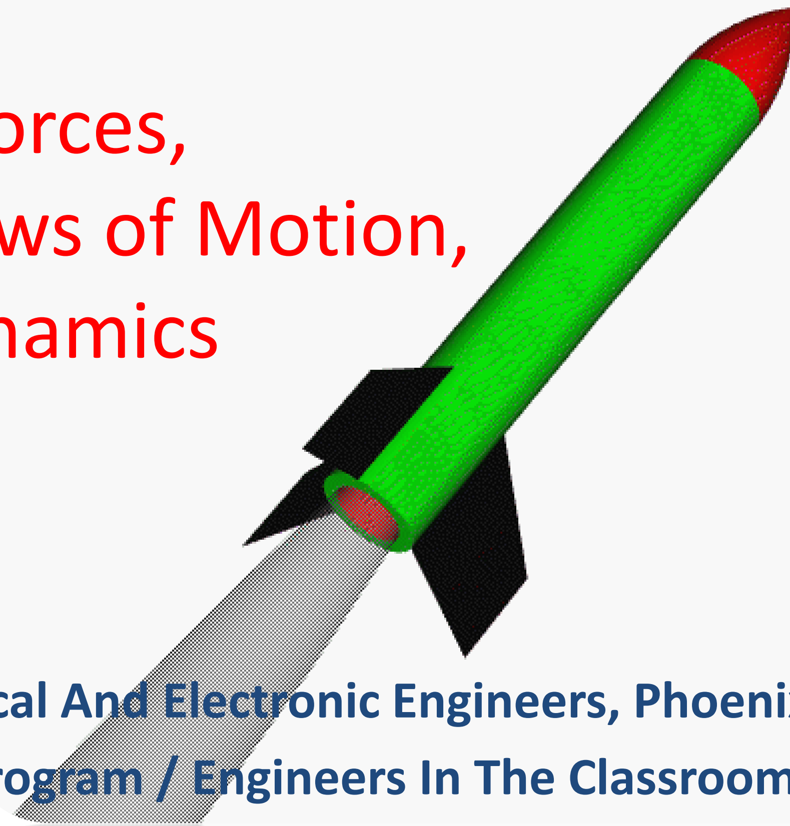
ARIZONA SCIENCE LAB

Rockets

Up, Up, and Away !!!

A Study of Forces,
Newton's Laws of Motion,
And Aerodynamics



Institute Of Electrical And Electronic Engineers, Phoenix Section
Teacher In Service Program / Engineers In The Classroom (TISP/EIC)

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Information on Rockets

Much of the material in this presentation is courtesy of the National Aeronautics and Space Administration, United States of America.

Go to their website: www.nasa.gov where they have some great information for students!

Engineering a Rocket

- Today we will explore the science, engineering, and technology of rocketry.
- You will experience the engineering process by designing, building, and launching a model rocket!
- You will learn to work together as a team!
- So, how does a really bad and a really great rocket fly?

Let's go outside and see!!

History of Rockets

- Hero's engine: 60 BC

Hero Engine

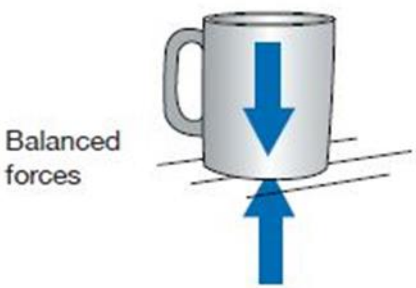
Sir Isaac Newton
&
The Laws of Motion

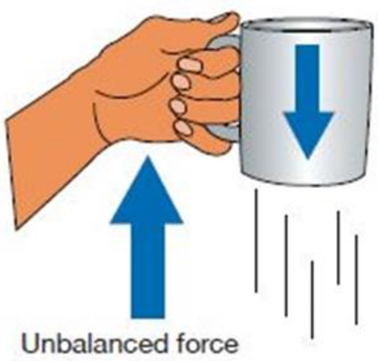
- English scientist in physics, mathematics, and astronomy, 1643-1727.
- One of the most influential people in human history.

Sir Isaac Newton summarized how objects move with three simple laws. They're often called ***Newton's Laws*** and they apply to everything in the world around us!

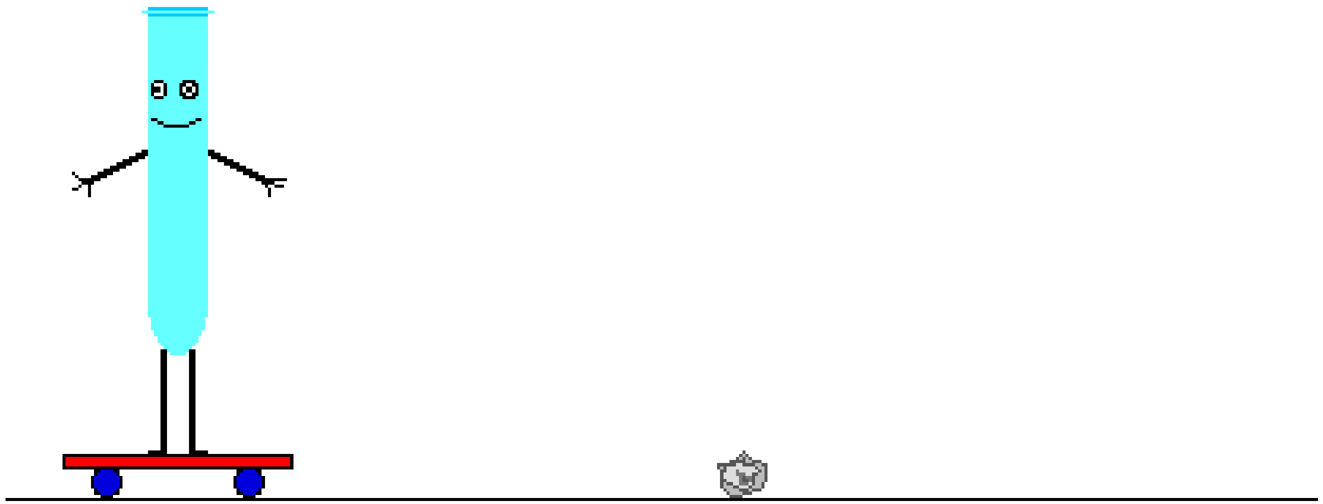
Newton's First Law of Motion

- **Objects at <u>rest</u> remain at rest, and objects in <u>motion</u> remain in motion in a straight line,**
  unless acted upon by an <u>unbalanced net force</u>.
- A **Force** is a push or pull exerted on an object
- **Net Force** is the sum of all forces acting on an object:

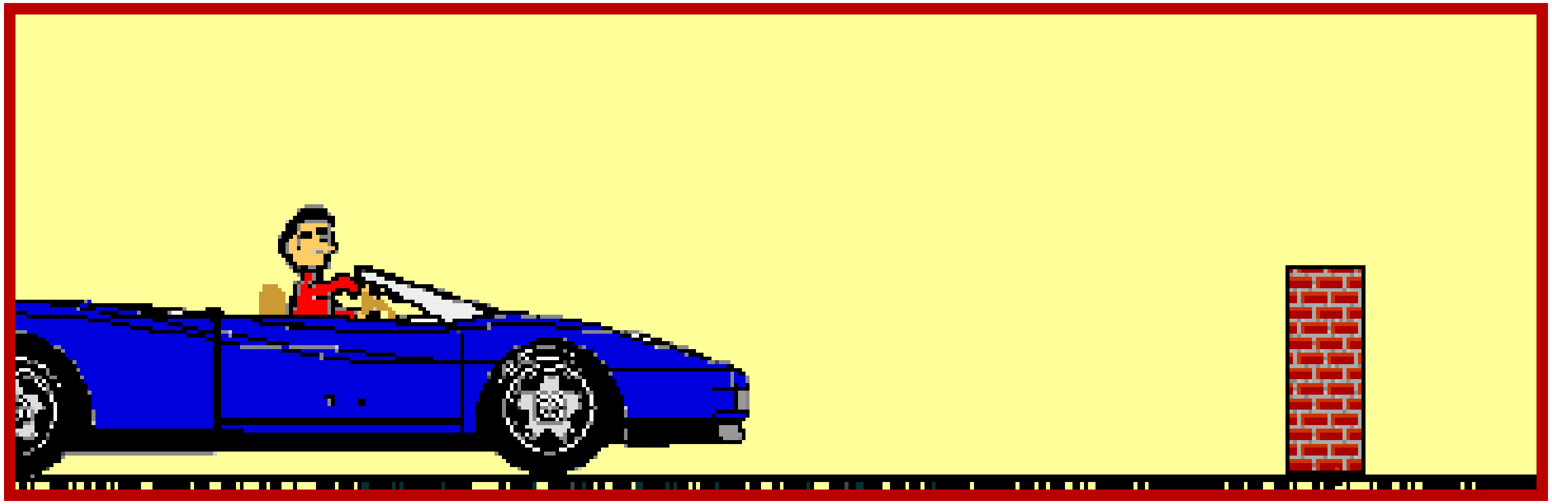




Newton’s First Law - Example

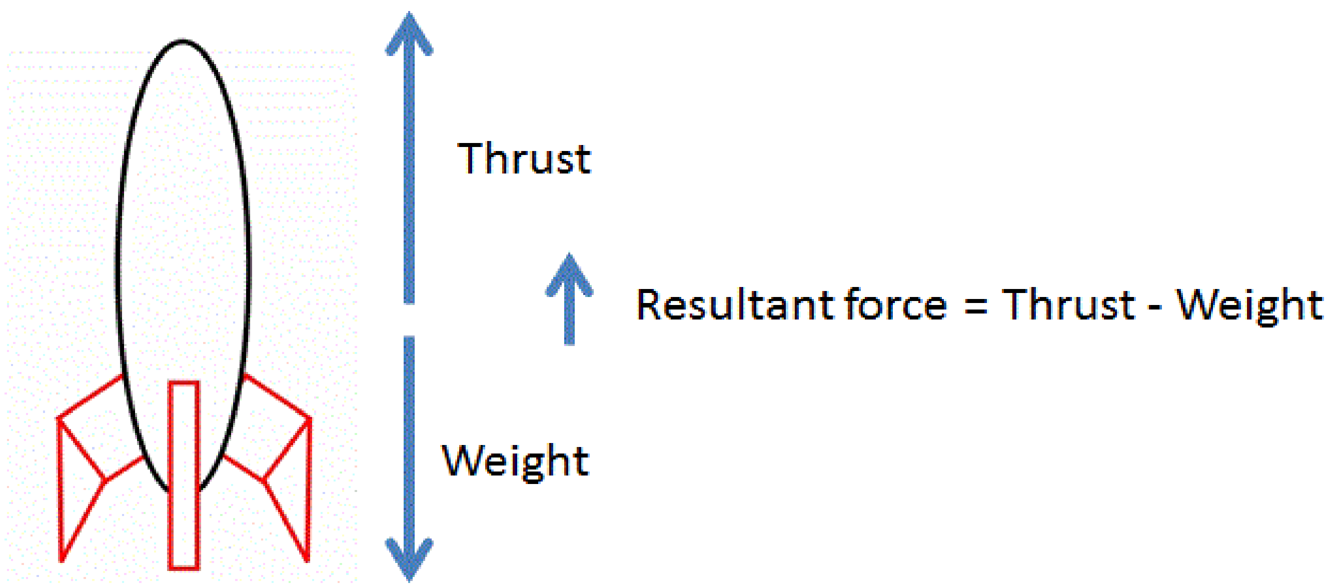


Newton's First Law - Example



Newton's 1st Law Applied to Rockets

- A rocket at rest will stay at rest until a force is applied to move it upward.
- The upward force called thrust must exceed the downward pull of gravity (weight).



