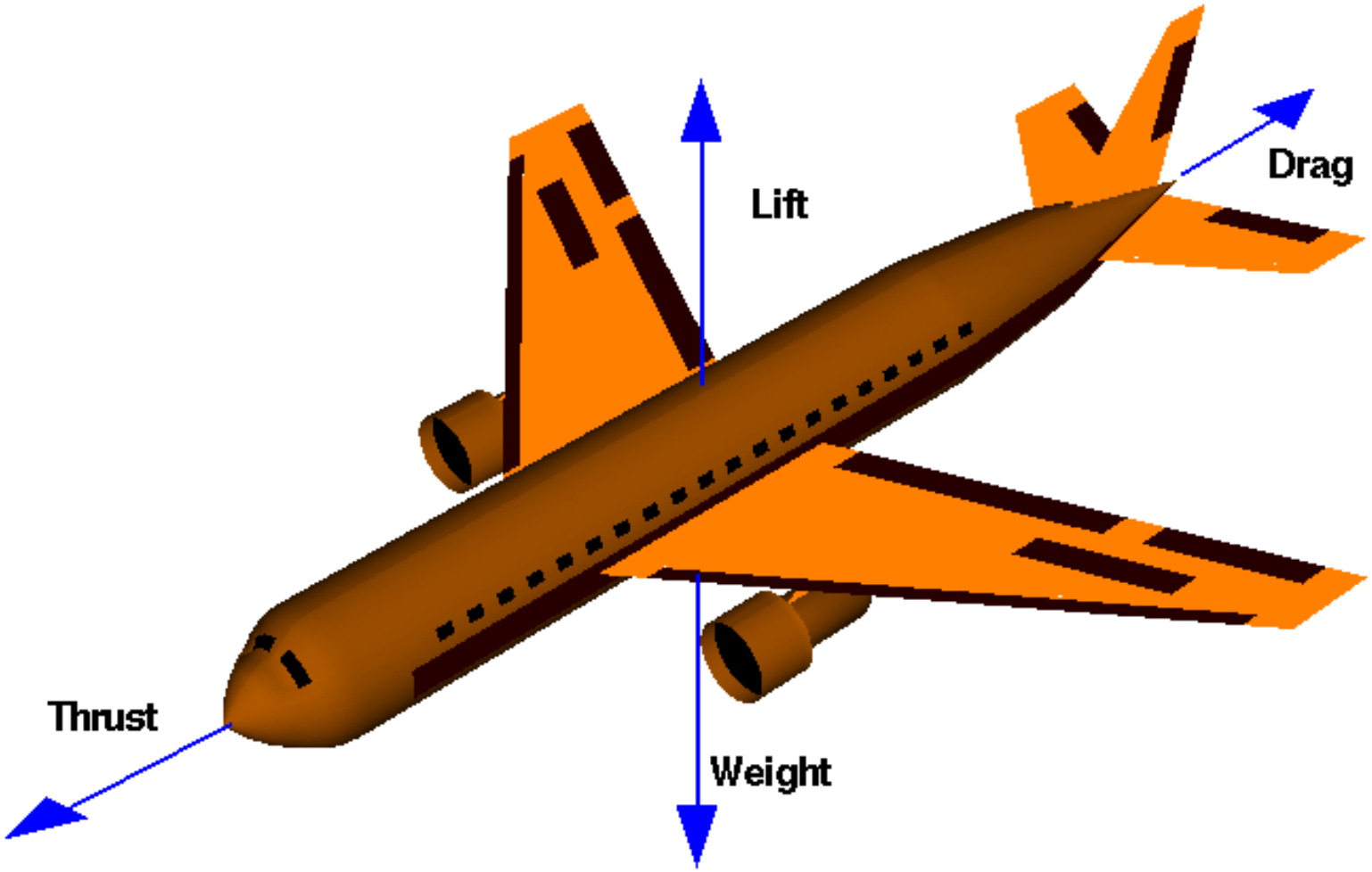
# Force Diagrams

- If there is a force being strongly applied to an object then the arrow will be longer.
- Draw a force diagram for the following:
  - An elevator at rest
  - An elevator going to the top floor
  - An elevator going to the main floor

