ARIZONA SCIENCE LAB

BOATS and BOATS!

SAIL AWAY:

MOTION AND FORCES

Engineering Sailboats!

Institute Of Electrical And Electronics Engineers, Phoenix Section

Teacher In Service Program / Engineers In The Classroom (TISP/EIC)

"Helping Students Transfer What Is Learned In The Classroom To The World Beyond"

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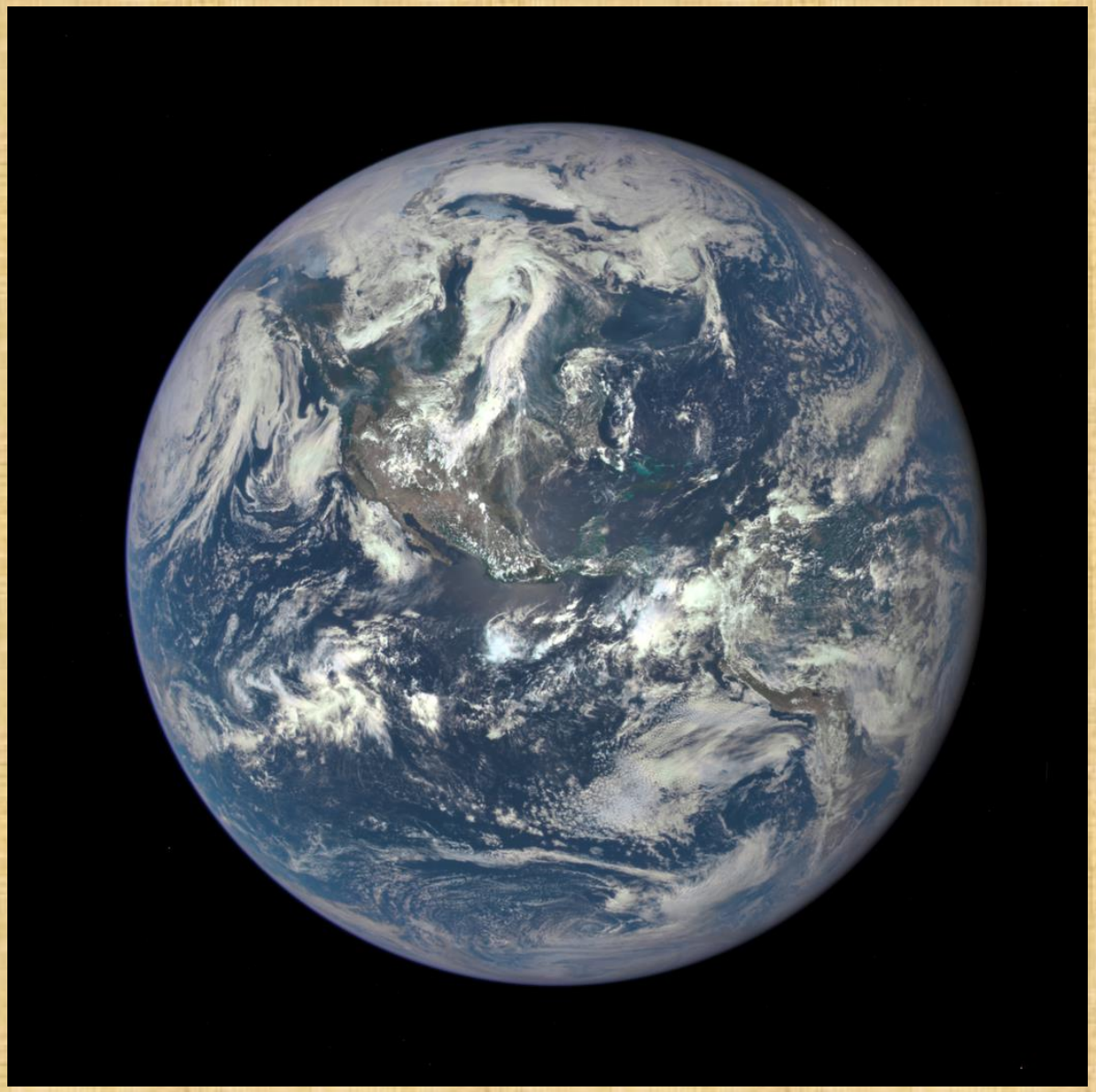
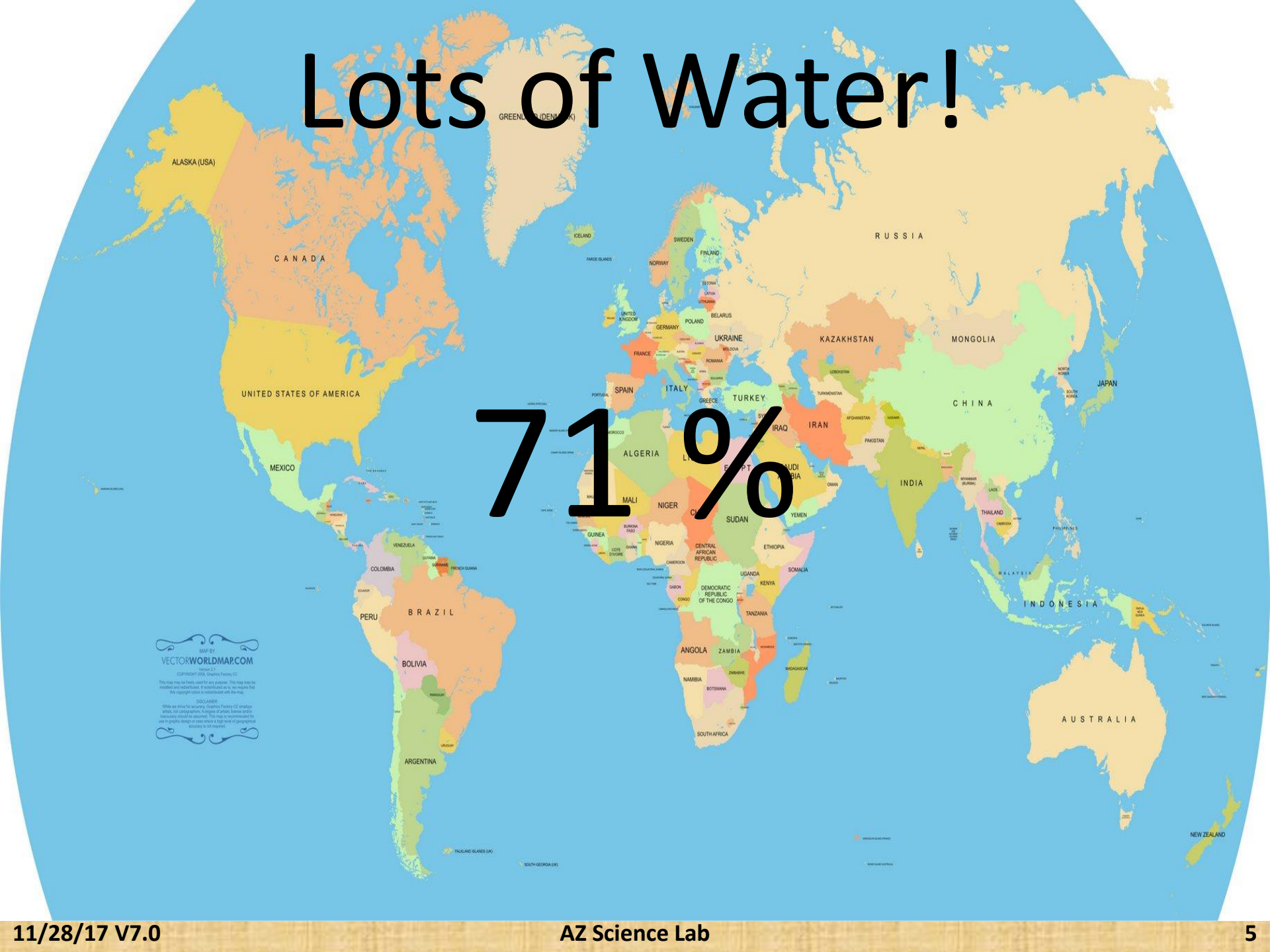
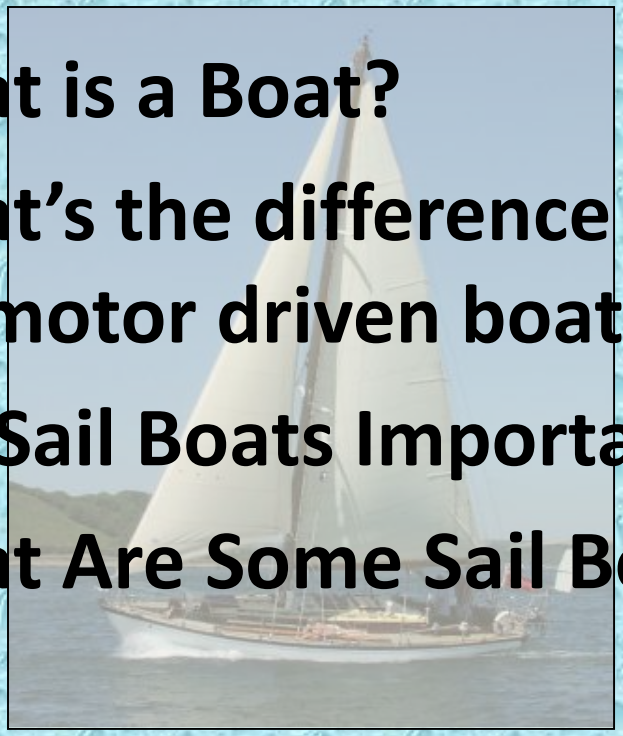
Our Earth – Water & Land

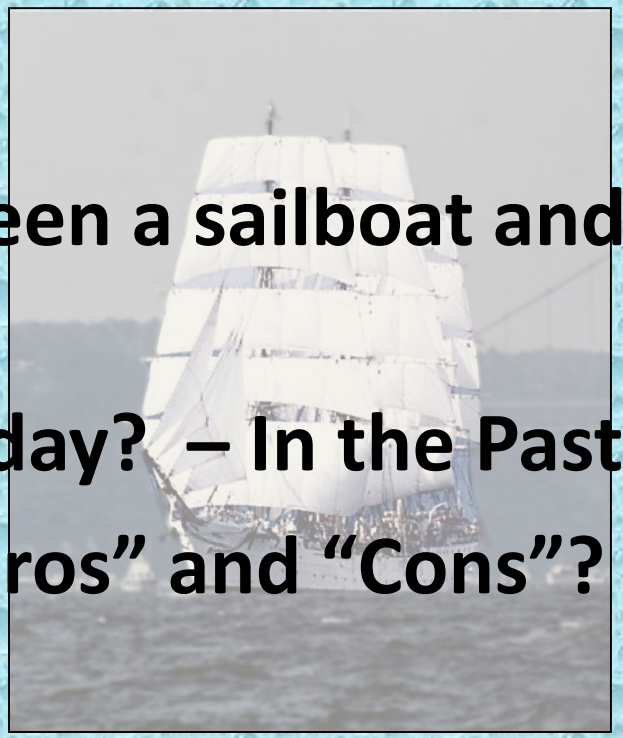


Lots of Water!



What Do We Know About Boats?





What is a Boat?

What's the difference between a sailboat and a motor driven boat?

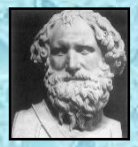
Are Sail Boats Important Today? – In the Past?

What Are Some Sail Boat "Pros" and "Cons"?