Newton's Second Law of Motion

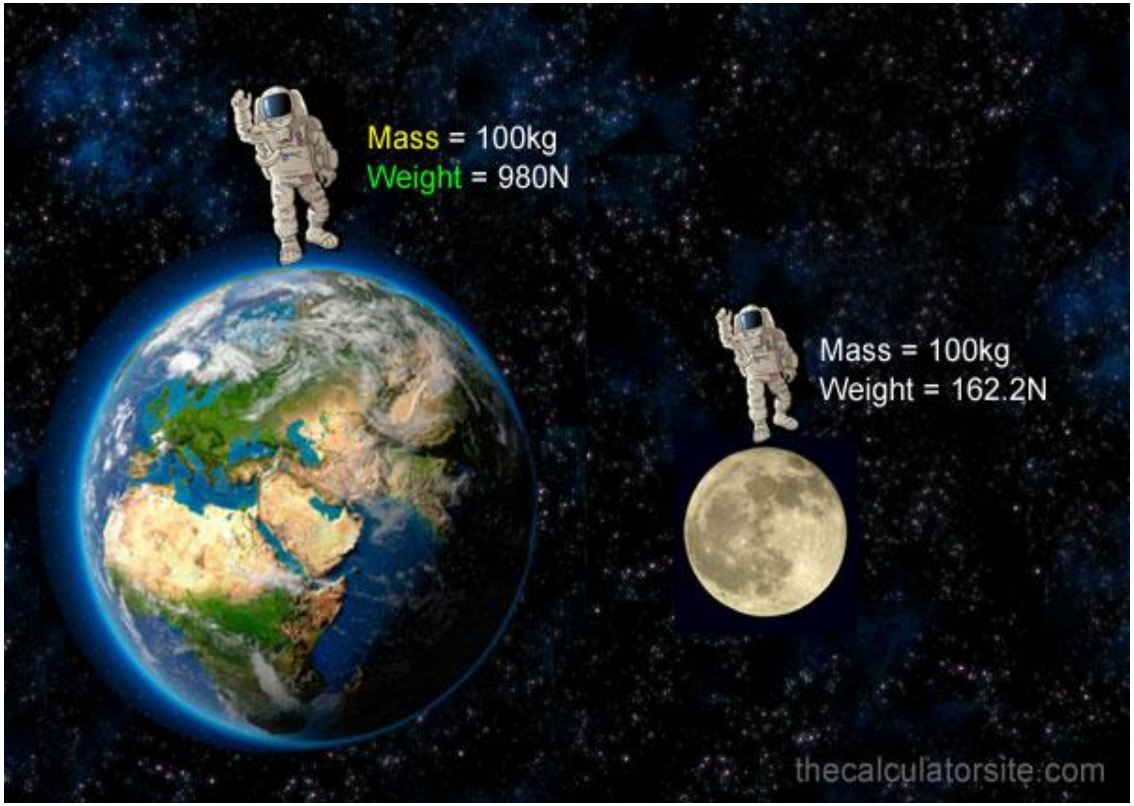
Force equals mass times acceleration: **F = m * a**

- Force is a push or pull exerted on an object.
- Mass is the amount of matter in an object.
- *Mass is not weight, mass is the same no matter where an object is!*
- Acceleration is a **change** in motion, i.e. increasing speed or changing direction.

Mass vs. Weight

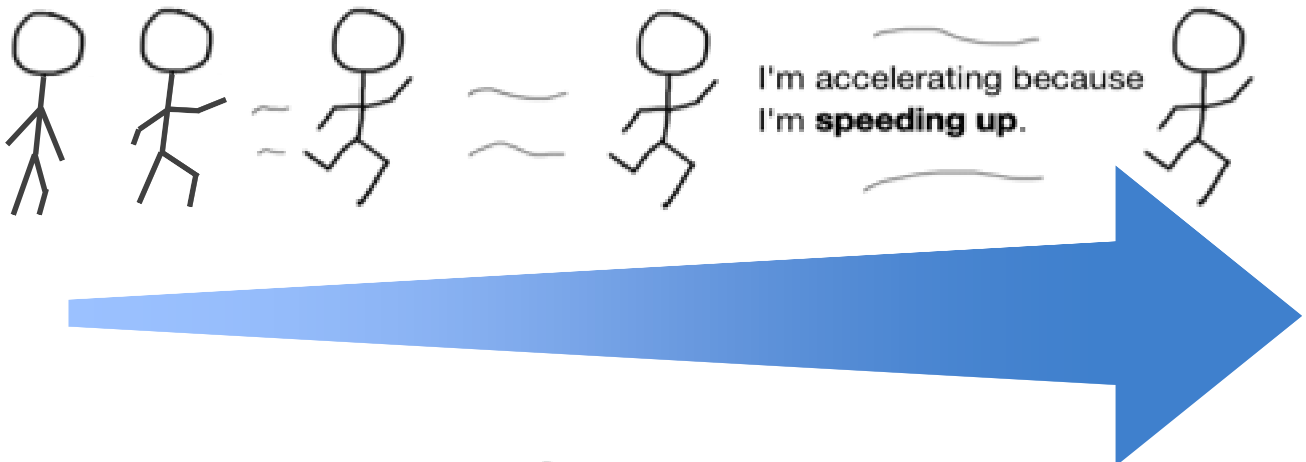
Earth's gravity is the pull on an object by the earth.

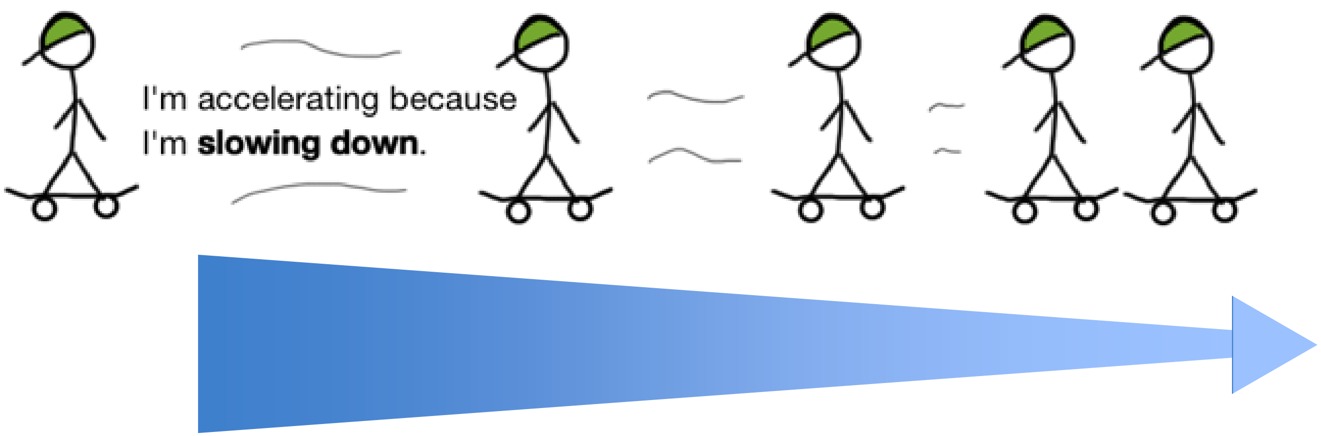
- **Weight is the gravity force, W=m * g**
- At sea level: acceleration due to gravity (**g**) is 9.807 meters/second/second – a constant!
- Weight (in Newtons) = mass * 9.807
- Weight varies depending on the gravity force, the mass of an object is always the same!



Acceleration

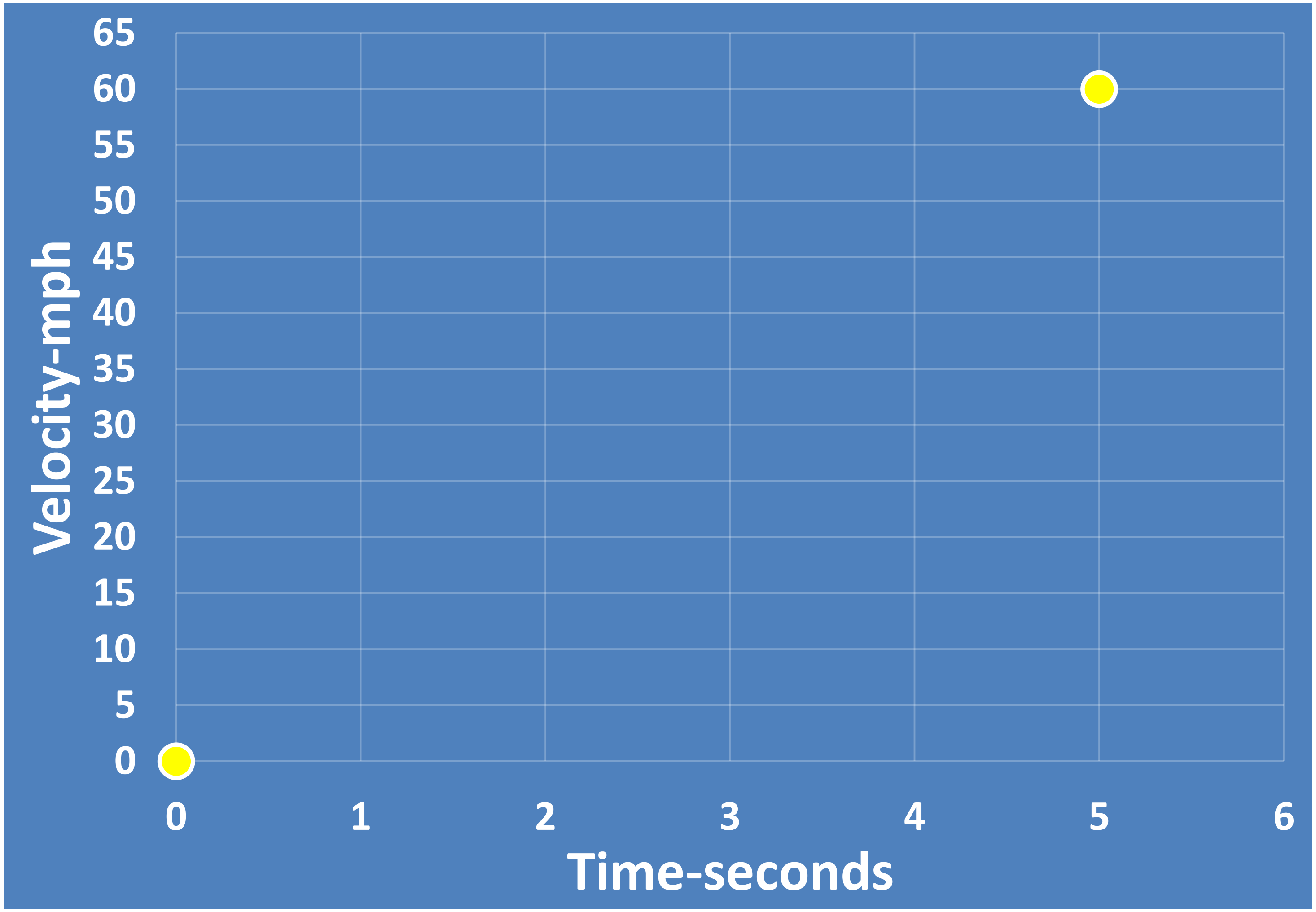
Acceleration is a <u>change</u> in velocity over time:





Problem: A car starts from a stop and gets to 60 miles/hour in 5 seconds. How fast is the car accelerating?