- Pushing a box
- Pull up
- Tug of war
- Elevator

# Four Forces on an Airplane

Glenn Research Center



# What is Lift ?

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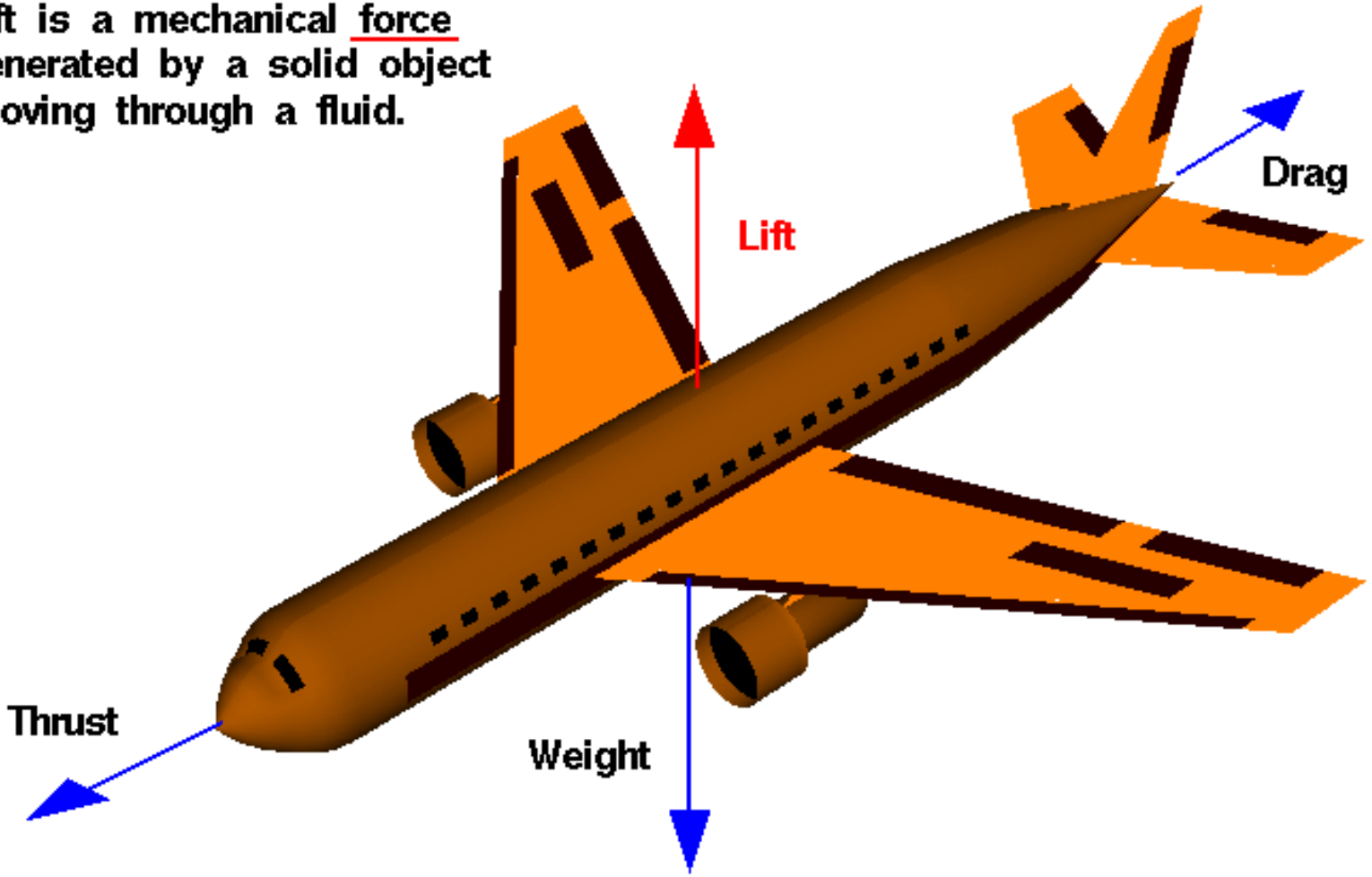
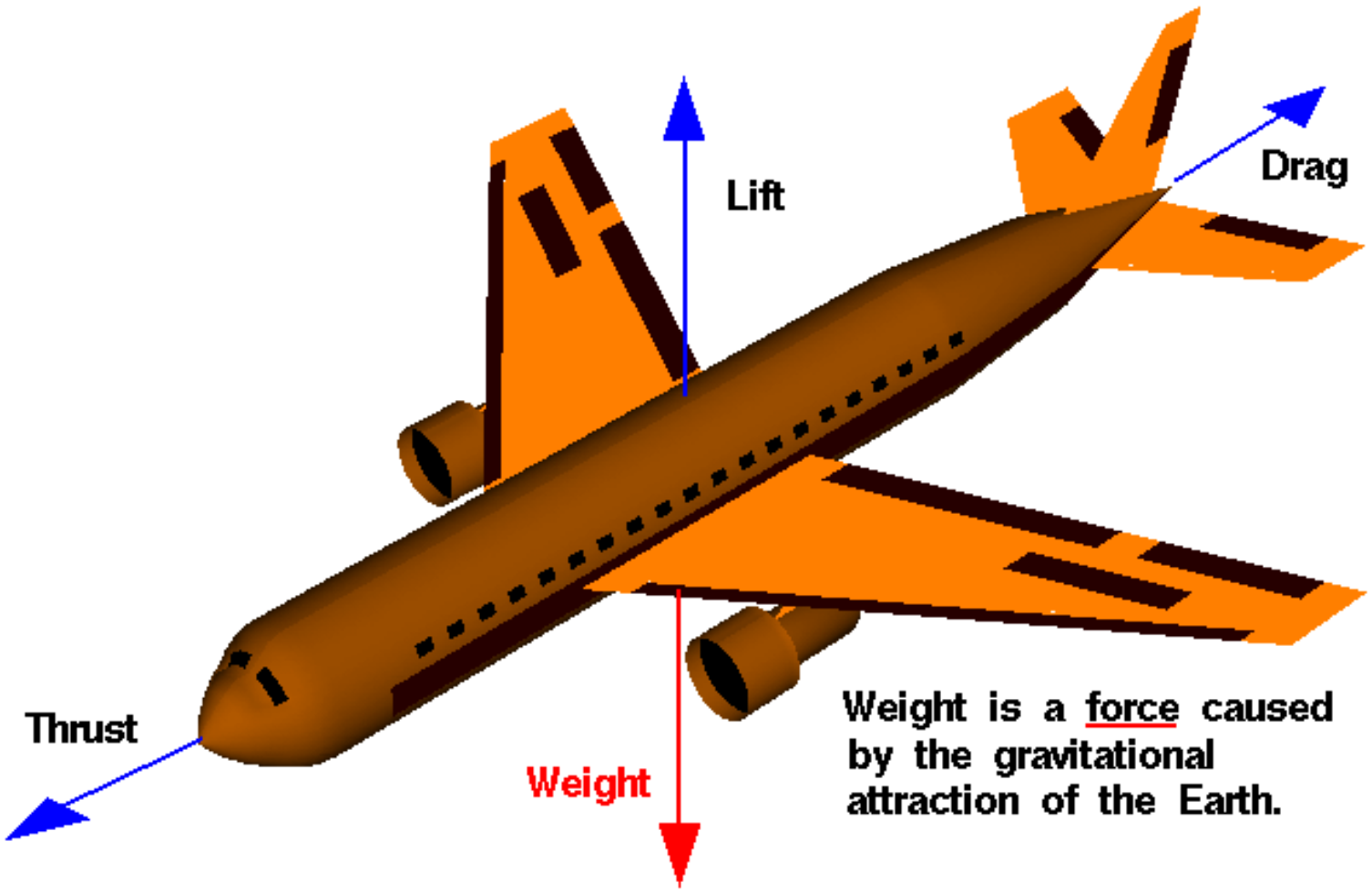
Lift is a mechanical force generated by a solid object moving through a fluid.