A Boat is a Vehicle That Floats on the Water
AND
We Control Its Speed and Direction

What We're Going to Talk About

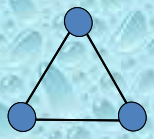
Parts of a Boat



Archimedes Principle

Forces and Moments

Parts of a Boat - Review



Design a Boat

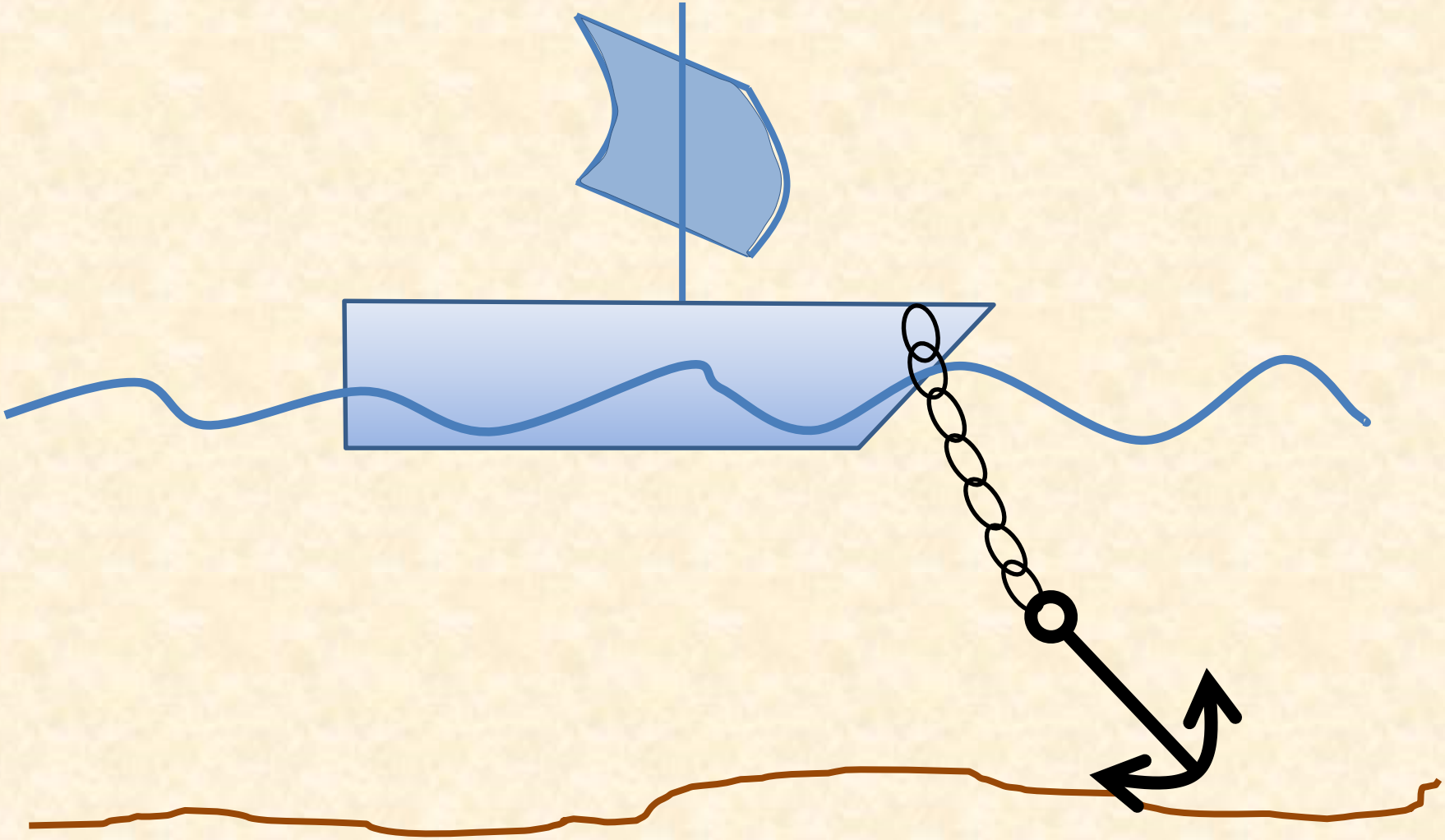
Build & Test a Boat

Major Parts of a Sail Boat

- Hull
  - Keel
    - Rudder
      - Sail
        - Mast

WHY DO THINGS FLOAT?

What Keeps the Boat UP And the Anchor DOWN?



It's All About Density

- Which of these pairs is **more dense**:
  1. A small **rock** or a large **wad of crumpled paper**?
  2. A **Styrofoam cup** or a **ceramic cup**?
  3. **A boat that floats** or a **boat that sinks**?
- The **density, ρ ("rho")**, of a material is its **mass**, m, **divided by** its **volume**: mass per unit of volume (g/cc):

DEFINITION:

ρ = mass / Volume

= m / V

Let's Look At Some Densities

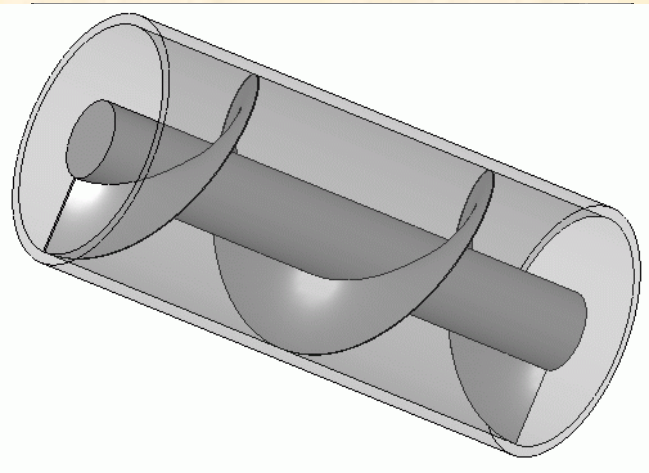
Which of these materials float in water?

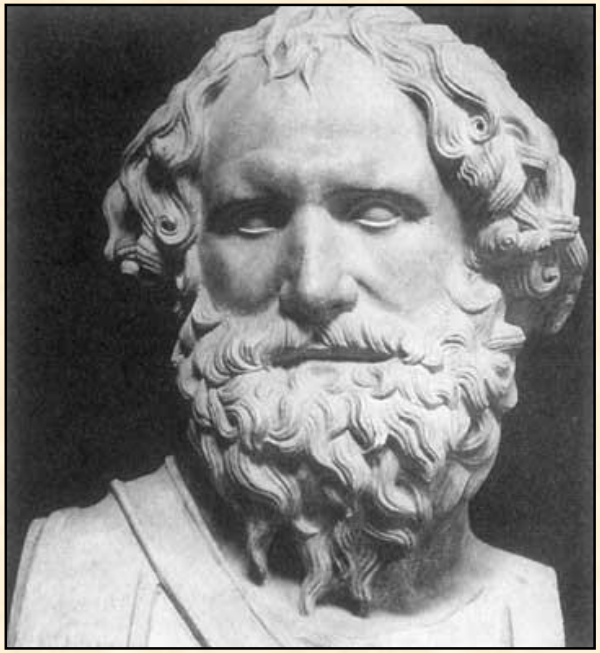
Substance	Density: kg/m^3	g/cc
1. Gold	19,320.	19.32
2. Lead	11,340.	11.34
3. Silver	10,500.	10.50
4. Aluminum	2,700.	2.70
5. Ironwood	1,200.	1.20
6. Sea Water	1,030.	1.03
7. Water	1,000.	1.00
8. Ice, Icebergs	920.	0.92
9. Woods		
• Cherry	630.	0.63
• Oak	560.	0.56
• Pine	500.	0.50
• Balsa	160.	0.16

Archimedes

Archimedes of Syracuse

(290 BC – c. 211 BC)





$$A = \pi r^2$$

$$V = \frac{4}{3}\pi r^3$$

$$SA = 4\pi r^2$$

$$A = \frac{2}{3}BH$$

Greek mathematician, physicist, engineer, inventor, and astronomer

Buoyancy and Archimedes Principle

A body
immersed in a fluid
is ***buoyed*** up
by a **force**
equal to the **weight**
of the displaced fluid.

Or

In Simpler Terms . . .

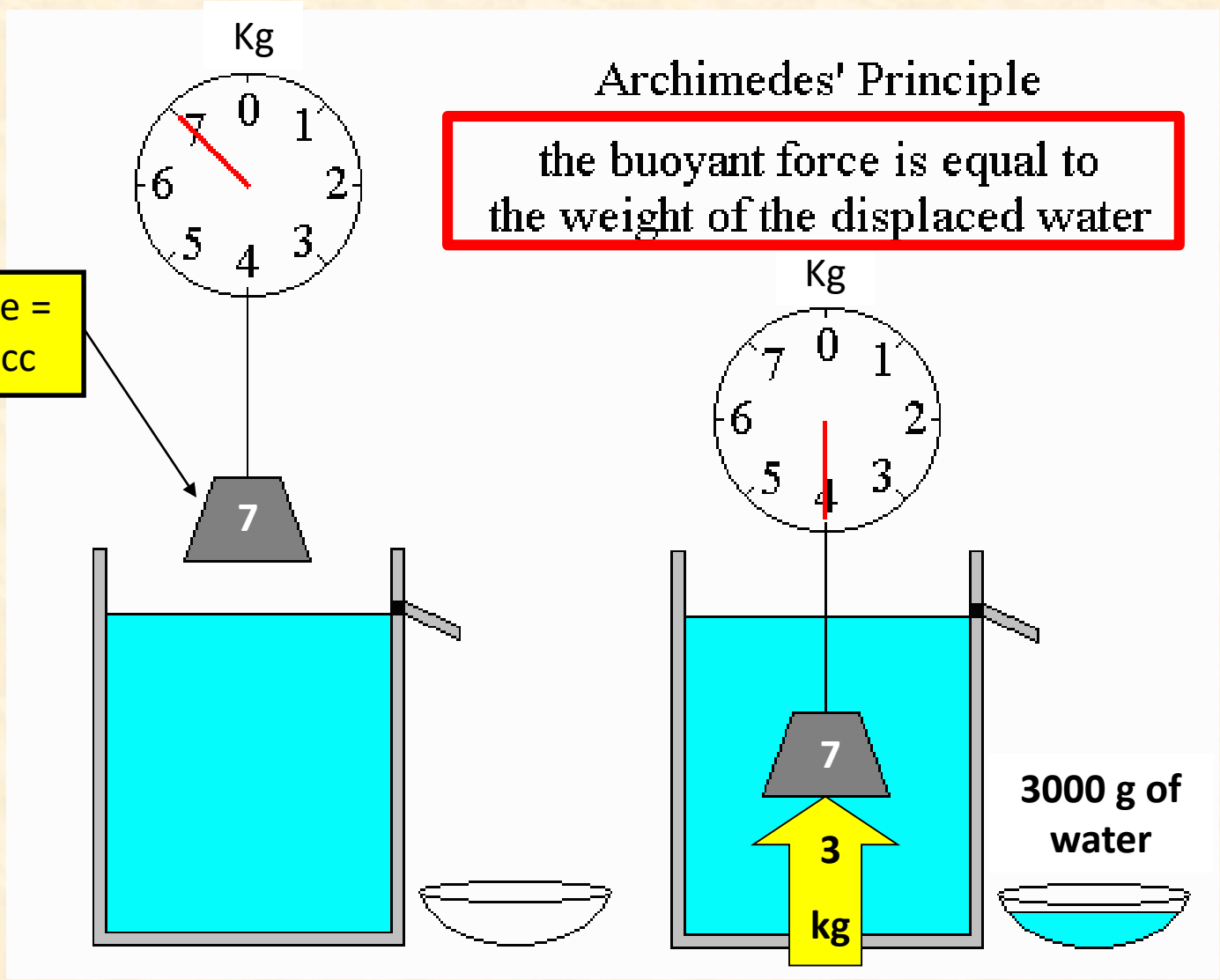
Buoyancy And Archimedes' Principle

An object in a fluid with a **density greater** than the fluid **sinks**,

and

an object in a fluid with a **density less** than the fluid **floats**.