Hint: How fast is the car going after 1 second?



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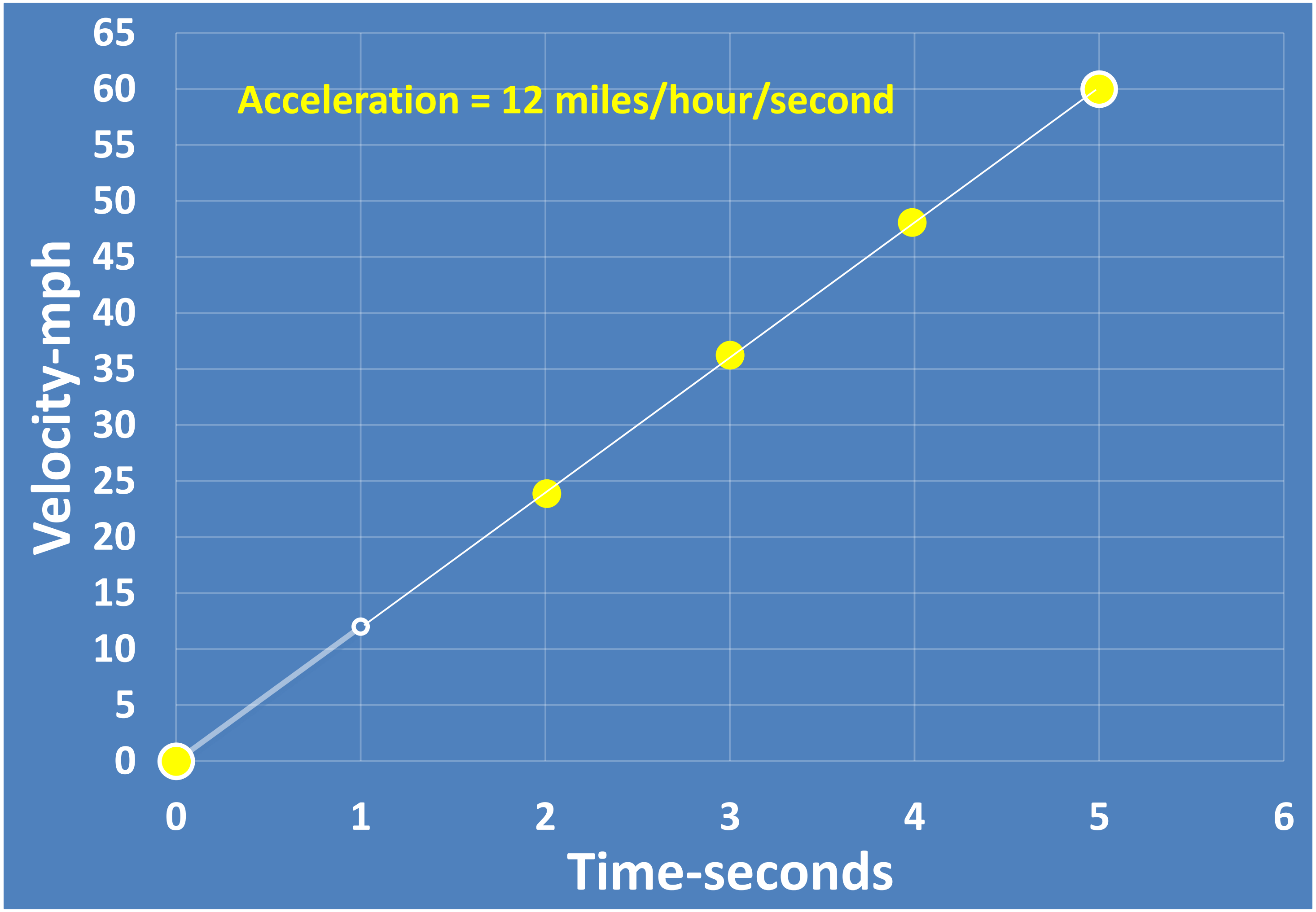


The Force Equation

- **Force = mass $*$ acceleration:**

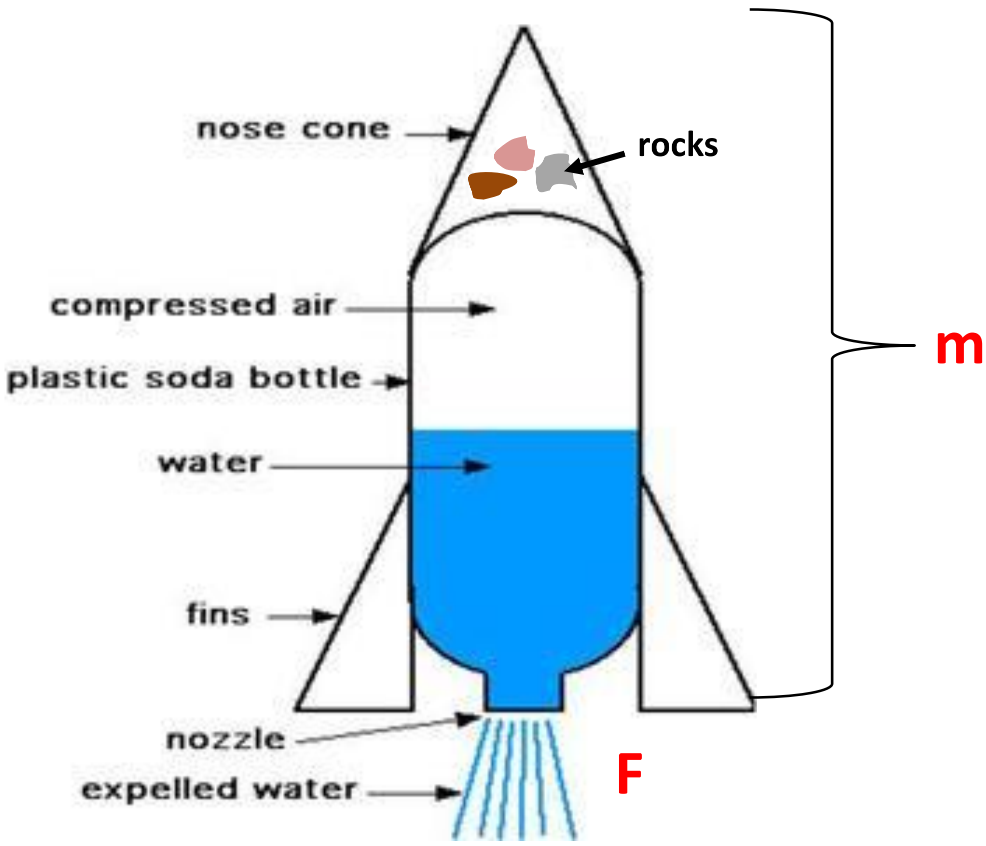
or

acceleration = Force/mass

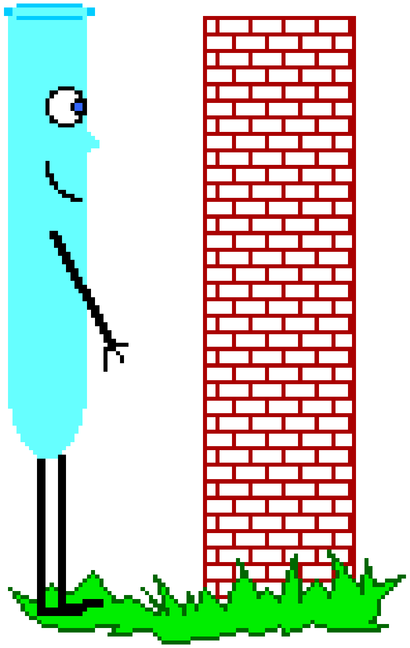
$$\boldsymbol{a = \frac{F}{m}}$$

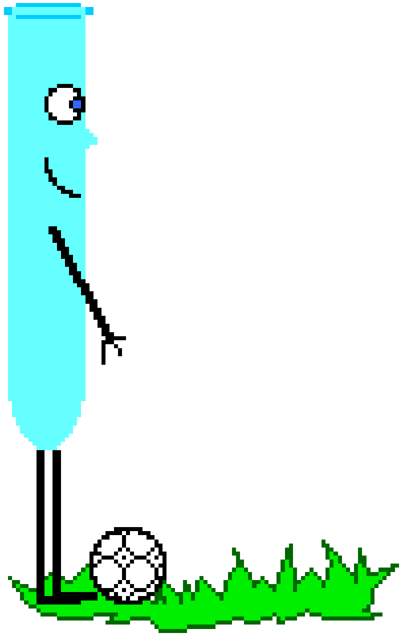
- **Thus, acceleration of an object is:**
  - **<u>directly proportional</u> to the net force applied and**
  - **<u>inversely proportional</u> to its mass.**

Newton's Second Law applied to Rockets $a = \frac{F}{m}$



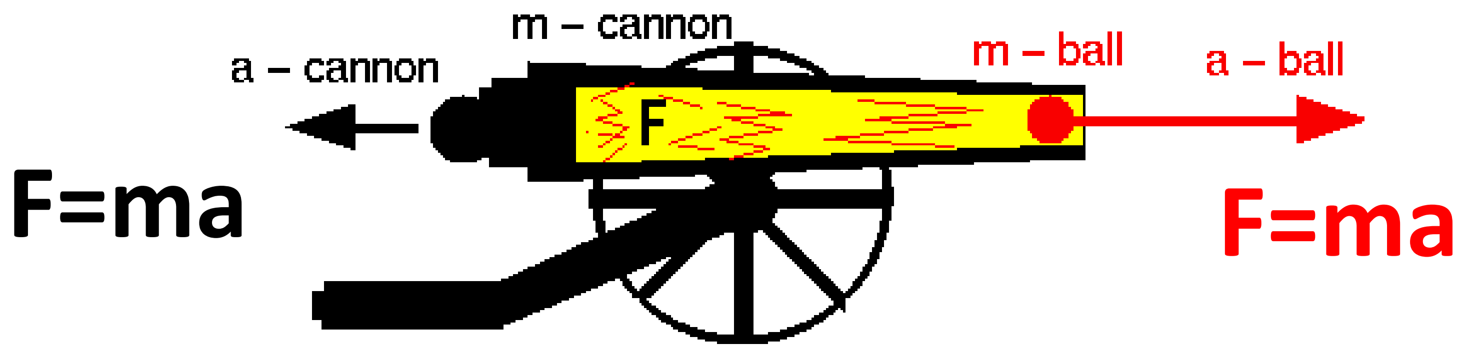
Newton's Second Law





Newton's Third Law

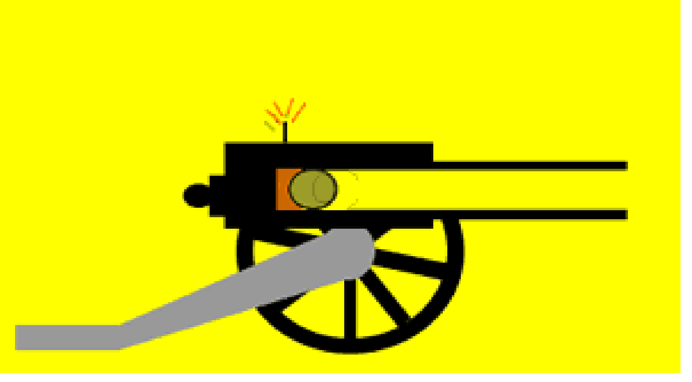
For every action there is an equal and opposite reaction



- An action is the result of a force, e.g., a cannon fires and a cannon ball flies through the air. The movement of the cannon ball is an <u>action.</u>

- A reaction is related to an action, i.e. the cannon moves backward in <u>reaction</u> to the cannon ball moving forward.