# What is Weight?

Glenn Research Center

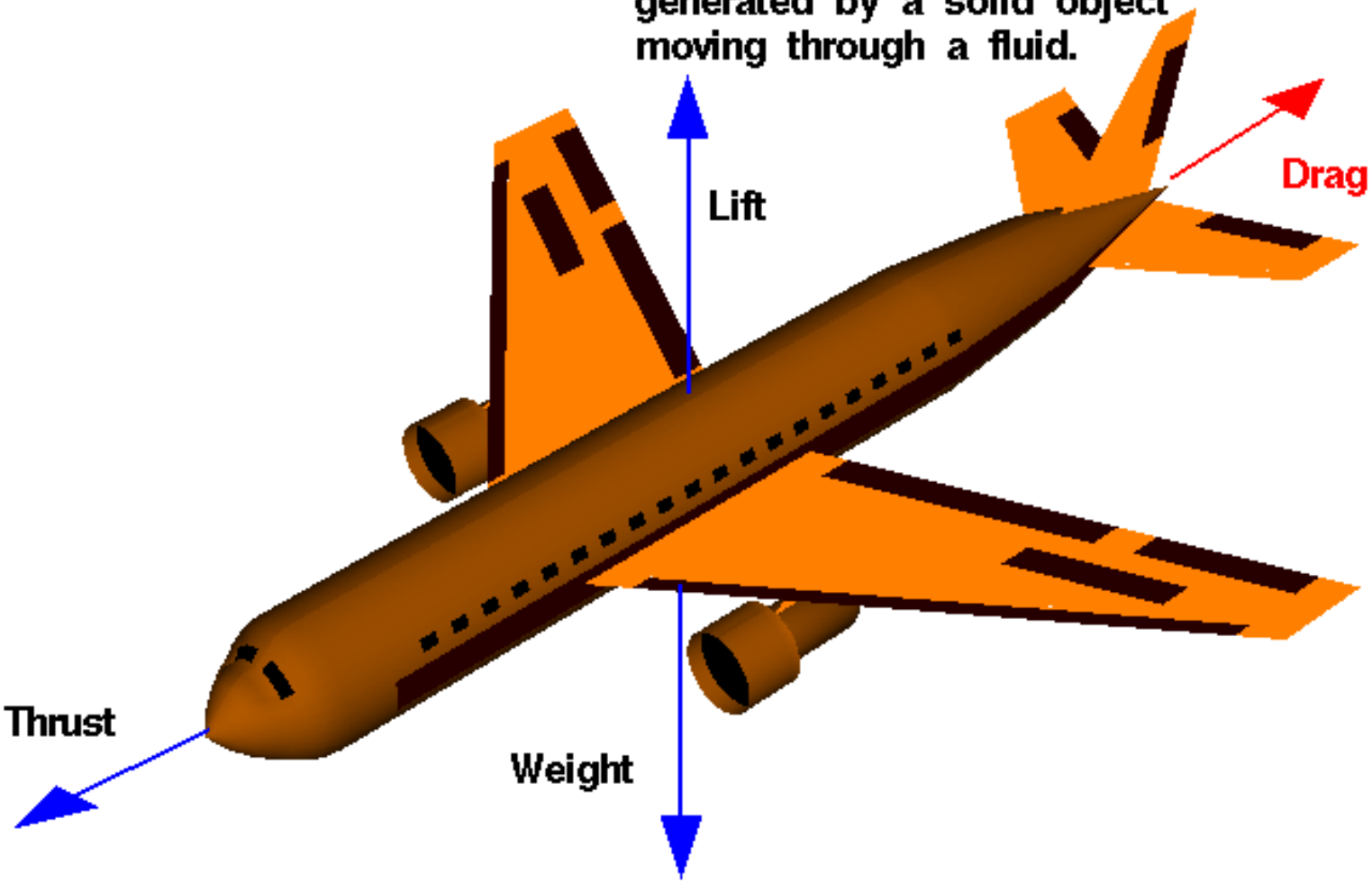



Weight is a force caused by the gravitational attraction of the Earth.