Archimedes Principle – Buoyancy



Archimedes & the King of Syracuse

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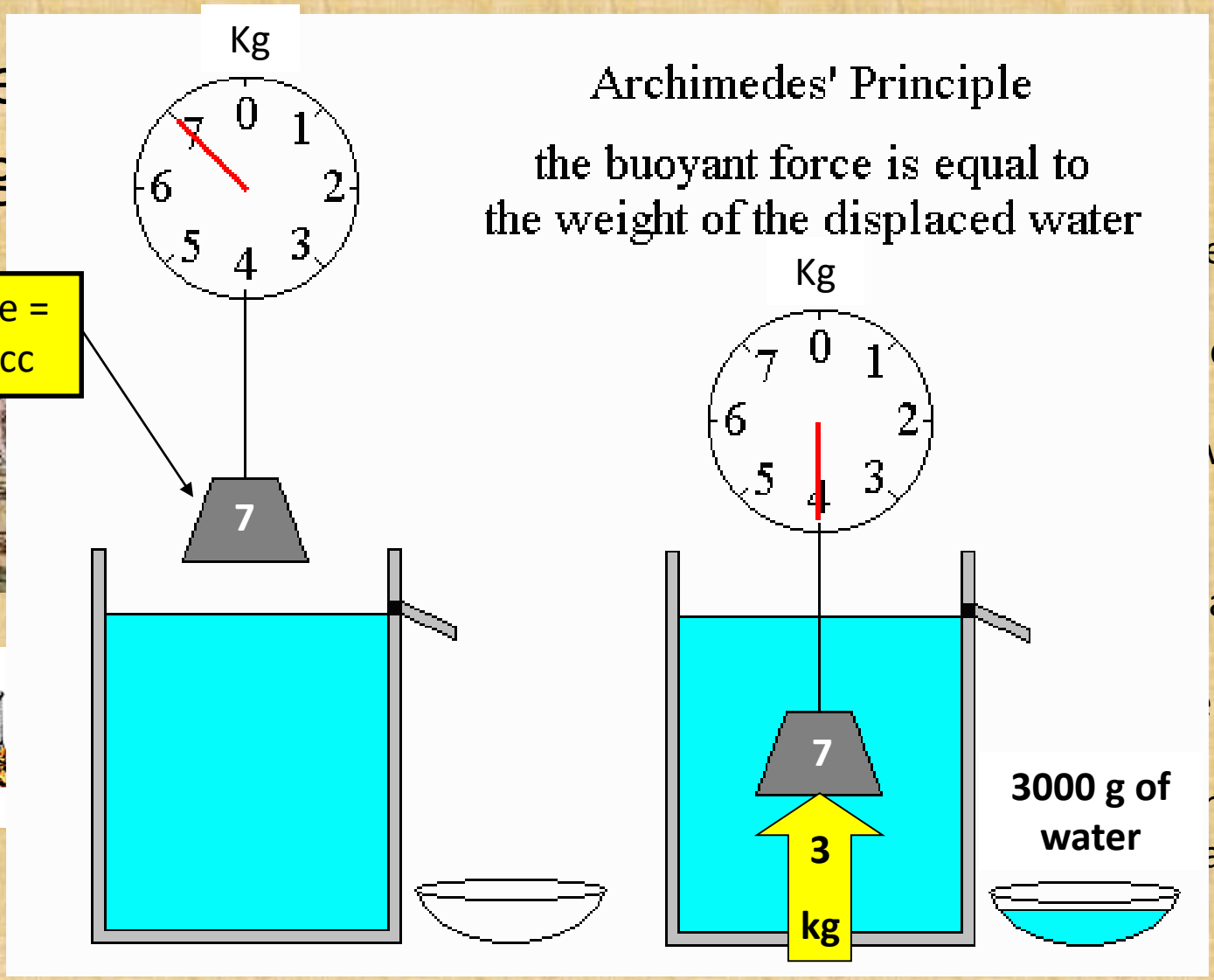
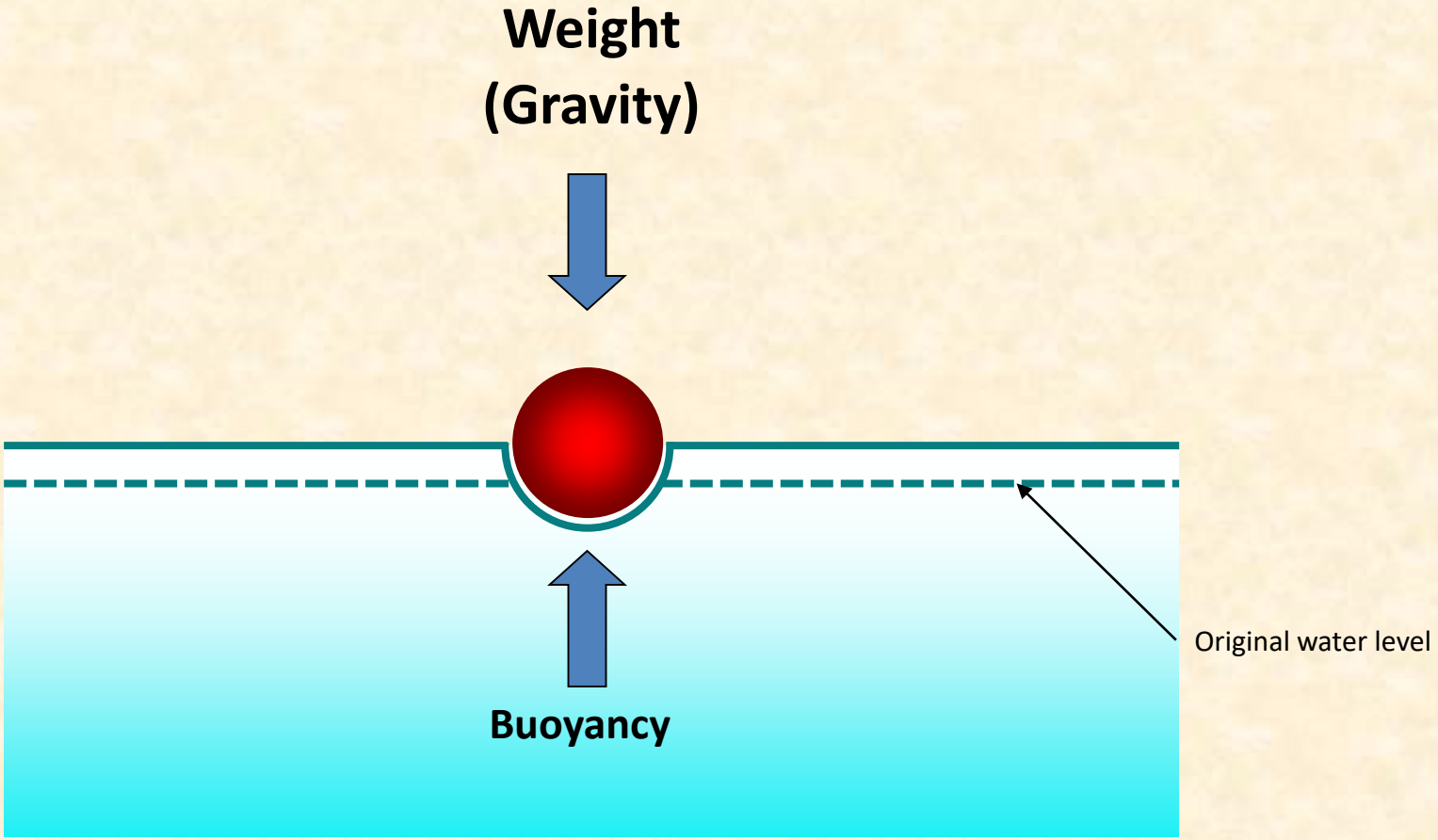


Why Some Objects Float

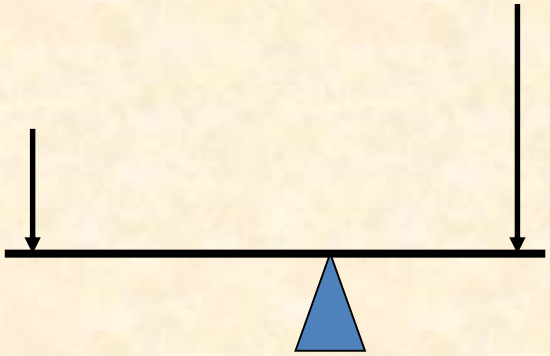


"because they are less dense than water"

How Does This 97,000 Ton Warship Float?

The shape of the hull ensures 97,000 tons of water is displaced while the water level on the outside of the hull is well below any dangerous line

By ***Archimedes Principle***, the aircraft carrier floats because it is ***less dense*** than water!



FORCES
&
MOMENTS

What are Some Common Forces?

- Push or a pull
- Force of running water (river)
- Force of the wind

What Is A Force?

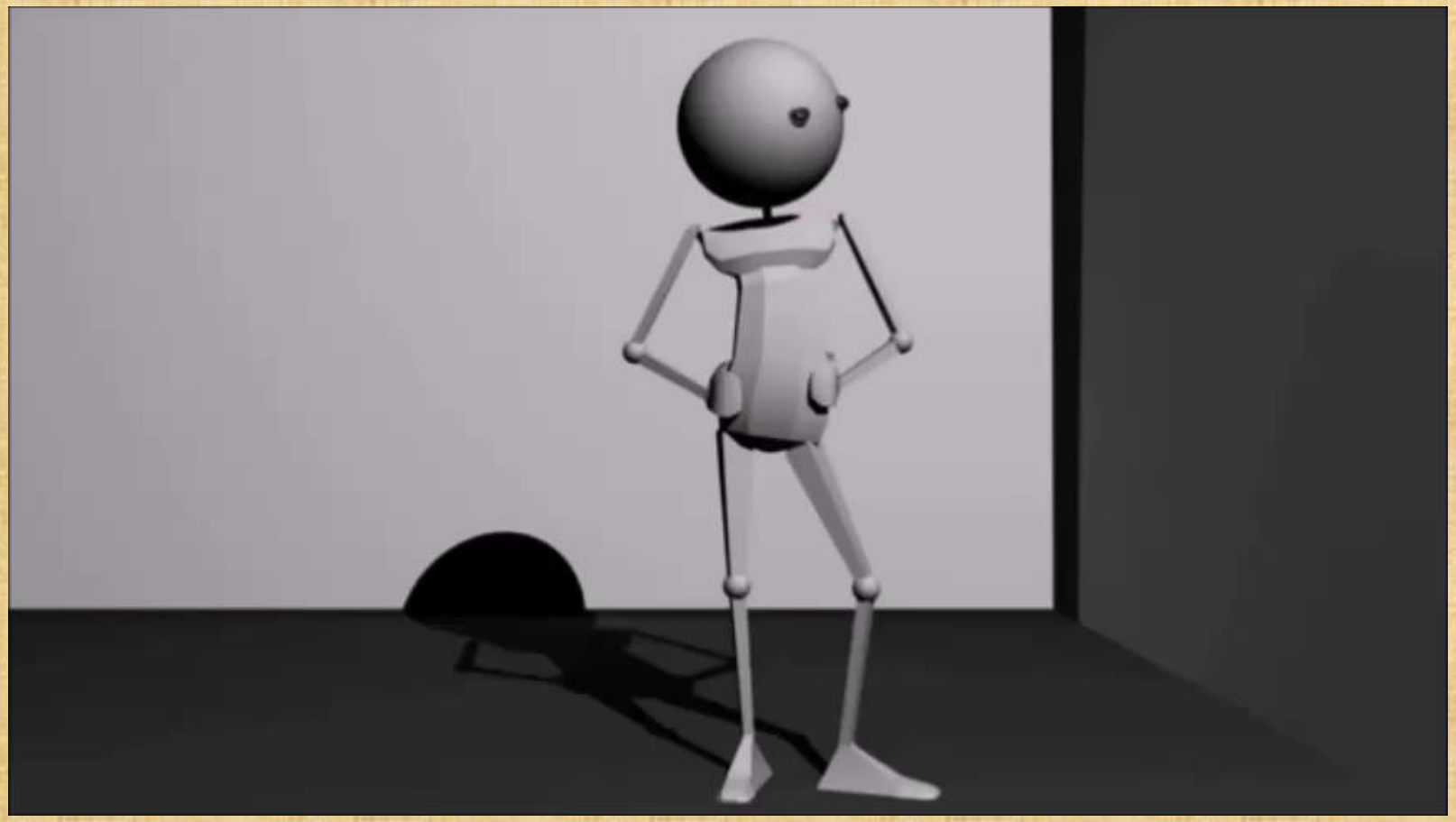
In physics, a **force** is any *external agent* that causes a *change in the motion* of a *free body*, or that causes stress in a fixed body.

or

In Simpler Terms . . .

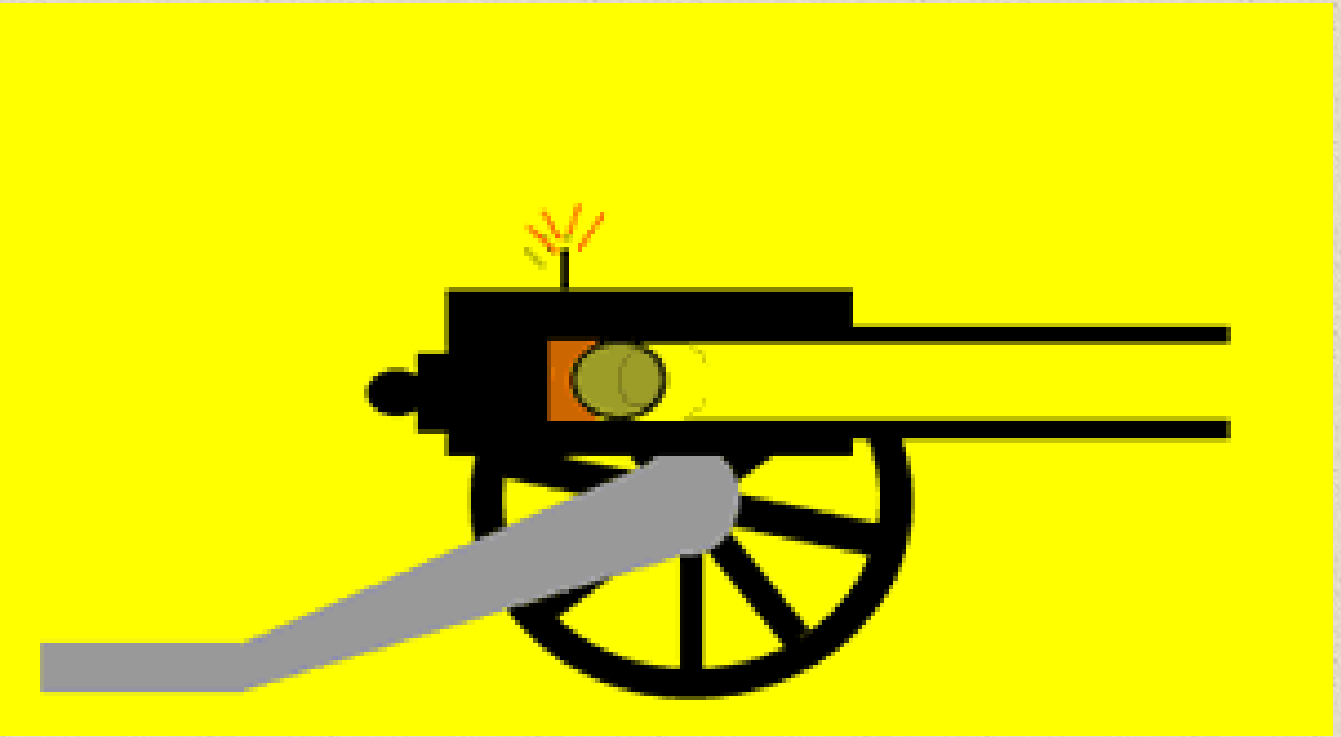
What is a Force?