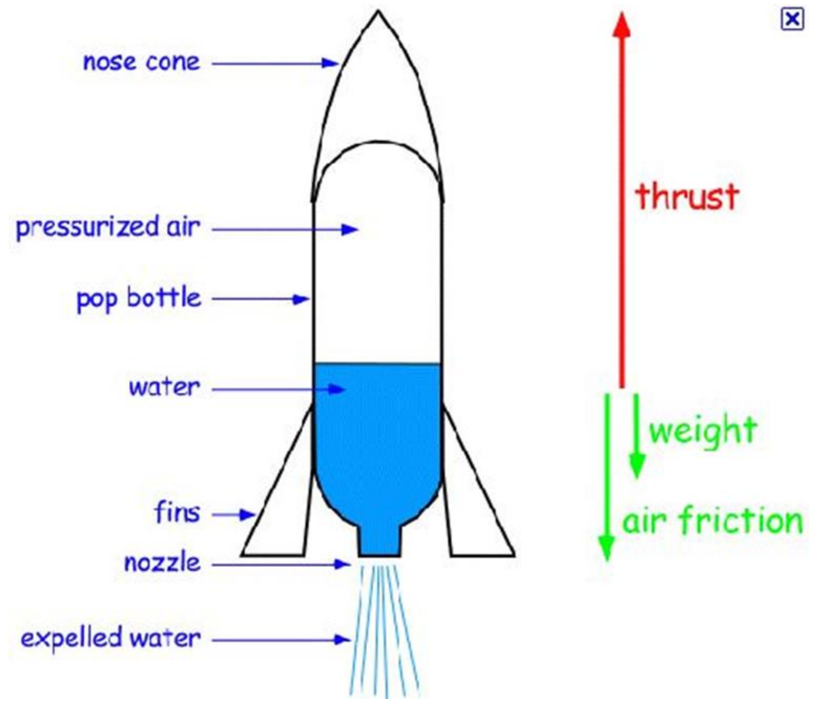
- Actions and reactions happen simultaneously.



Rocket weight vs. engine thrust

- A Rocket is pulled towards the earth by Gravity.
- It is pushed upward by the expanding gases from the nozzle, in our case by the water/air leaving the nozzle.

$$a_{rocket} = \frac{(F_{thrust} - F_{gravity} - F_{friction})}{m_{total}}$$

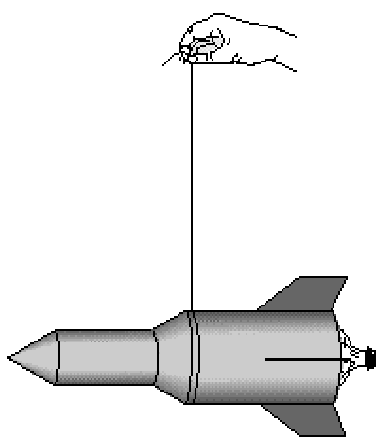


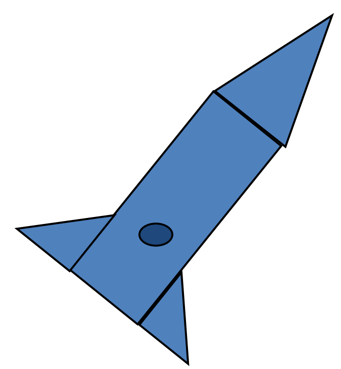
The Three Newton Laws

- <u>All three laws work together for rockets</u>:
  - **Law 1:** Thrust force overcomes the gravity force – unbalanced net force is upward.
  - **Law 2:** How fast a rocket accelerates is directly proportional to thrust and inversely proportional to the rocket mass.
  - **Law 3:** The downward force of the engine gases moves the rocket upward into space.

Rocket Stability

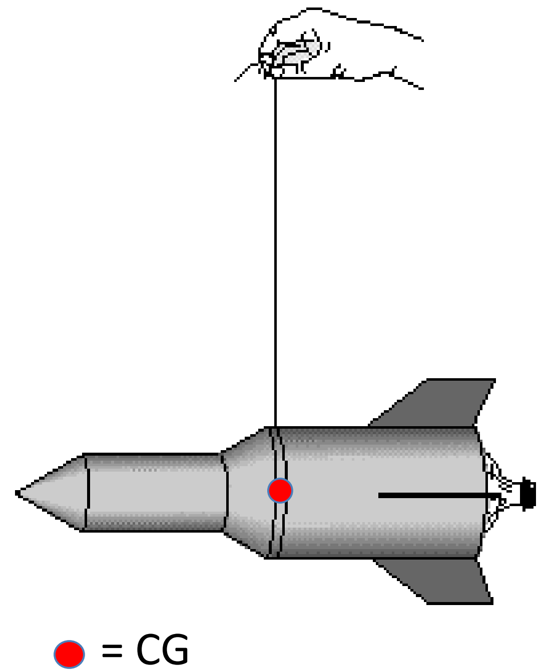
- The stability of the rocket in flight depends on:
  - The Center of Gravity of the Rocket – the balance point
  - The Center of Pressure of the Rocket – the surface area center

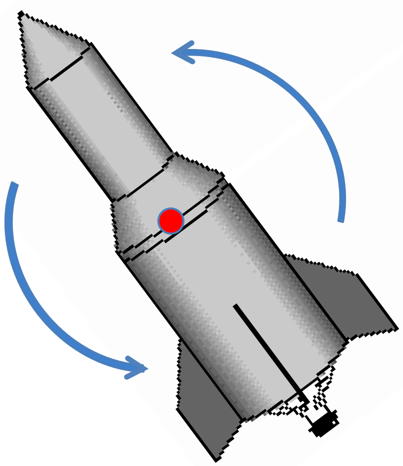




Center of Gravity

- The center of gravity (CG) is a point through which the entire weight of an object appears to act.
- All of the obj[illegible]eight balances at the CG point.

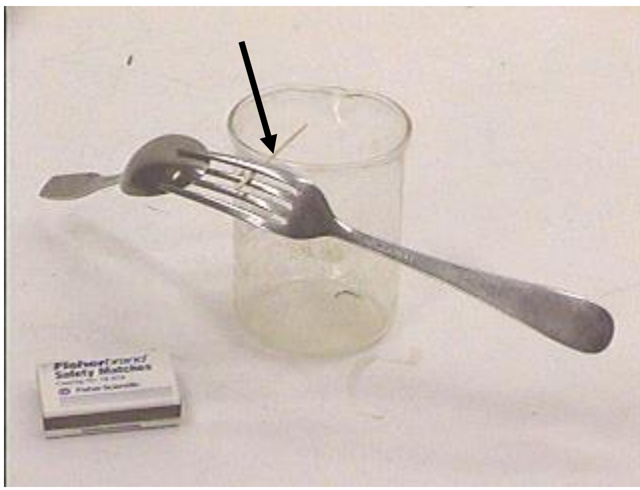




- The CG is the point about which an object will rotate.
- For a rocket, end-over-end rotation about the CG is to be avoided for a safe, efficient, tumble-free flight.

Center of Gravity, (Center of Mass)

All objects have a Center of Gravity

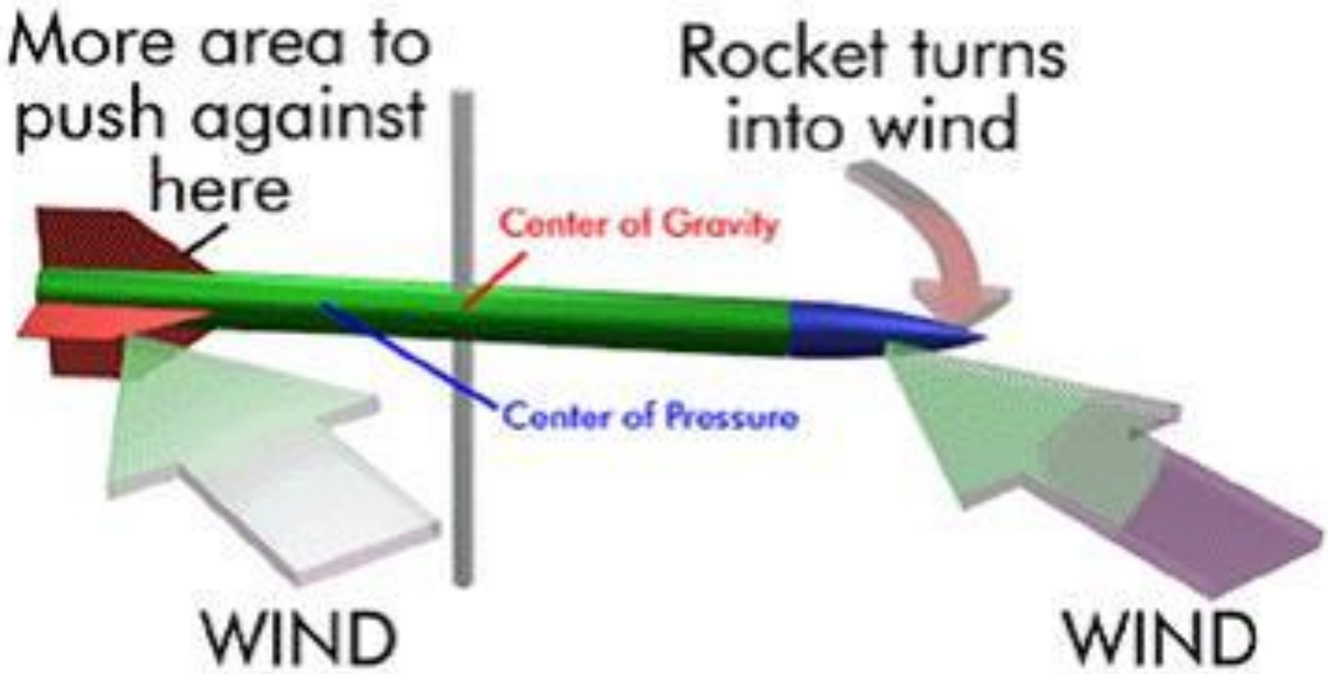


Where is the center of gravity in each of these examples?

Aerodynamic Forces

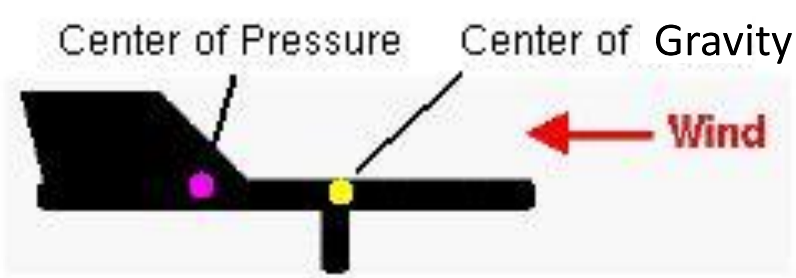
- Aerodynamic forces act through the "Center of Pressure" of the rocket.
- Generated by the nose cone, body, and fins of the rocket.
- Based on surface area and location of each component.
- Air moves across all of the surfaces of the rocket.