# What is Drag?

Glenn Research Center

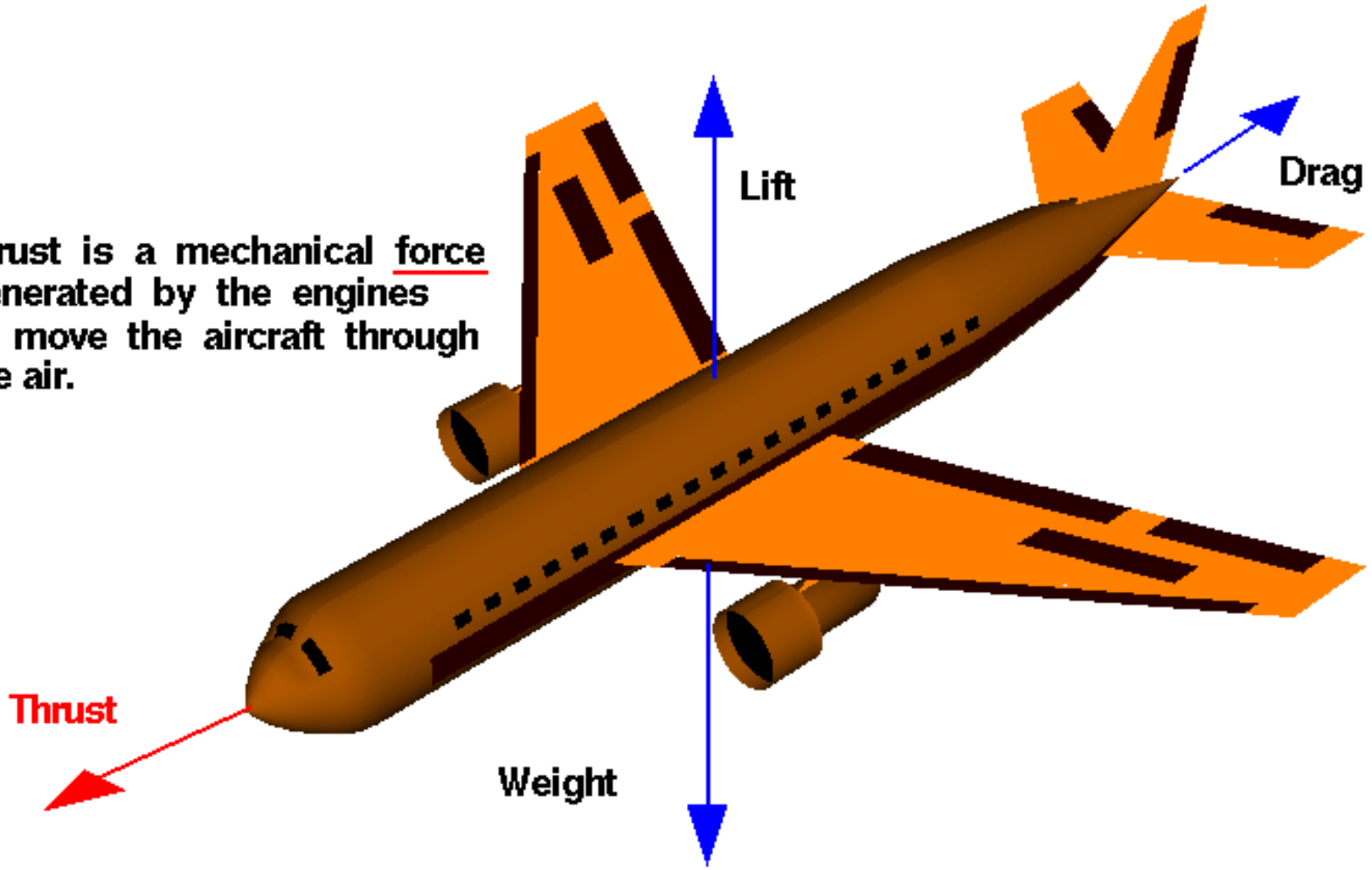
Drag is a mechanical force generated by a solid object moving through a fluid.