A **Force** is a push or a pull that changes the motion of an object.

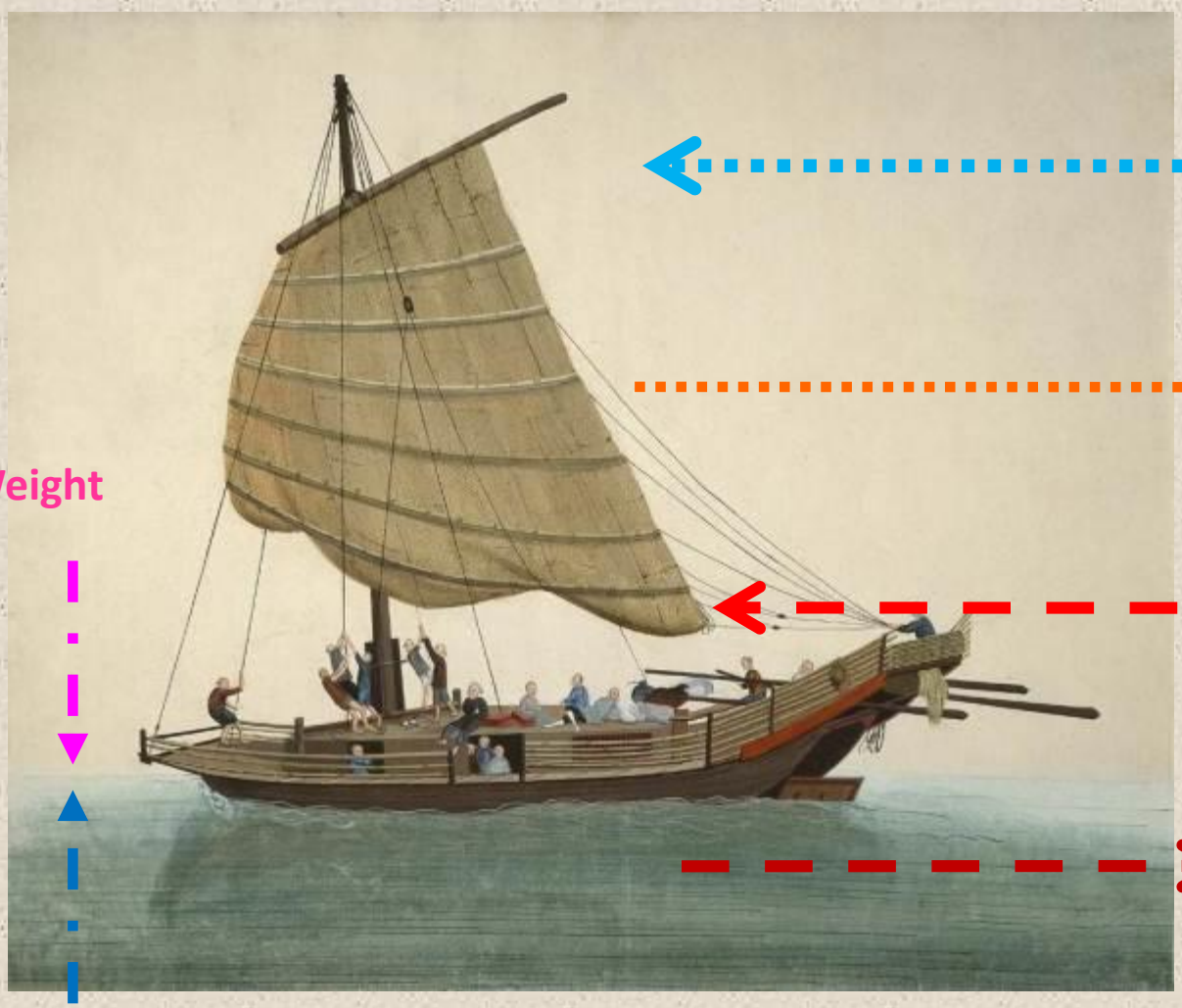


Newton's Third Law of Motion

For every action there is an equal and opposite reaction



Newton's Third Law and Sail Boats



WIND EXERTS FORWARD FORCE ON SAIL

SAIL PUSHES BACK ON WIND

Weight

SAIL PULLS ON MAST AND PULLS BOAT FORWARD

DRAG FROM WATER RESISTS FORWARD MOTION OF BOAT

Buoyancy

Some Forces That Act on Boats

- Moving water (water currents, waves)
- Gravity
- Buoyancy (Archimedes Principle)
- Wind
- Friction or Drag (water, air)
- Righting Force

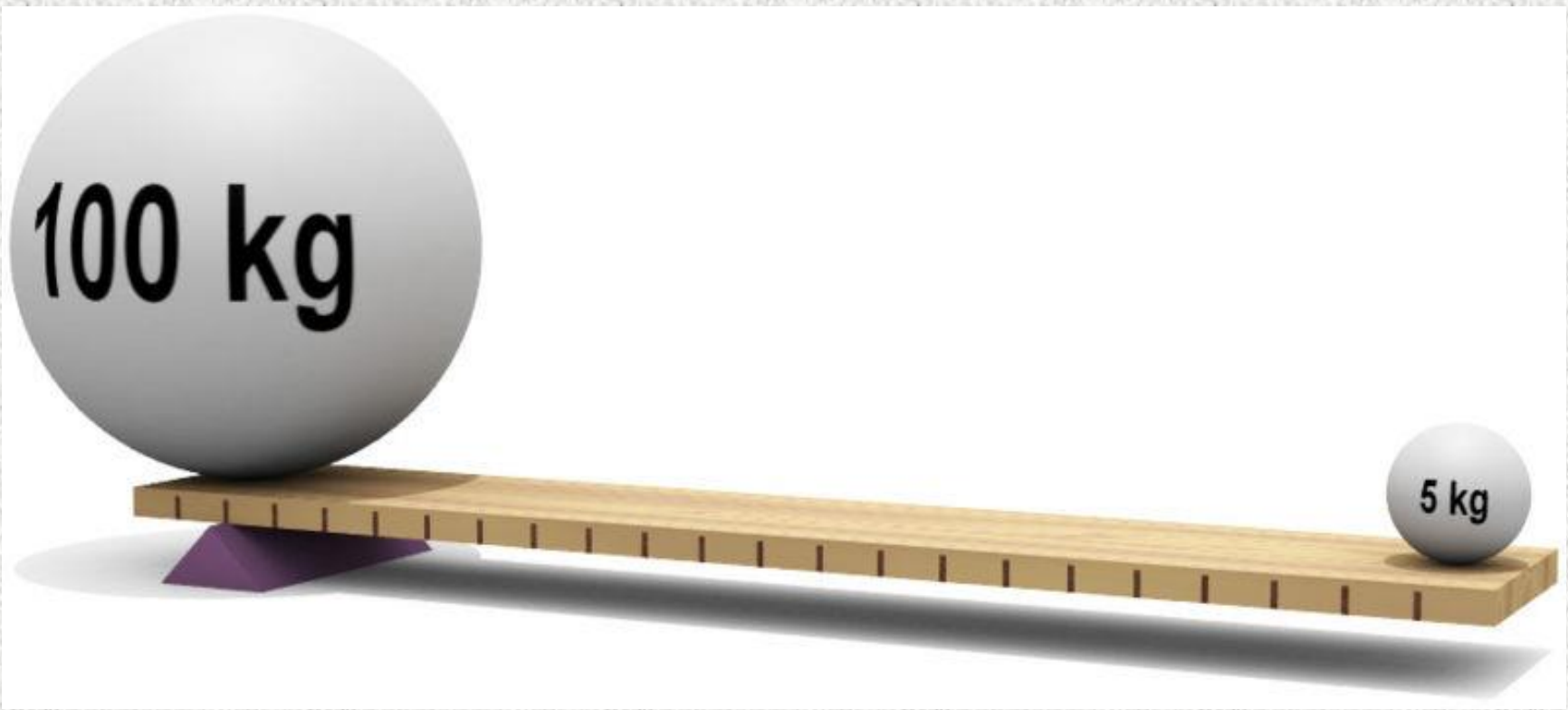
All these forces are acting on a boat at the same time!

These forces usually create "Moments" that act on the boat.

What is a “Moment”

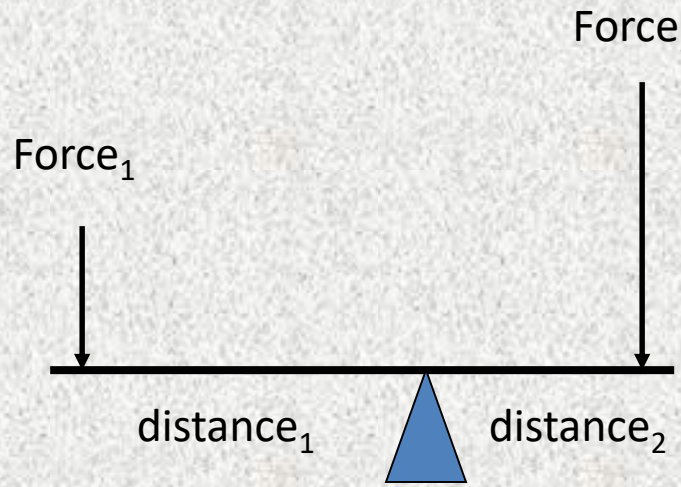
DEFINITION

A Force Acting Over a Distance



Calculating a "Moment"