Center of Pressure

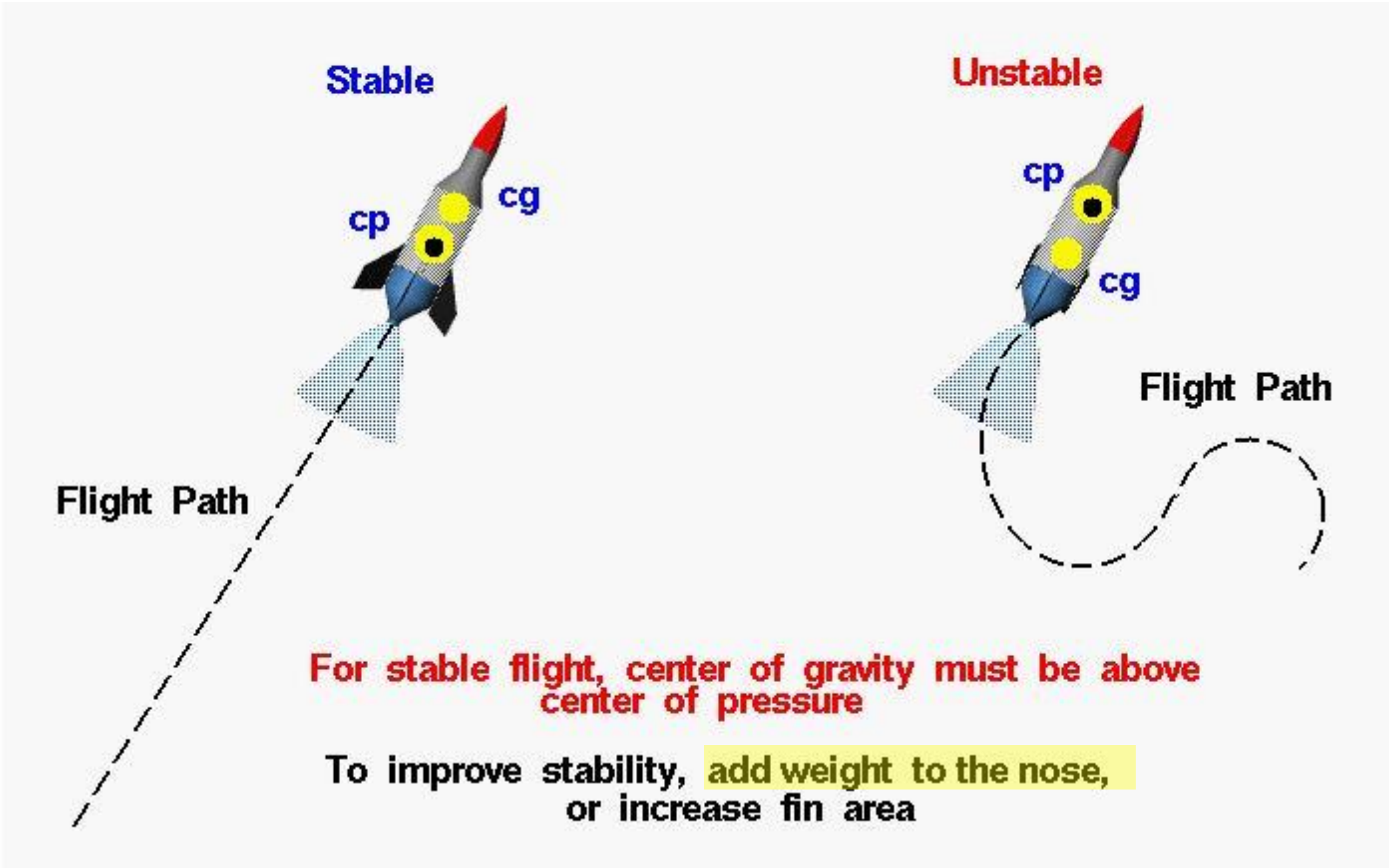


Rocket Stability

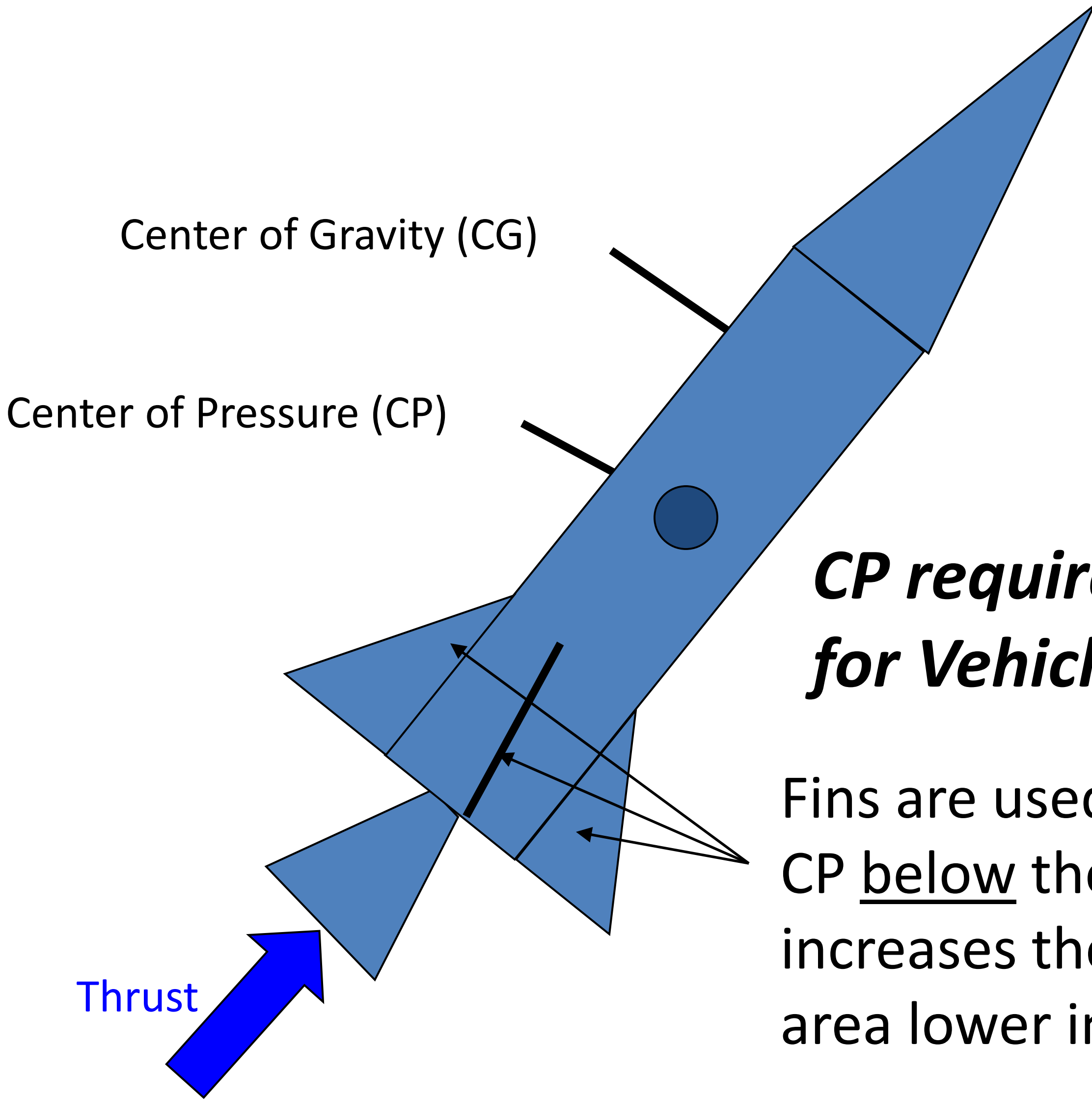
- To be stable, an unguided rocket with fixed fins: the CG (center of gravity) must be above the CP (center of pressure):
  - **The CG is the point where the rocket weight balances.**
  - **The CP is the point where the aerodynamic forces balance.**



Rocket Stability



Unguided Vehicle Stability



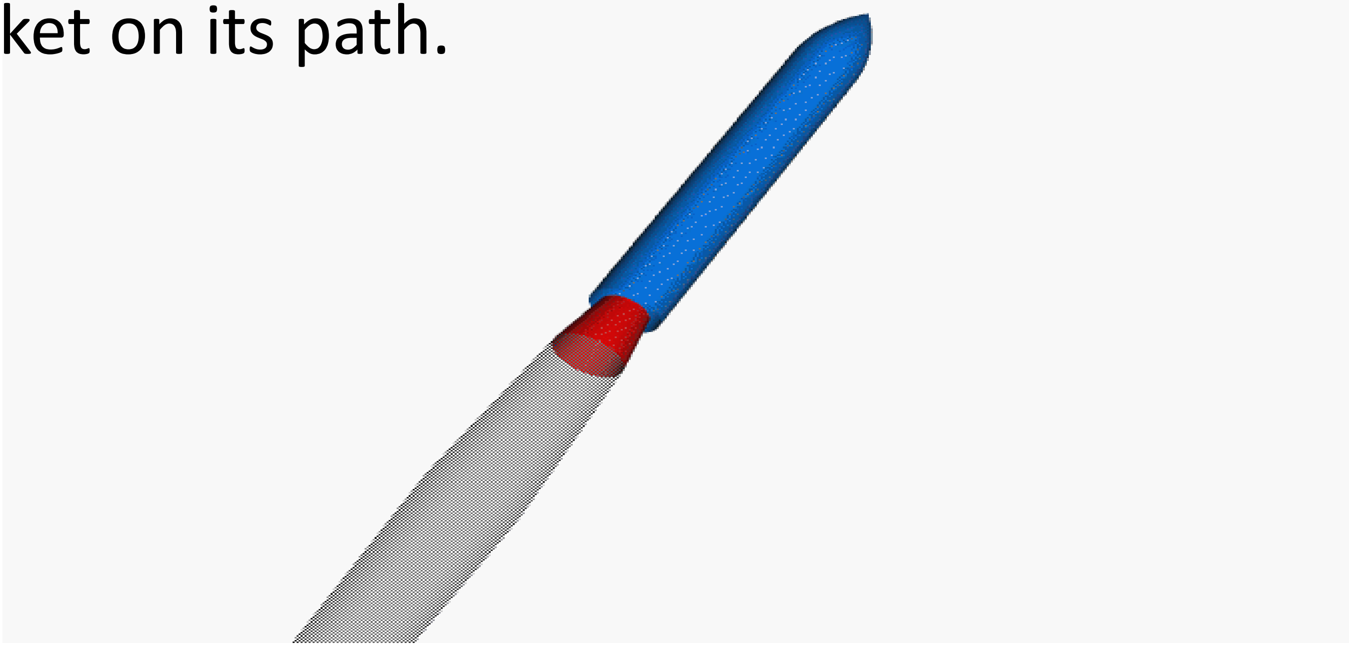
CP required to be below CG for Vehicle Stability!

Fins are used to shift the CP below the CG, this increases the surface area lower in the rocket!