# What is Thrust?

Glenn Research Center

Thrust is a mechanical force generated by the engines to move the aircraft through the air.



# Topic #4

# Forces, Loads, and Stresses

# Tension: the pulling force

- It stretches materials.
- Examples: rope bridges, telephone wires, tents, suspension bridges, inflated stadium domes, steel cables supporting a full elevator, and hair when someone yanks on it

# Compression: the pushing force

- It squashes materials
- Examples: pyramids, telephone poles, arch bridges, elephant legs, tree trunks, and your little brother when you sit on him

# Tension and Compression


When a load is placed on a beam, as above, the top half of the beam shortens in compression. The bottom half lengthens in tension.

# Torsion

- The twisting of an object

# Shear Force

- Bend or tear a material by pressing different parts in opposite directions at the same time
- Example: scissors

# Dead or Alive?

# Dead Loads

- Dead loads do not move.
- The structure always has to support them. They are, well… "dead".
- Dead loads: walls, beams, arches, floors, ceilings.

# Live Loads

- Live loads are the things a structure supports through regular use.
- Like "live" things, these loads can change and move.
- Live loads: snow, rain, people, cars, furniture, wind.

Forces of Wonder
http://www.wonderville.ca/v1/home.html

Compression and Tension of Arches (6 min)
http://www.youtube.com/watch?v=UYtIFM1ek_M

Geodesic Domes (18 min)
http://video.google.ca/videoplay?docid=1183983212430151077

# Topic 5: How Structures Fail

- Failure can occur if the force is too strong for the structure's design or if the force is acting on a vulnerable part of the structure.

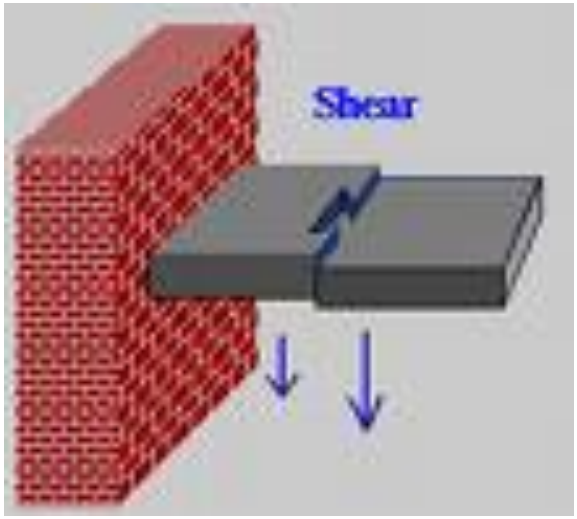

# Levers

- A device that can change the amount of force needed to move an object. When a force is applied to the effort arm, a large force, which can move the structure. This can be intentional- like when a crowbar is used to move a heavy rock, or it can be unintentional- like when a gust of wind knocks down a flagpole.

# Material Failure

- **Shear-** minor weaknesses in a material can cause failure because the particles move farther apart and are less attracted to each other.  This can be cause by compression.