MOMENT = FORCE X DISTANCE



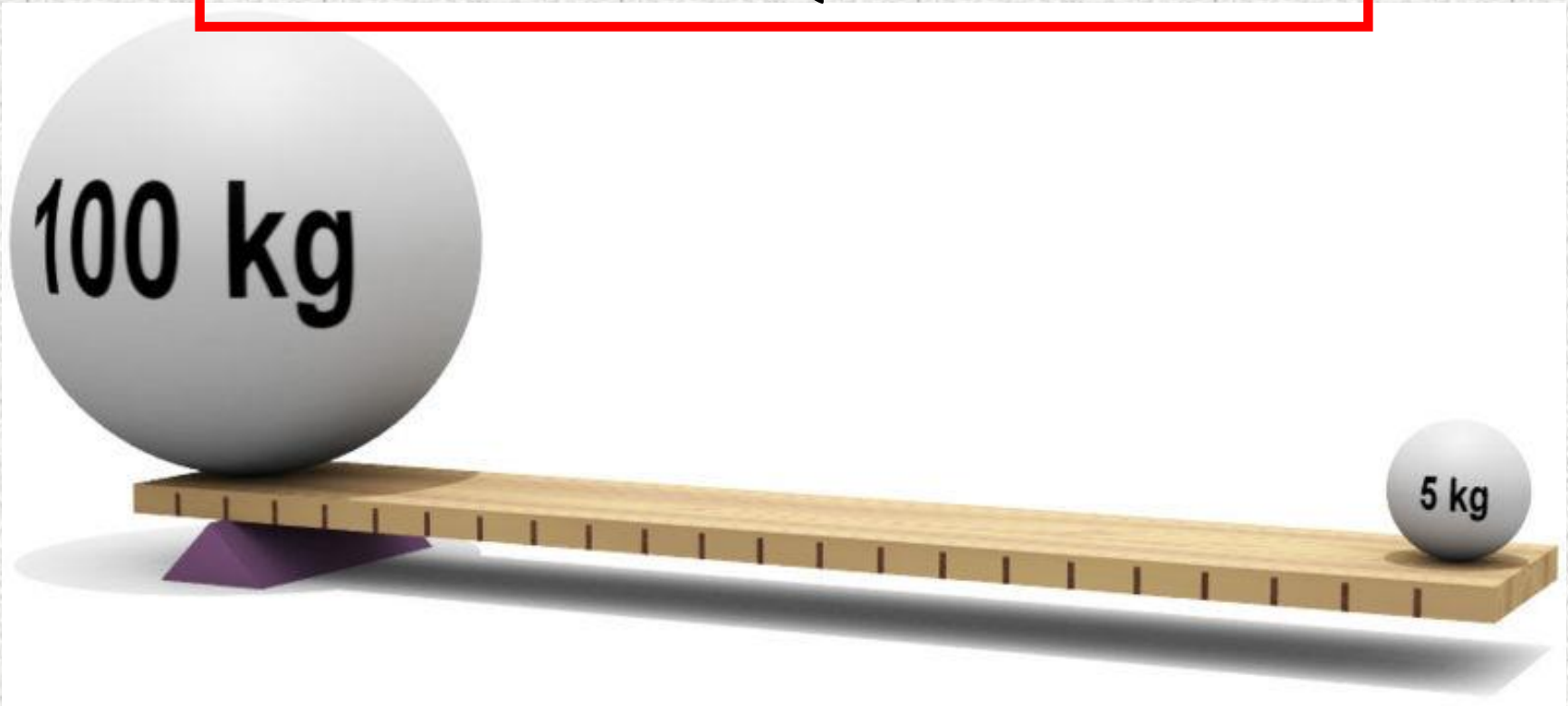
Moment$_1$ = Force$_1$ x distance$_1$

Moment$_2$ = Force$_2$ x distance$_2$

The unit of measurement for Moments is the "Newton-Meter"

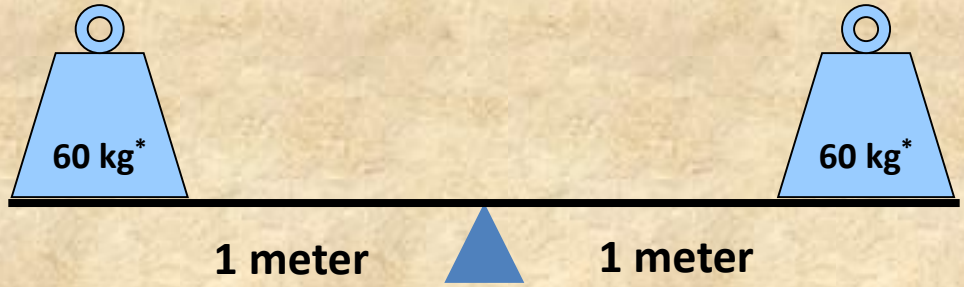
What's a "Moment"

Balance happens when the ***moments*** are EQUAL



EQUAL FORCES

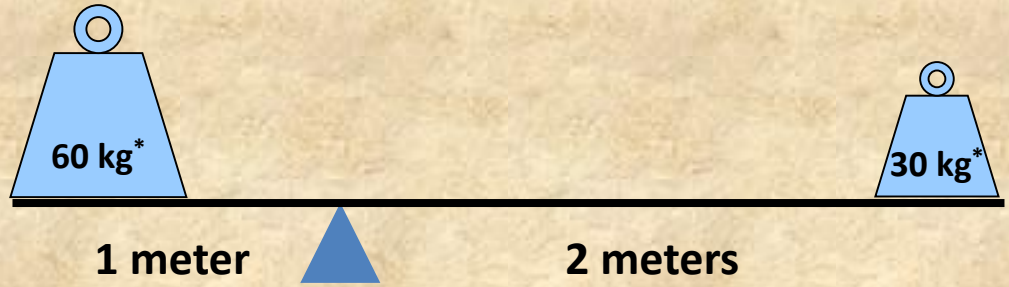
MOMENT = FORCE X DISTANCE



What are the moments?

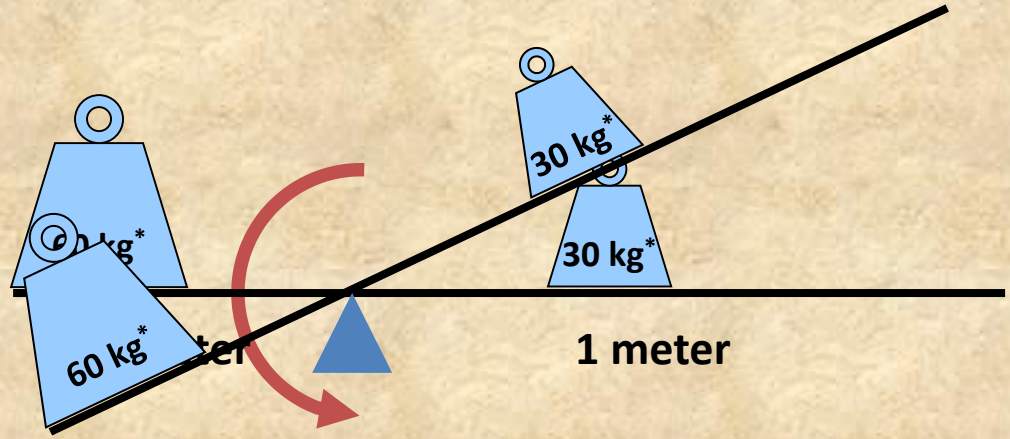
EQUAL MOMENTS

MOMENT = FORCE X DISTANCE



What are the moments?

UNEQUAL MOMENTS



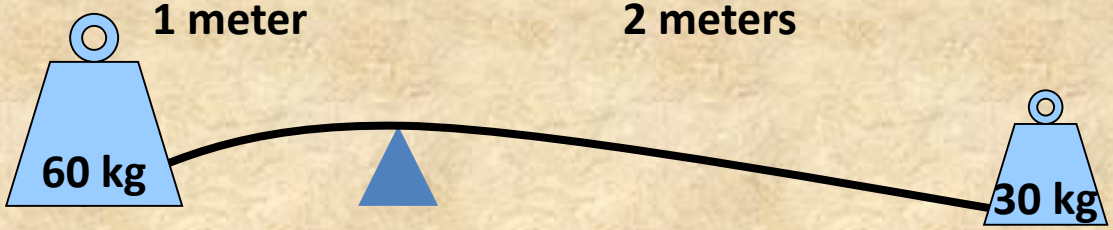
What happens now?

It rotates!

FLEXIBLE BODY

Force = 600 Nt

Force = 300 Nt



What are the moments?

Where Do You Find "Moments"?

- Some Places Where Moments are at work:
  - ✓ **Boats**
  - See – Saw
  - Swing Set
  - Lever
  - Airplanes
  - You and Me
  - This Building

Almost anywhere a force is at work!

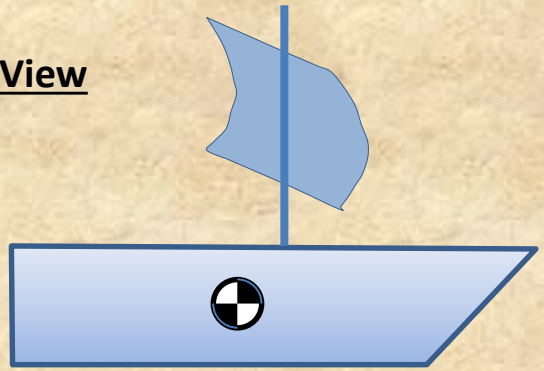
Moments on a Boat (Stability)

What Does It Mean To Be Stable?

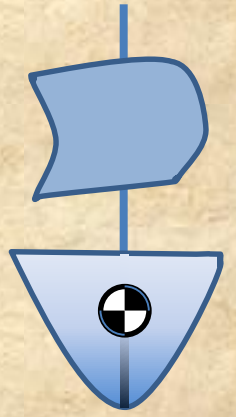
Stability is the tendency of an object to return to its original state after it is slightly moved.

Boats in 3D!

Right Side View



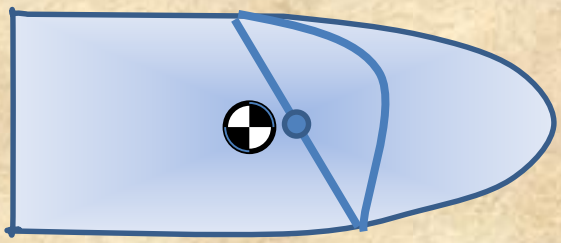
Front View



Pitch Axis

Roll Axis

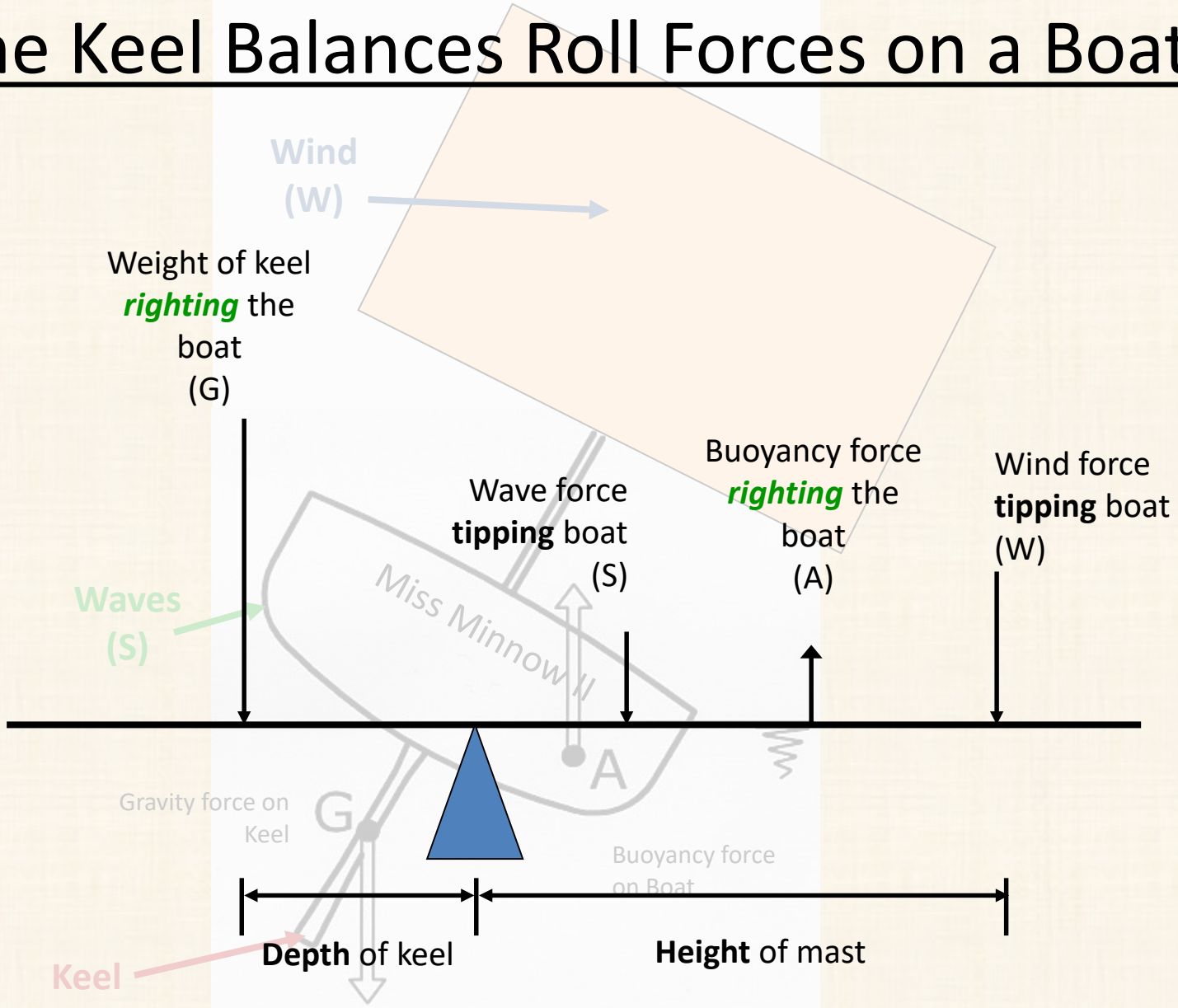
Yaw Axis



What Forces might be at work in each of these axes?