Rocket Control

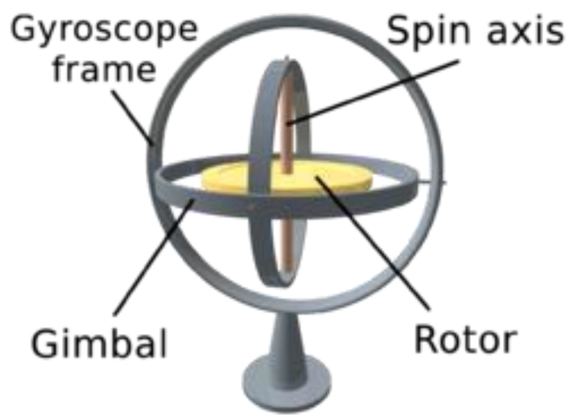
Gimbal Mount Exhaust

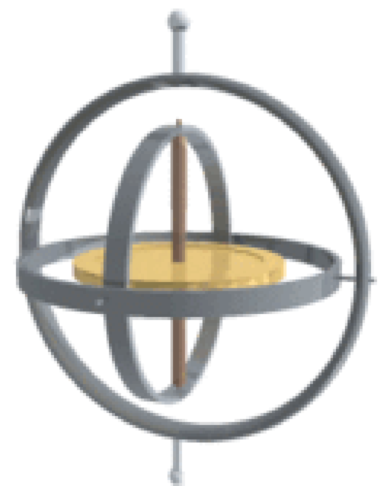
- In real rockets, complex guidance systems, **gyroscopes**, and swivel mount nozzles guide the rocket on its path.



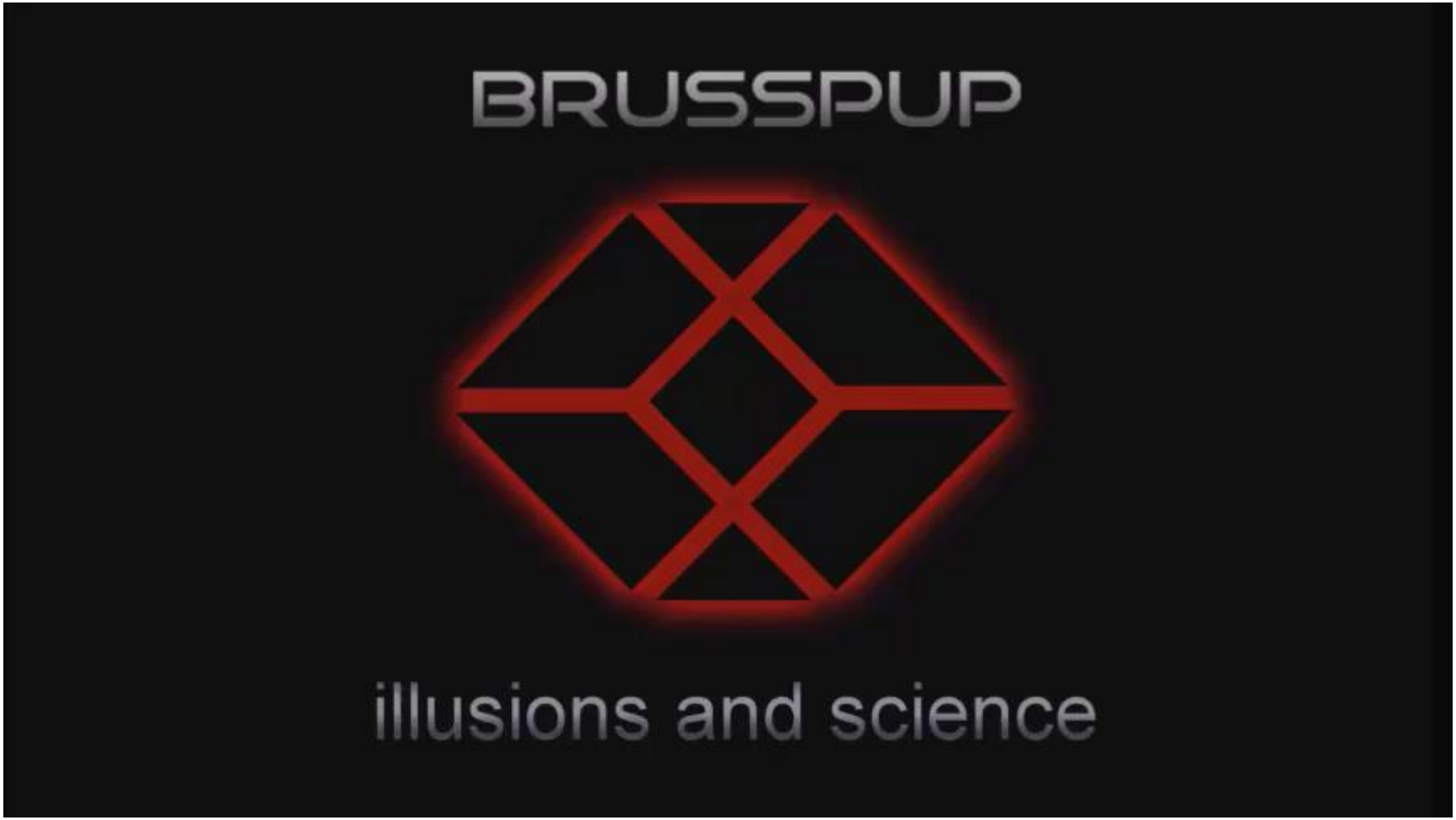
Gyroscope

- A device for measuring or maintaining its orientation in space.
- A rotating device that exhibits the property of Newton's First Law – it resists changes in direction.
- Rocket guidance systems use gyroscopes to monitor position/direction.





Gyroscope Demo

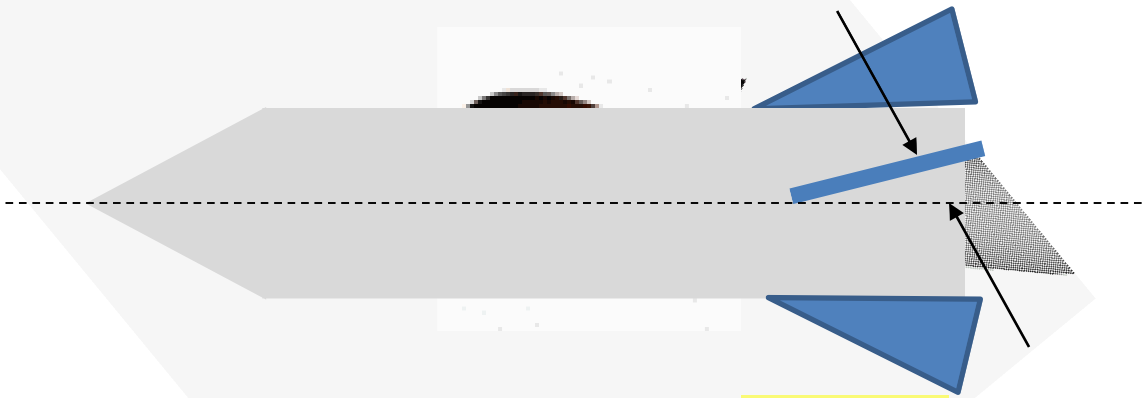


Rifling

- Making helical groves in the barrel of a gun or rifle imparts a spin to the bullet around its long axis.
- The spin creates a gyroscopic stiffness – resistance to change in the projectile direction.

Spinning stability

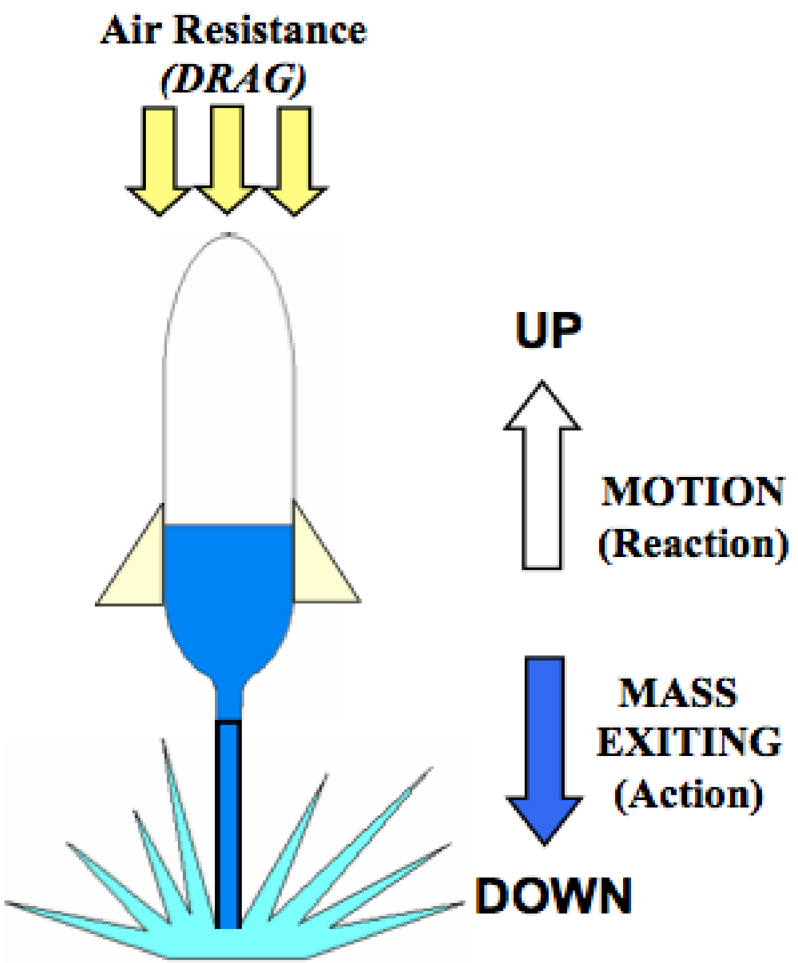
- For unguided rockets and projectiles, spinning them gives them “gyroscopic stiffness”.



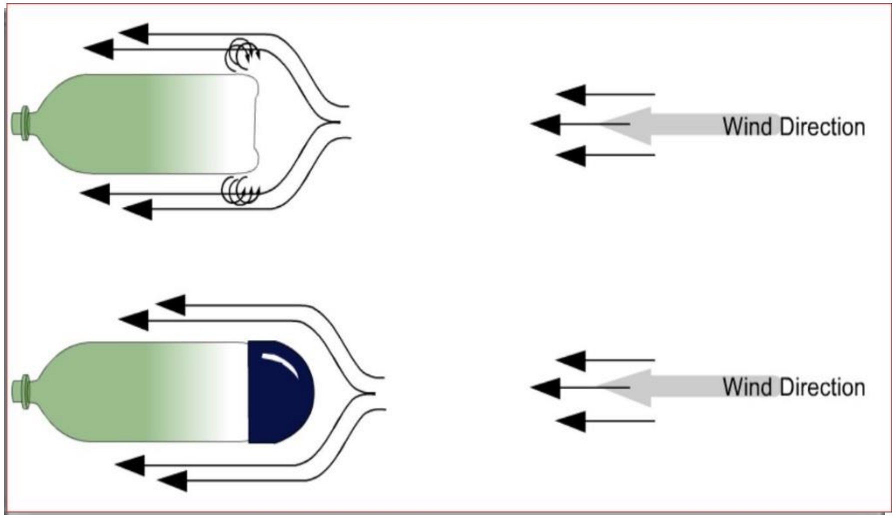
- For our rockets we use **tilted** fins to spin the rocket.
- Like the football, the rocket resists changes in its direction.

Aerodynamic Drag

- Drag is air resistance that works against thrust and will slow down the rocket.
- Drag must be minimized for best rocket performance.