- YouTube - House Payload

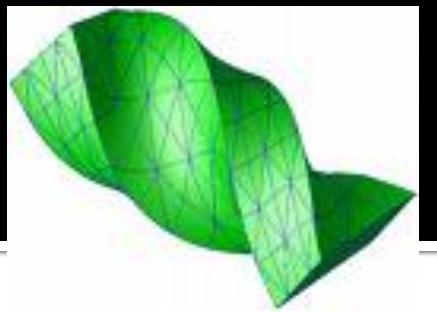


# Material Failure

- **<u>Bend or buckle-</u>** compression can also cause a material to bend and buckle- like a pop can that is stepped on. To prevent this, reinforcements – stringers and ribs- are used to strengthen the structure.

- YouTube - Boomer Bridges Are Falling Down: i-35 Bridge Collapse

# Material Failure



- **Torsion-** twisting can cause material failure. When sections of the structure slide past each other the structure and crack or break in two. When the twisting action makes the structure unusable (not broken) is has failed because it has lost its shape.

- YouTube - Tacoma Bridge Disaster

# Making Use of Stresses

- **<u>Buckle:</u>** Car bumpers are designed to buckle in a collision – as the metal fails, it absorbs some of the energy of the impact, which protects the occupants of the vehicle.
  - YouTube - Lexus bumper

# Making Uses of Stresses

- **<u>Shear:</u>** Shear pins are used in outboard motors to prevent failure of the motor (when the propeller gets tangled in weeds), a shear pin breaks and the propeller becomes disengaged  with the motor and gears.

http://www.youtube.com/watch?v=d-TJw52PGYs

# Making Use of Stresses

- **Twist:** Spinning wheels twist cotton or wool fibres so they lock together – making them strong enough to make cloth.
- Controlled twisting can also be useful in hair braids, ropes and telecommunication cables.

http://www.youtube.com/watch?v=yrrJLAXwUBU

http://www.youtube.com/watch?v=uejRaFfrOZg&feature=related

http://www.youtube.com/watch?v=kKXca2l0RPo&feature=related

# Metal Fatigue

- Metal fatigue is the phenomenon leading to fracture under repeated or fluctuating stress. Fatigue fractures are progressive beginning as minute cracks and grow under continued stress. The particles in the metal move further apart and have less attraction to each other. When a crack develops it weakens the metal and can eventually fail even if a s applied.

# Topic 6: Designing with Forces

- 3 key methods to help structures withstand forces are:
  - Distribute the load
  - Direct the forces along angled components
  - Shape the parts to withstand the specific type of force acting on them.
    - Build A Tipi

# Flying Buttresses

- Columns on the outside of a structure that connect to the building near the top and are used to support the outer walls in much the same way that two sides of an arch support each other
- http://www.pbs.org/wgbh/buildingbig/educator/act_mini_arch.html

# Strengthening Structures

- All materials have limitations.
- Materials can be strengthened or weakened as they are made.
  - Ex. Concrete can be very strong, but if the proportions are incorrect, the resulting concrete can crumble and fail, however it does not have very good shear or torsion strength

# Strengthening Structures

- Shear forces can be fatal in metal if the shear strength is not analyzed when the metal is manufactured.
- The cooling process can eliminate almost all defects if it is done properly.

# Using Frictional Forces

- Force of friction resists movement between two surfaces that rub together.
- A brick wall is held together and kept evenly spaced with mortar, which helps to create large friction forces between each brick.