Bird's Eye View

The Keel Balances Roll Forces on a Boat



Ballast Stones – Roll

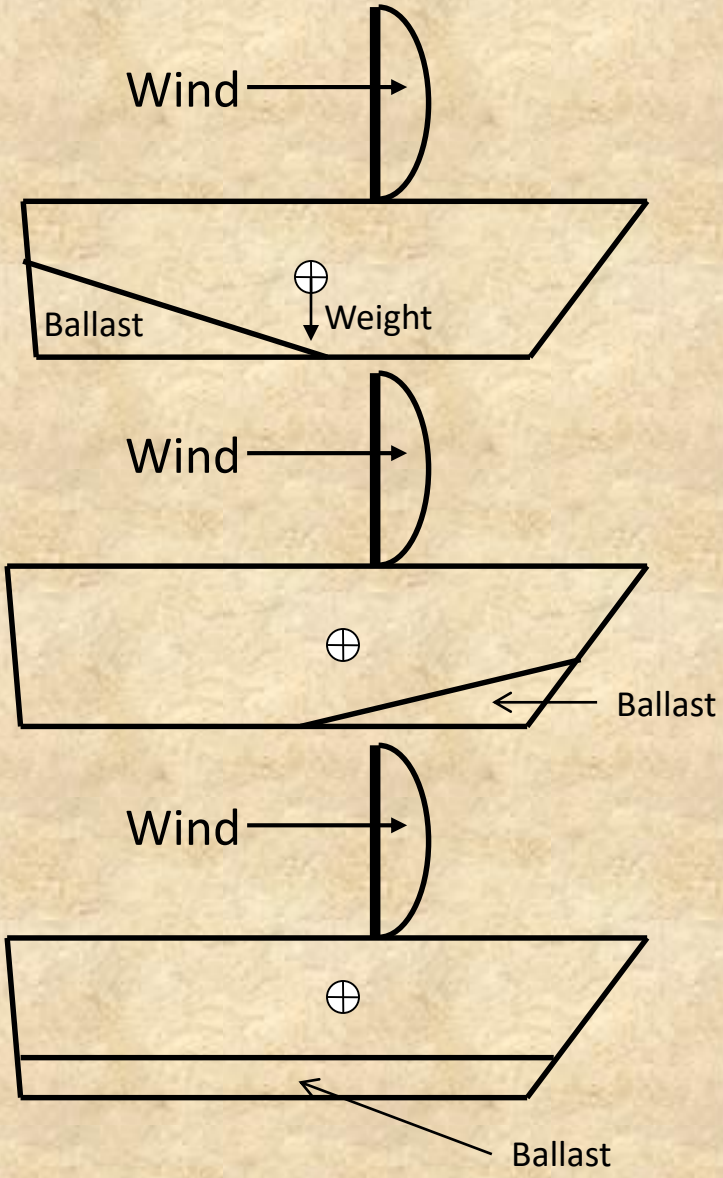
- ***Ballast*** is dead weight added in the bottom of the boat hull.
- ***Ballast*** can be used in sailboats in place of a heavy keel to provide a moment of force to resist the overturning ROLL forces from the sail.

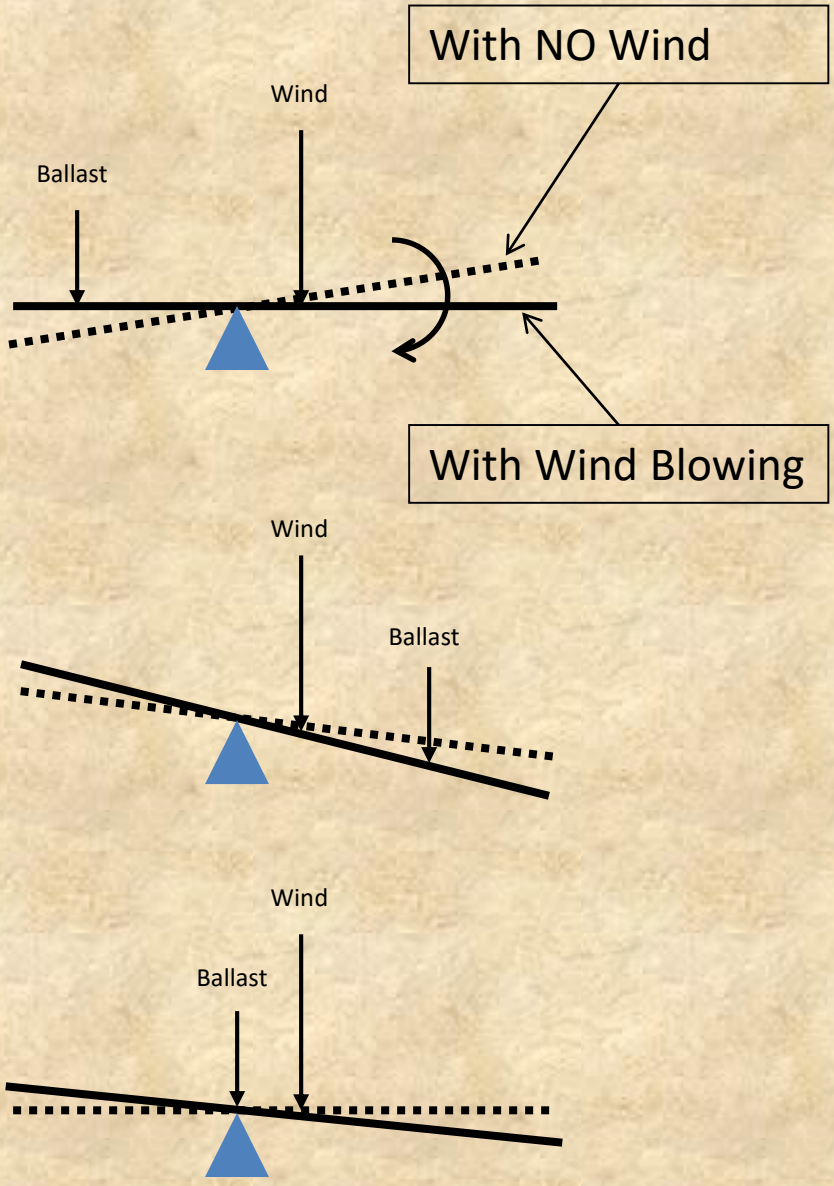
Using The Sailor's Body As An Additional Counterweight for ROLL stability!

Ballast – Works for Pitch, Too!

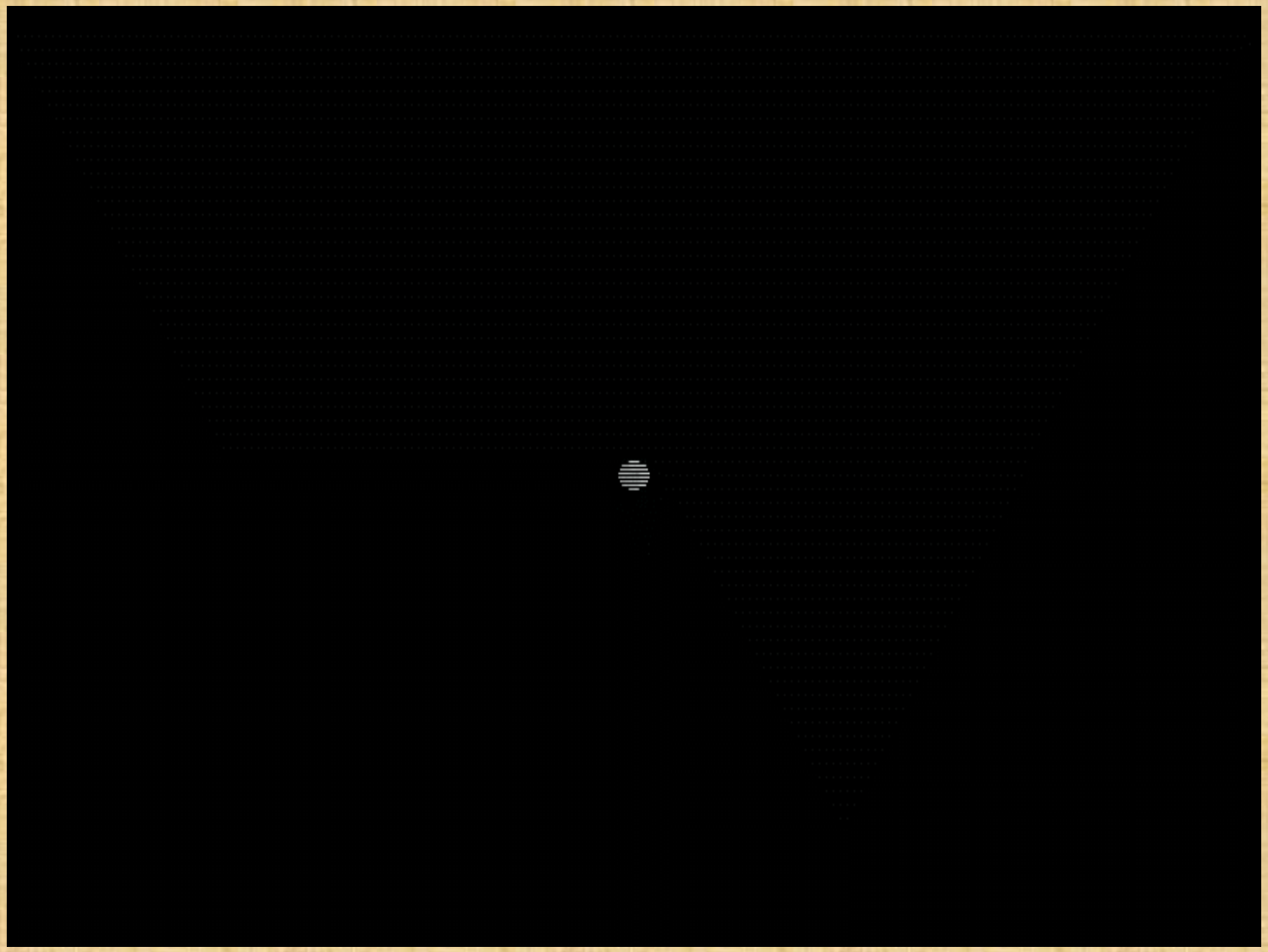
- **Wind and waves can cause the *bow* of a boat to dive into the water**
- **Ballast can also be used to tune the motion of the boat in the *PITCH* axis.**

Effects of Ballast Placement – Pitch





Ballast



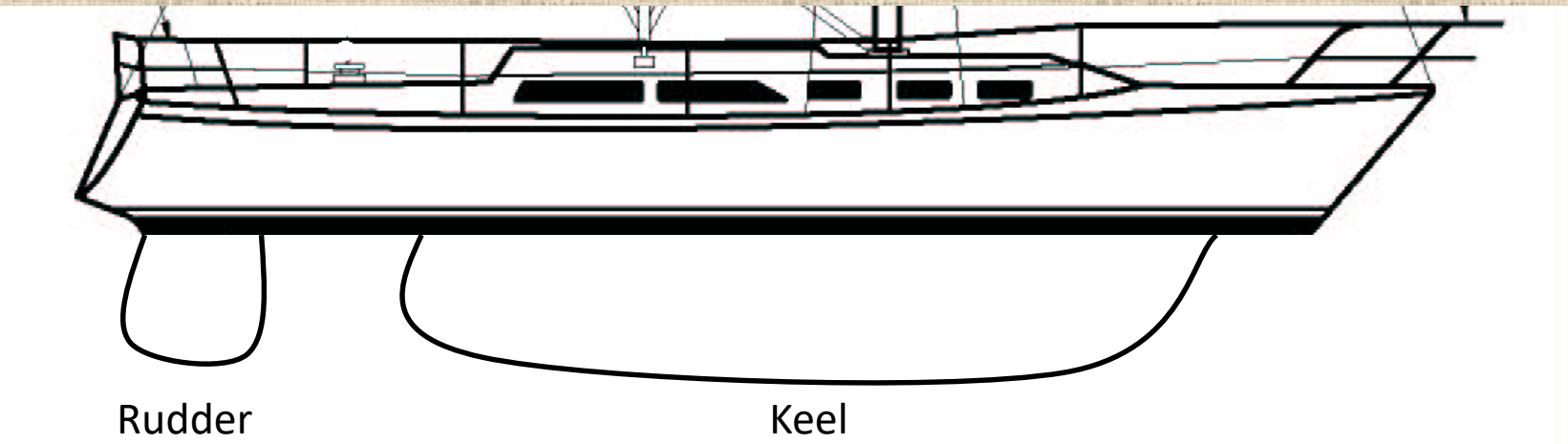
Rudder – Directional Control (*Yaw*)

- In basic form, a *rudder* is a flat sheet of material attached with hinges to the craft's *stern*, tail or *aft* end
- A rudder operates by redirecting the water past the hull, thus imparting a turning moment to the craft