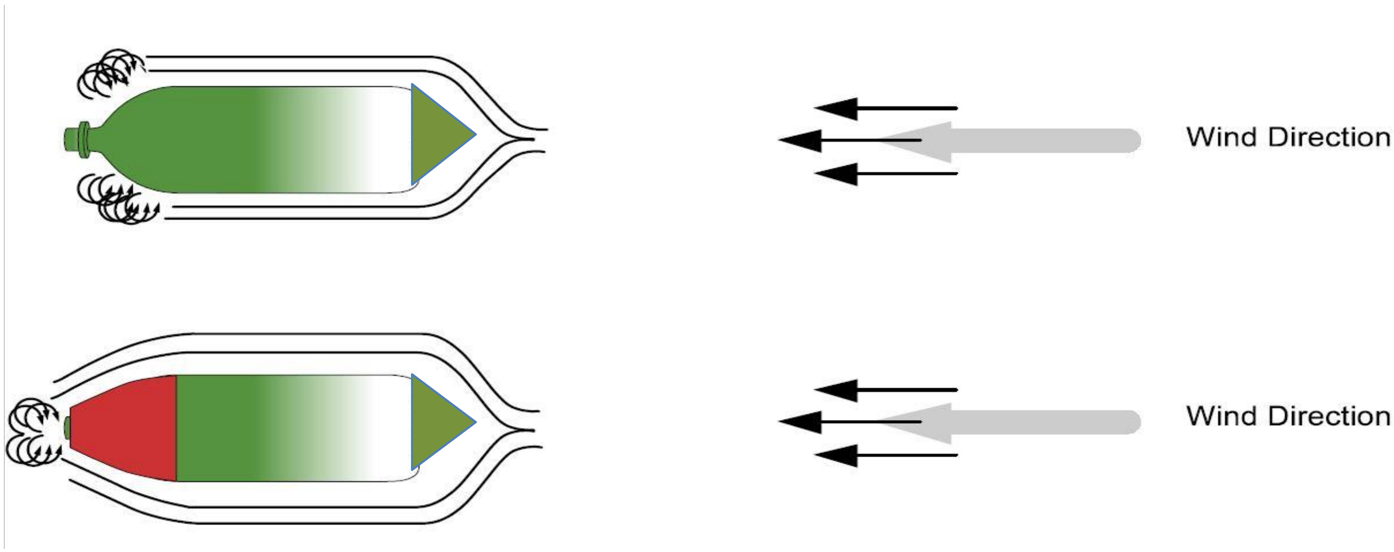
Rocket Aerodynamics

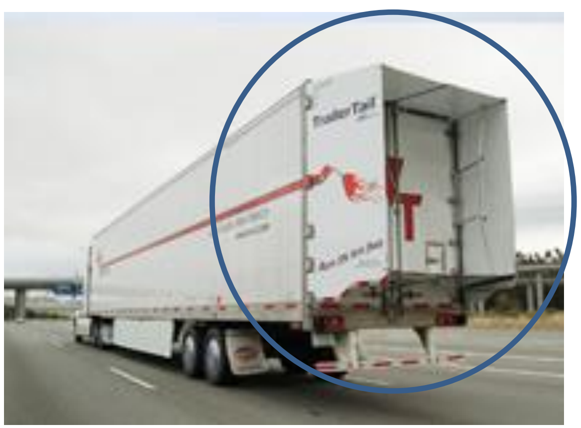


- The shape of an object greatly affects its air resistance (drag).
- A nose cone is very effective at reducing air resistance.

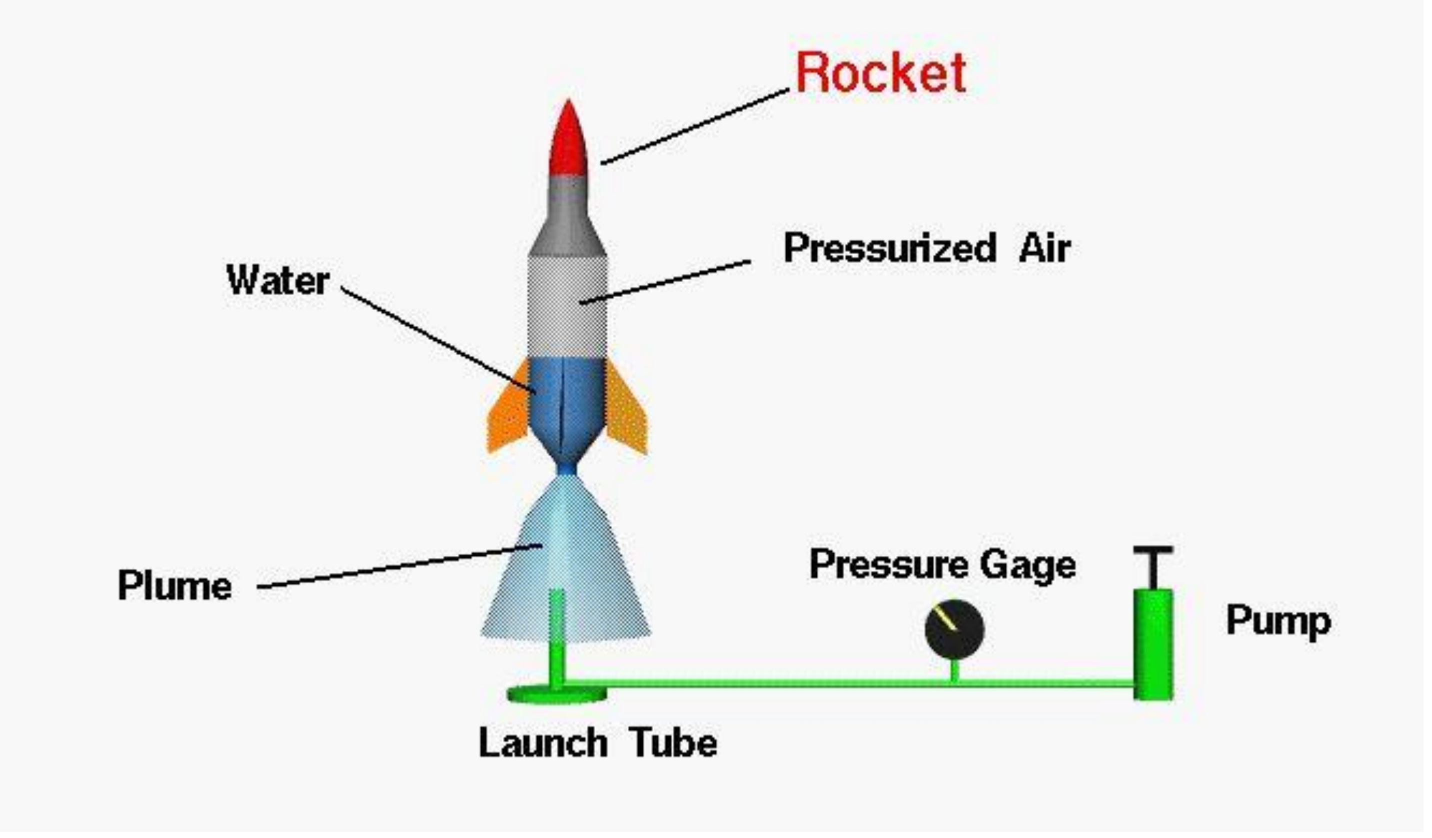
For our bottle rocket, a paper nose cone like this is simple and effective:

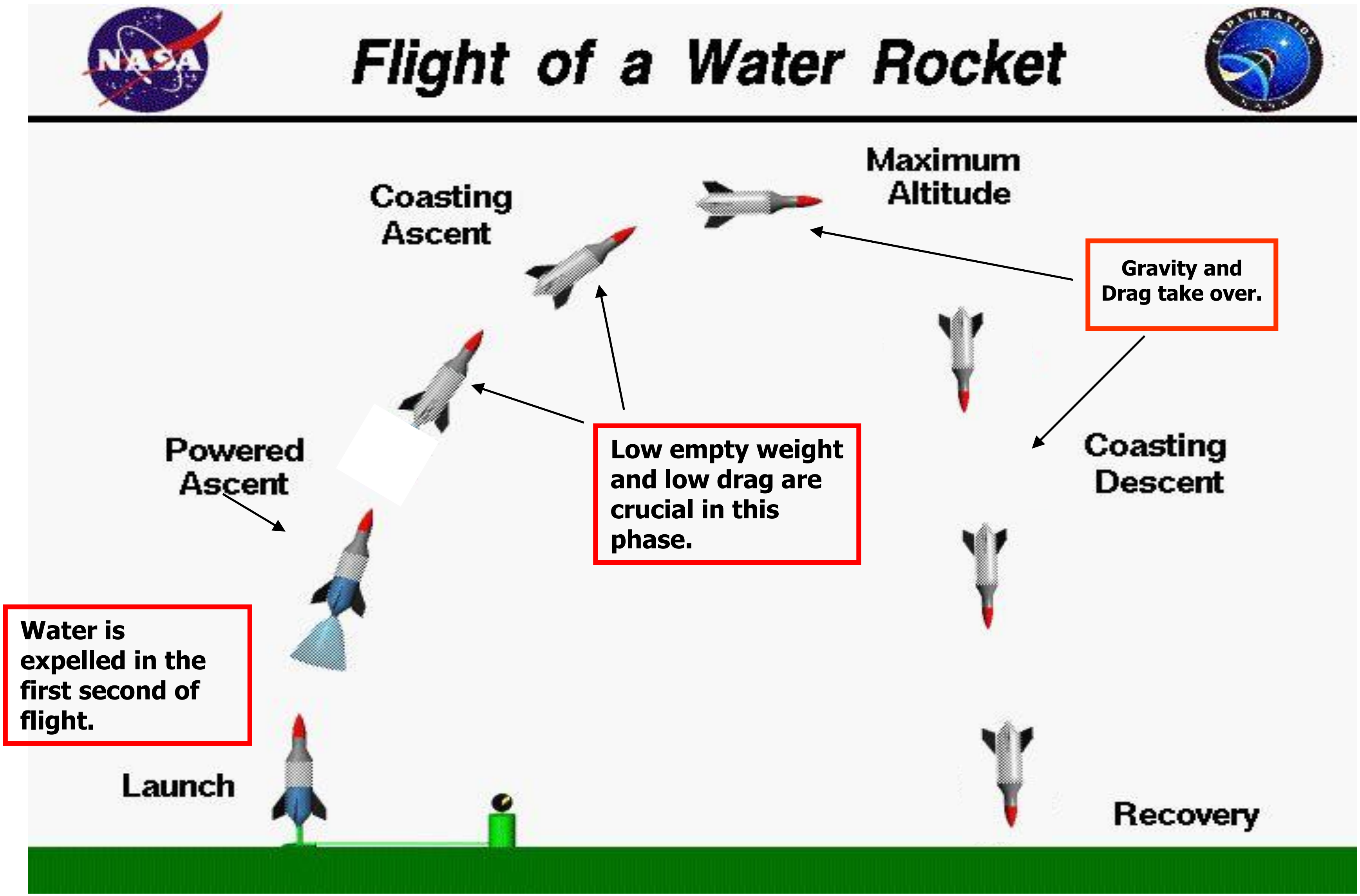
Air Flow Reaction to Fairing





Air/Water Rocket Launch Setup





Flight of a Water Rocket
NASA
Maximum Altitude
Coasting Ascent
Gravity and Drag take over.
Powered Ascent
Low empty weight and low drag are crucial in this phase.
Coasting Descent
Water is expelled in the first second of flight.
Launch
Recovery

Slow Motion ASL Rocket Launch

Let's Review – Rocket Engineering

Rocket Aerodynamics – The **Nose Cone** creates a smooth airflow at the front of the rocket.