# Using Frictional Forces

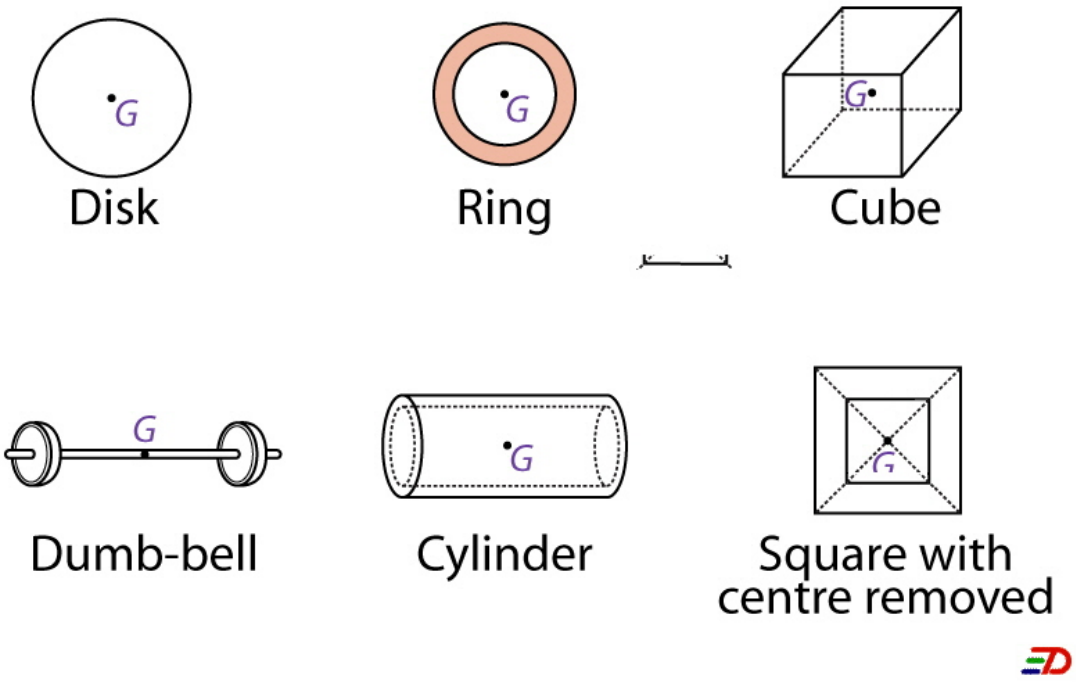
- Friction is also important in frame structures.
- The friction between the nail and the wood keeps the nail in place and the joints solid.
- Different types of nails provide differing amounts of friction.
- Windmill activity

# Topic 7: Stable Structures

- The collapse of a structure can occur when the external forces cause the structure to become **unbalanced**.
- To design stable structures, engineers need to know what features of a leaning object determine whether it will tip over or stay balanced.

# Centre of Gravity

- The specific point where all of the mass of the structure is evenly distributed around.



- The force of gravity acts on all parts of the structure and if all parts are evenly distributed around the center of gravity, then the structure will be stable.

# Unbalanced Structures

- To determine whether a structure is unbalanced locate the centre of gravity and draw a line directly down toward Earth.
- If the arrow points to a solid foundation, the structure is balanced.
- If the arrow falls beside the foundation the structure is not!
- Check for yourself!  Page 333

# Firm Foundation

- Foundation upon which the structure is built must be STABLE. Especially if it is moist because compressive forces may cause the structure to tip.
- Take into account soil types and formations to avoid cracks in foundation and walls!

# Find Something Solid

- Foundations can be constructed on solid **bedrock** or **pilings** (large metal, concrete or wood cylinders)
- Pilings are used when the soil is loose and too deep.
- Some lightweight structures do not have to rest on the bedrock or have to have a foundation that goes down very deep, because the ground doesn't freeze.

# Make A Solid Layer

- Road builders always pack loose surface soil before paving to create a solid base for the asphalt or concrete.
- Easy to fill in cracks because they can replace the soil with a solid packed layer of gravel.

# Spread the Load

- Spreading the weight of a structure over a large area allows the ground to support only a small amount of weight.
- (Lying on a bed of nails, crowd surfing)
- This is why building are often constructed on many shallow piling rather than a few.
- Footings are used under a foundation wall to disperse the weight of the wall.