Modern ship rudder

Rudder – Directional Control

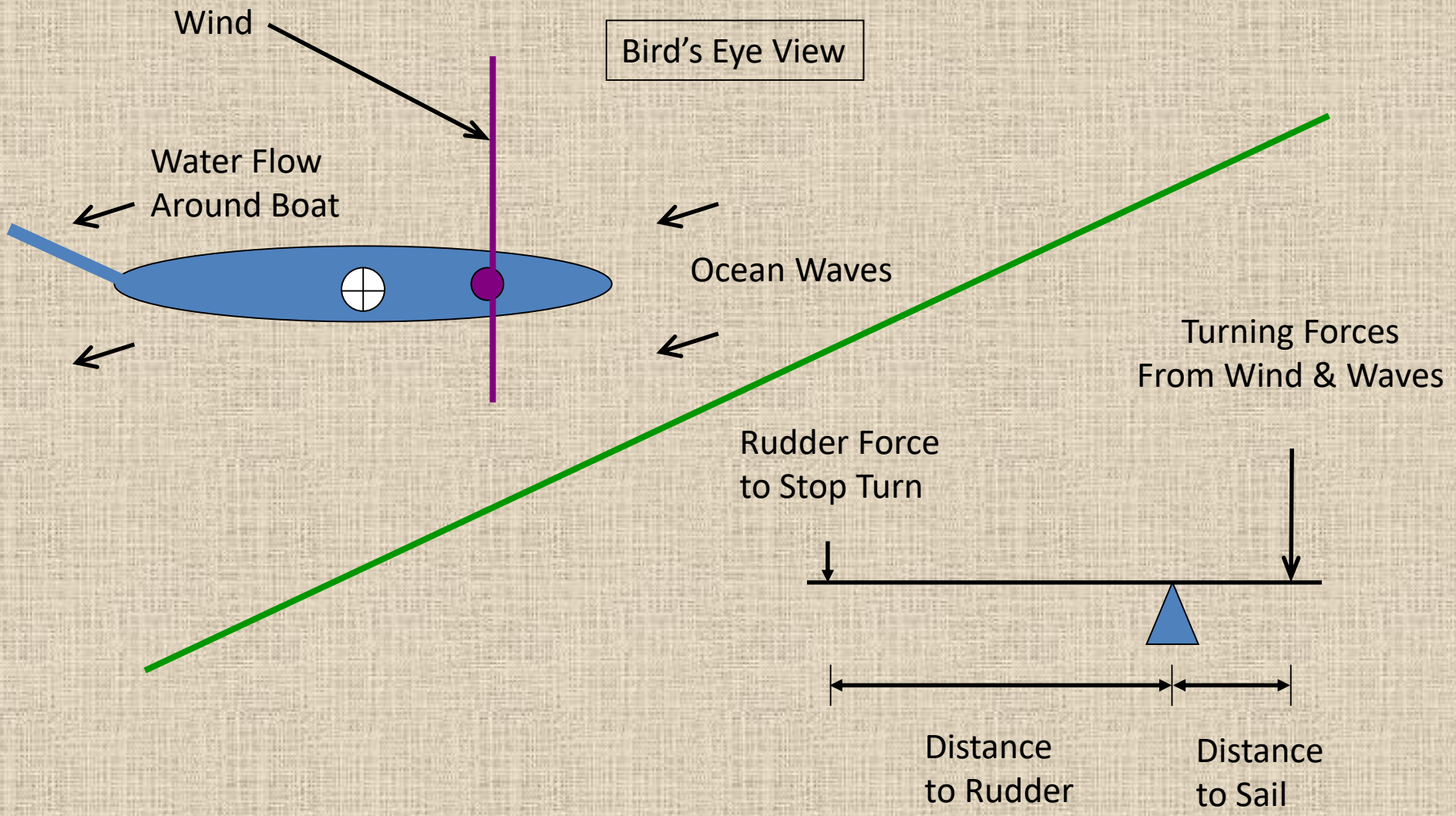
(Cont')



The rudder steers the boat

Without a rudder a sail boat will not move in a straight line!

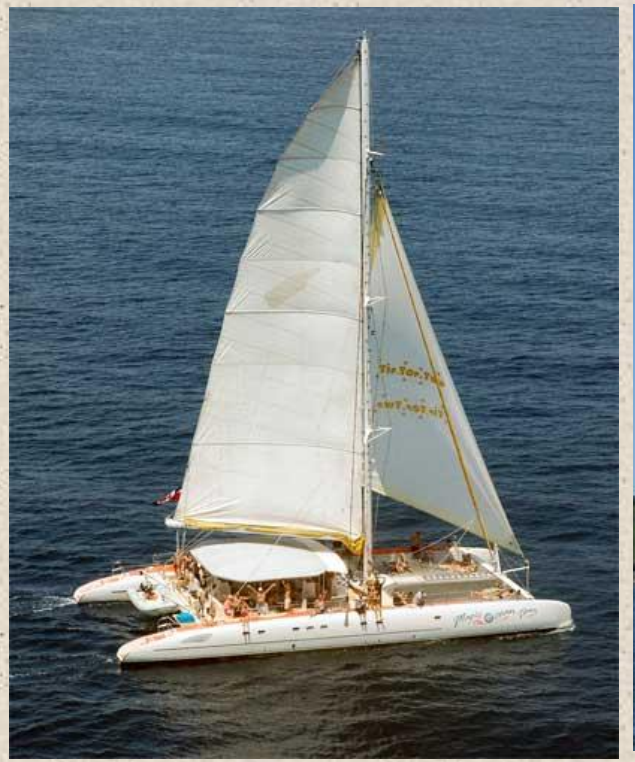
Rudder – Direction (Yaw)



Capturing the Wind Force

An Old Square Rigger

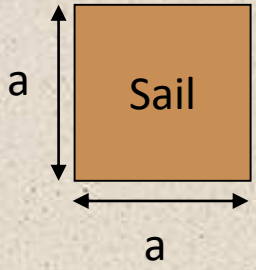
A Modern Catamaran



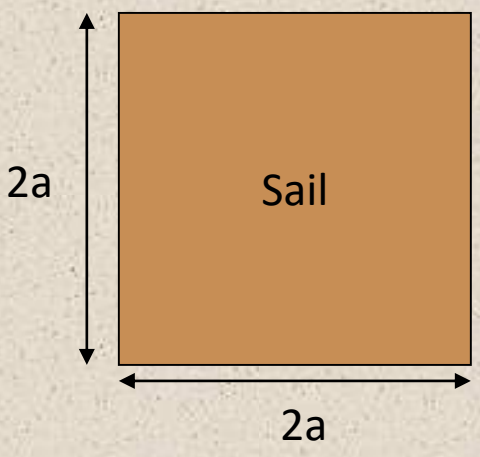
A Modern Sailing Yacht

Capturing the Wind Force

The wind force is proportional to the sail area:

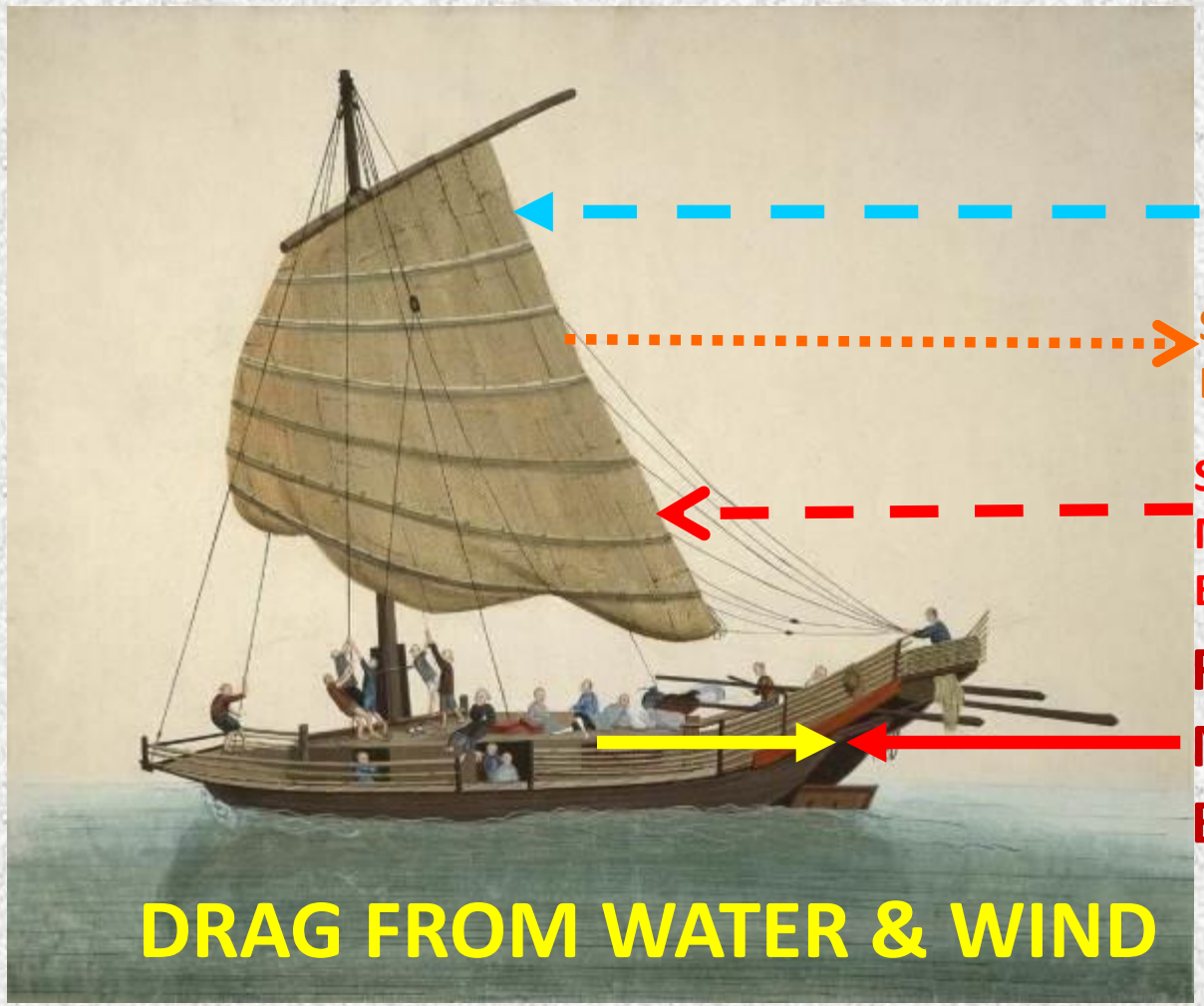


Sail Area = a x a = a^2



Sail Area = 2a x 2a = 4 x a^2

Drag Is The Friction Between The Water or Wind And The Boat



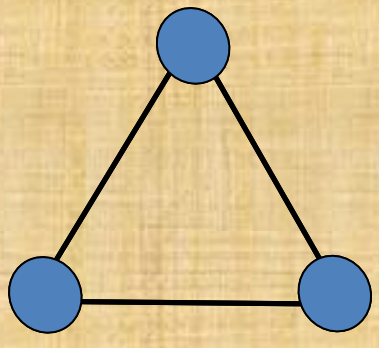
Controls Summary

Roll	**Keel / Ballast**
Pitch	**Keel / Ballast**
Yaw / Direction	**Rudder, Keel**
Speed	**Sail, Drag**

Parts Of A Sailboat
Fill in the Blanks

All sailboats have five basic components:

- ✓ The **Hull** **supports the mast,** rudder, and cargo.
- ✓ The **Mast** **supports the sails.**
- ✓ **The Sail catches the wind and provides the force to move the boat.**
- ✓ The **Keel or Ballast** stabilizes the hull in roll and pitch.
- ✓ **The Rudder** is used to steer **the boat.**