Stability- Center of Gravity (Cg) must be forward of Center of Pressure (Cp) – use **Ballast** (rocks) in the nose and **Fins**.

More aerodynamics – The **Fairing** reduces turbulence at the rear of the rocket.

Gyroscopic Stiffness - Spinning keeps rocket in straight line - use **Tilted Fins.**

Propulsion – A combination of water (mass) and pressurized air (force) overcomes gravity and propels the rocket upward.

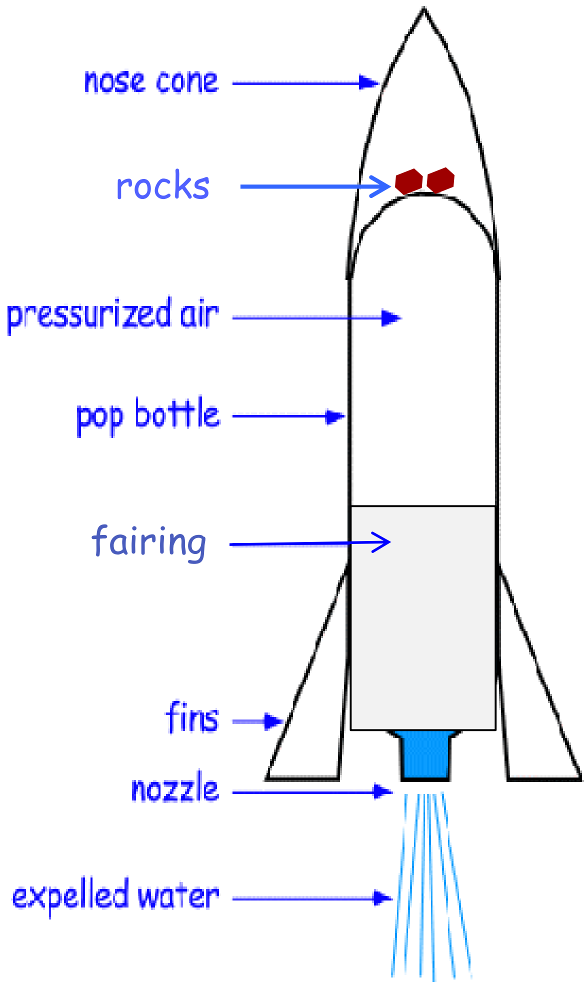
Building an Air/Water (Bottle) Rocket

- 2 liter Soda Bottle...Furnished
- Nose Cone & Aft Fairing...You Define and Shape
- Payload/Ballast...You Define the Amount
- Fins...You Choose the Shape, Size, and Location
- Assemble Rocket Components...You Assemble
- Load Propellant ...You Load
- Launch Rocket...You Launch
- Analyze Results (Fly Straight, High, and Far)...You Evaluate !

Rocket Engineering Tradeoffs

- A <u>positive</u> in one design element may become a <u>negative</u> in another.
- Designs must be balanced to achieve maximum project goals.
- For example:
  - Larger fins – lower CP (good), more drag (bad).
  - More payload/ballast – higher CG (good), more weight (bad).

Rocket Building Tasks and Tips



- Decide on fin shape and cut Fins
- Tape Ballast Rocks to top of Rocket (bottle bottom)
- Form & Attach Nose Cone
- If using Fairing – attach Fairing to bottom with Tape
- Use template to mark Fin locations – 3 or 4 fins
- Tape Fins to Rocket Assembly
- Check All Tape – Rocket Must Be Sturdy!

Build Your Rockets!!

Let’s launch our rockets!

Safety Comes First

- Real Rockets are very dangerous because they use explosives with a lot of stored energy!
- The Air/Water Rockets are also dangerous because of the stored energy.
- Teams will follow the explicit direction of Staff…NO EXCEPTIONS!
- Testing and Launch areas will be cleared of all personnel except those authorized..NO EXCEPTIONS!
- NO HORSING AROUND!!!

Failures in Engineering

- In engineering projects, failures may teach us even more than successes.
- Failure is just another step in learning and then finding success.
- There have been many rocket failures along the path to success.
- Failure is ok, if no one is hurt, and we learn from it!

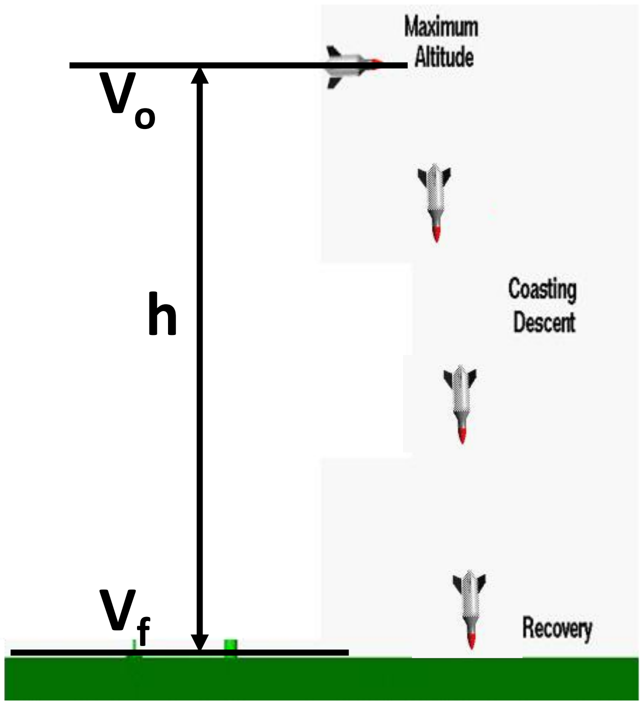
Rocket Failures – How We Learn!

How high did your rocket go?

Galileo's Experiment

Hammer & Feather – Apollo 15 on the Moon

How high did your rocket go?



$h = V_{avg} \cdot t \qquad V_f = g \cdot t$

now, $V_{avg} = (V_o + V_f)/2 = \frac{1}{2}V_f$

therefore, $V_{avg} = \frac{1}{2}\, g \cdot t$,

so, $h = (\frac{1}{2}\, g \cdot t) \cdot t$

or, $h = \frac{1}{2}\, g \cdot t^2$

g = 32ft/sec/sec, so: **$h = 16t^2$ ft.**

What did we learn today?

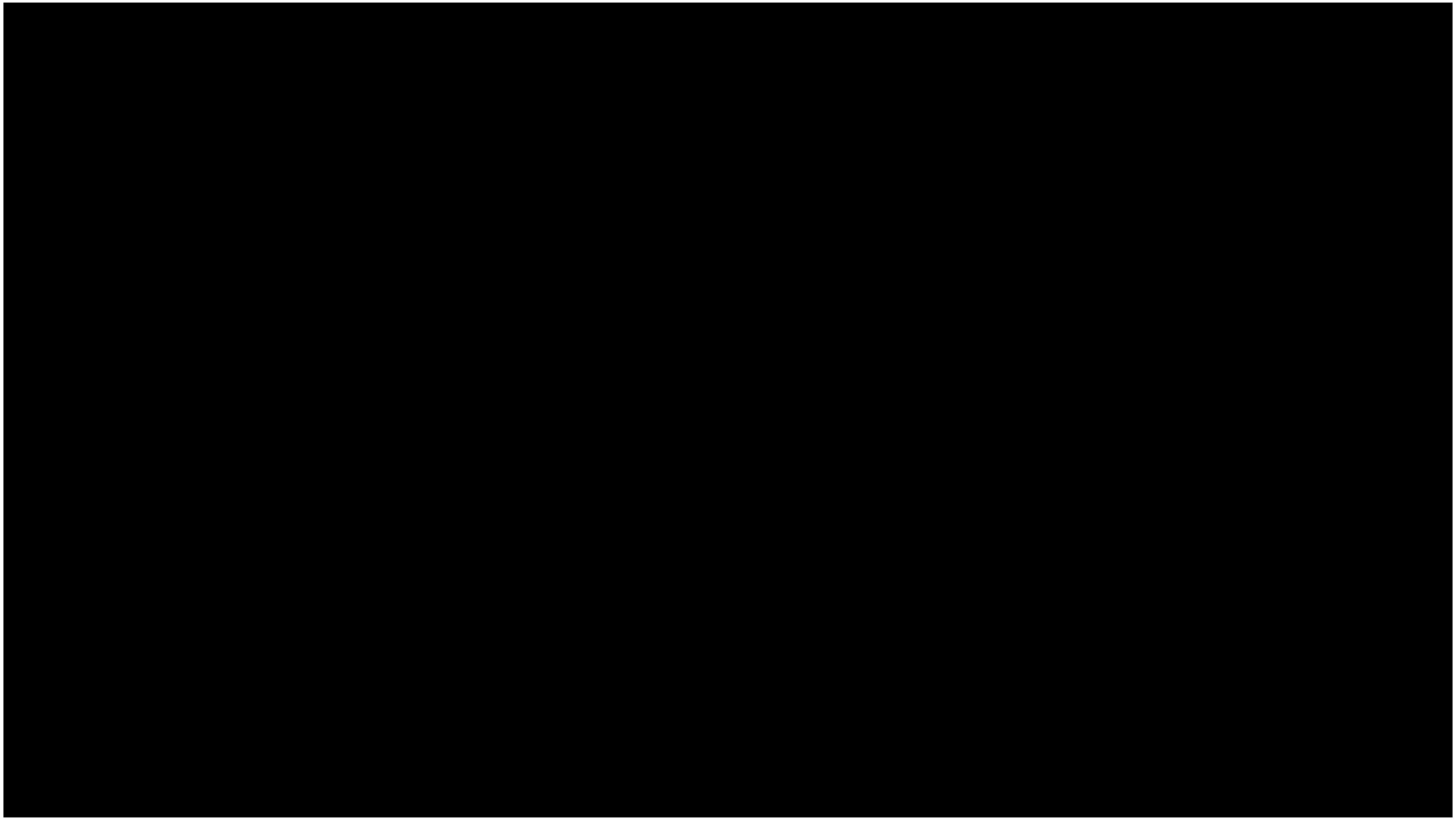
We explored the science, engineering, and technology of Rockets:

- Newton's Three Laws of Motion
- Rocket Stability
- Engineering Tradeoffs
- Failures & Lessons Learned
- Used math to find solutions
- Built very successful rockets!!!

Careers in STEM

- You must find your passion
- You can have a very <u>rewarding</u> career in science and engineering:
  - Financial, satisfaction, enjoyment
- Need learning and training (education)
- Maybe you will even be another Isaac Newton!

Careers in STEM



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, motion, and rockets!

Rocket Demos

- Hero's Engine - 3rd law
- Cup on Table - 1st law
- Large and Small Toy Cars – 2nd law
- Pepsi Bottle – Center of Gravity
- Forks – Center of Gravity
- Weathervane and Fan – Center of Pressure
- Broom and Foam Ring – Center gravity
- Bicycle Wheel - Stability
- Orange Gyroscope in Gimbal Mnt – Stability
- Football – Spin Stability
- 2 Tubes: straight/tilted fins – Spin Stability
- Ping pong and Golf balls – Galileo