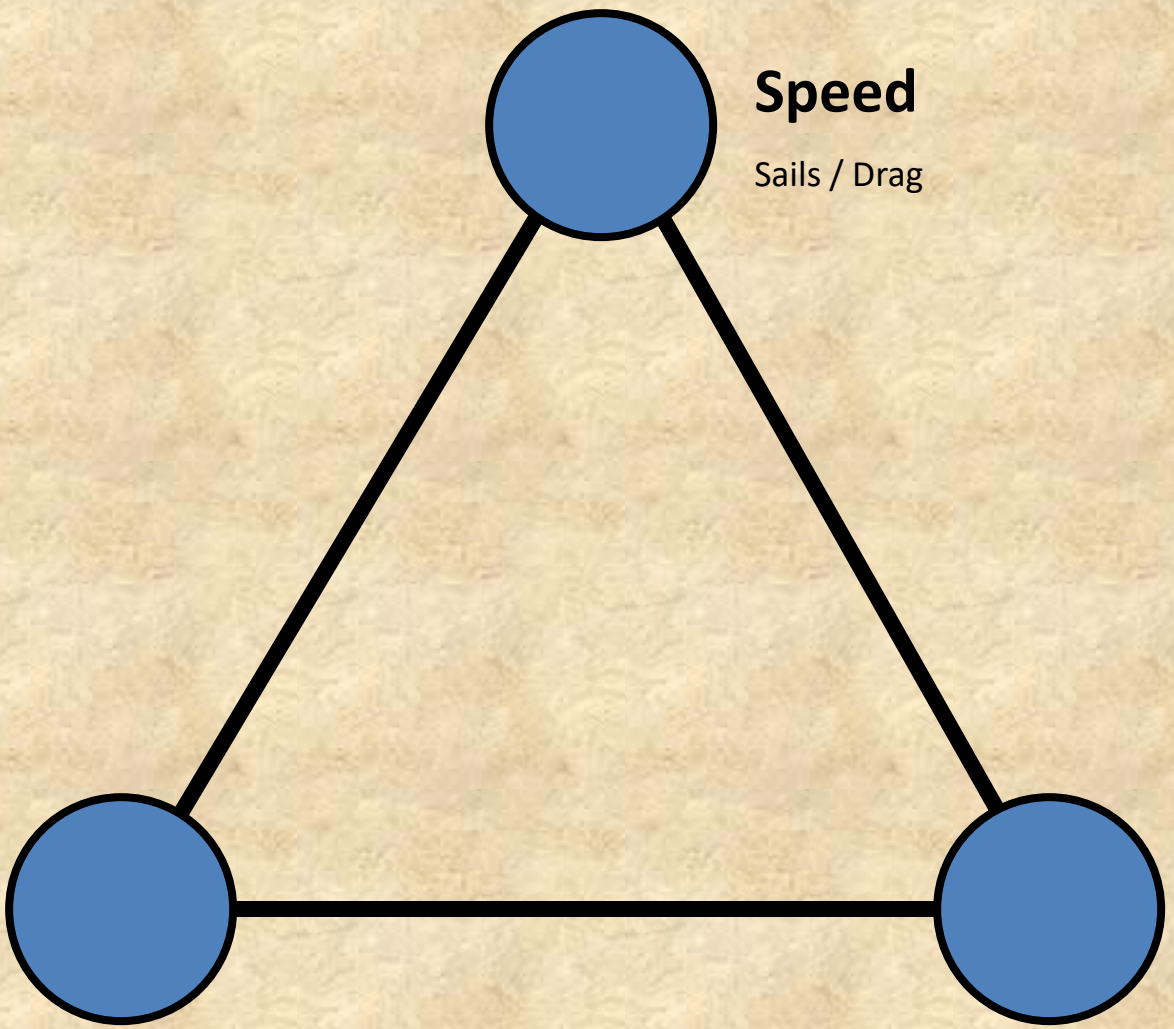


Design a Boat

Elements Of A Sail Boat Design

- **Float:**
  - Buoyancy → Density → Archimedes → **Hull**
- **Not tip – Be stable:**
  - Righting Moment → **Keel or Ballast**
- **Speed:**
  - Wind Force → Wind Speed and Area → **Sail and Mast**
- **Go Straight:**
  - Balanced Forces → Steering → **Rudder**

Engineering Trade-Offs



Speed

Sails / Drag

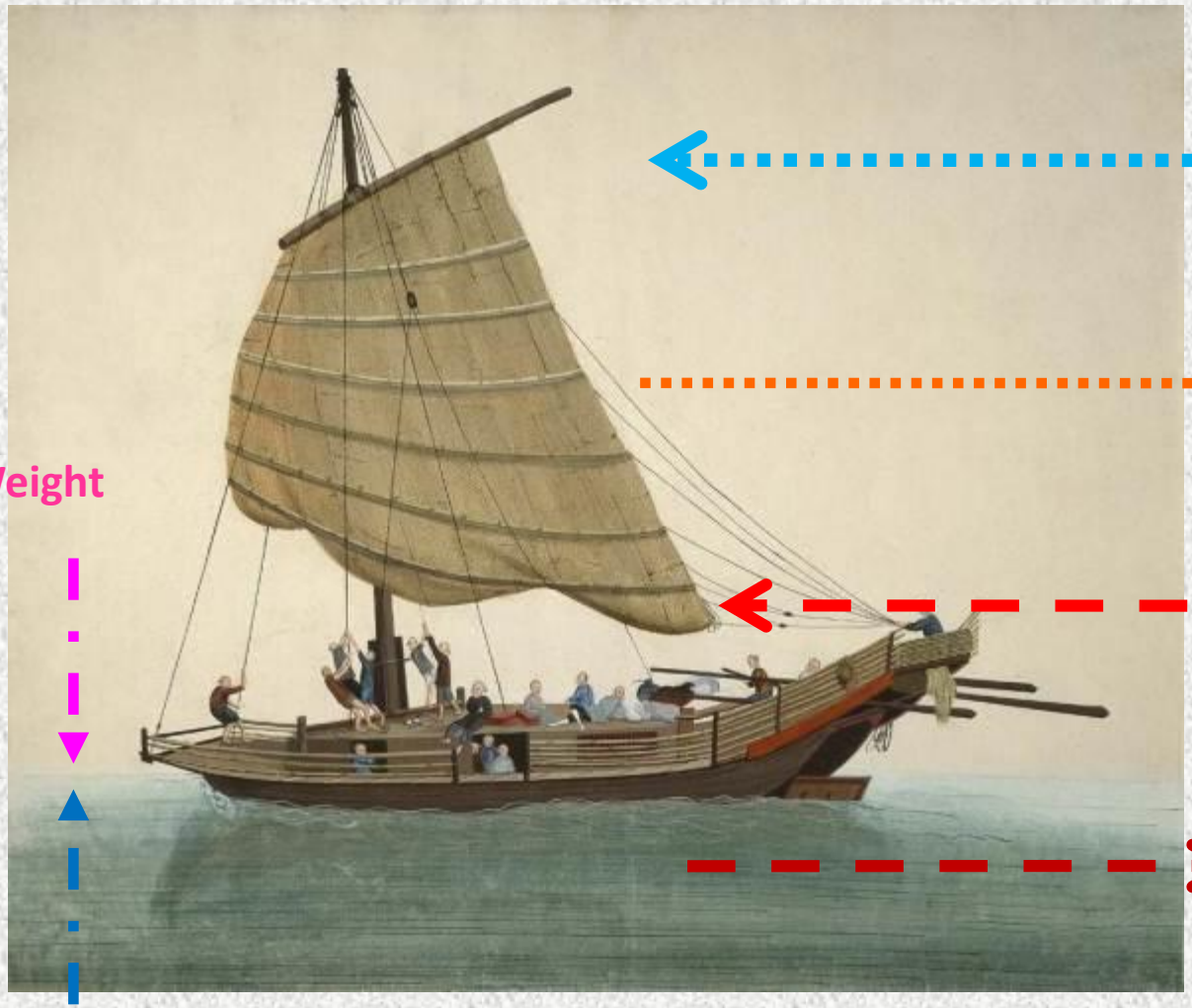
Stability

Hull / Ballast / Keel

Direction

Rudder / Sails

Forces on Sail Boats



WIND EXERTS FORWARD FORCE ON SAIL

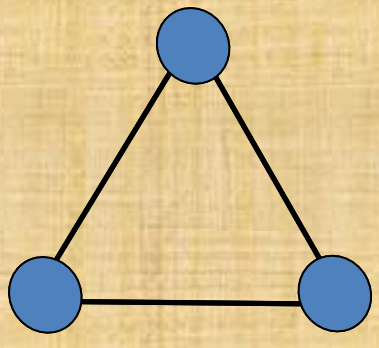
SAIL PUSHES BACK ON WIND

Weight

SAIL PULLS ON MAST AND PULLS BOAT FORWARD

DRAG FROM WATER RESISTS FORWARD MOTION OF BOAT

Buoyancy



You Deserve a Break!

Design a Boat

Build and Test a Boat

Materials for Boat Building

Water Bottles
Barbeque Skewers
Tooth Picks
Foam Core Boards
Rubber Bands
Clear Tape
Plastic Sheets
Twist Ties
Gravel
Construction Paper
String
Aluminum Foil
Plastic Food Wrap
Paper Clamps
Twist Ties

Tools for Boat Building

Pencil
Paper
Scissors
Paper Punch

The Objectives

Design and Build a sail boat that:

A. Goes Straight

B. Goes Fast

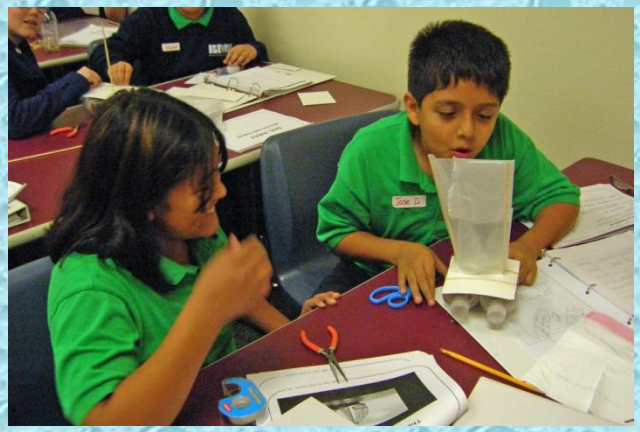
The Design Guide

- **Page 1 – Your design**
  - *Plan* your concept. Consider stability, speed, direction, cargo capacity
  - Use the design Triangle: Stability, Speed, Direction
  - Include all the parts: hull, mast, sail, keel, rudder
- **Page 2 – Testing: Stability, Direction, Speed**
  - Test and adjust as you go
  - Observe what others are doing to “fix” their problems
- **Page 3 – Record your observations**
  - What worked -- What didn’t work
  - What discoveries did you make

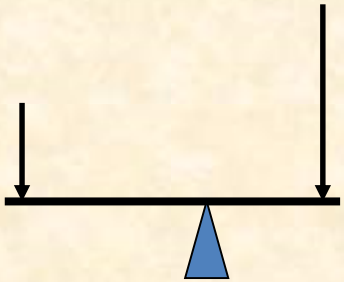
The Rules!

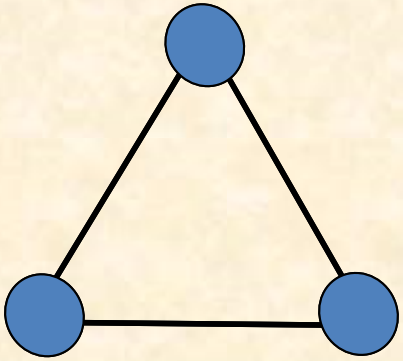
- Work in teams
- You can use any of the materials laid out on the tables
- Keep in mind that all your parts will be exposed to water
- Your design has to operate in the test pool for at least three minutes without falling apart
- It may have to carry a load of steel washers from one end of the pool to the other
- Be sure to watch the tests of the other teams and observe how their different designs worked
- After testing your first design, see if you can improve the design to overcome the deficiencies you noted
- Make and test as many different sail boat designs as you have time for

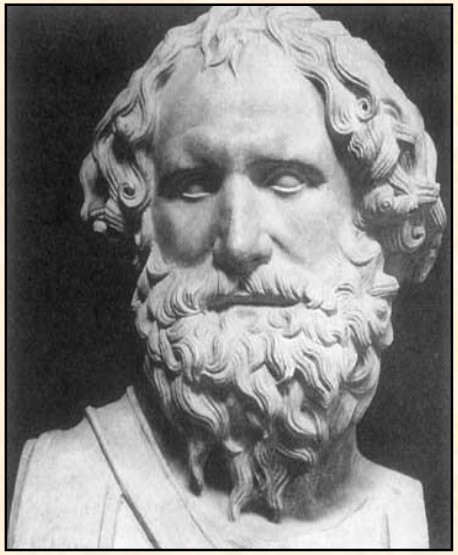
Let's Build And Test



Sail Away Review

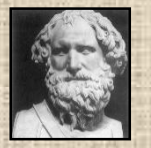




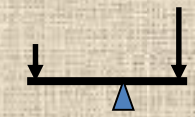


BOATS – Once More!

What We've Talked About

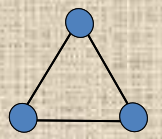


Archimedes Principle



Forces and Moments

Parts of a Boat



Design a Boat

Build & Test a Boat

Careers in STEM

Questions?

Have Fun Today?

Check out our website: www.azsciencelab.org
click on the “For Students” tab!

Thanks for coming and exploring with us
the world of forces, moments, and sailboats!