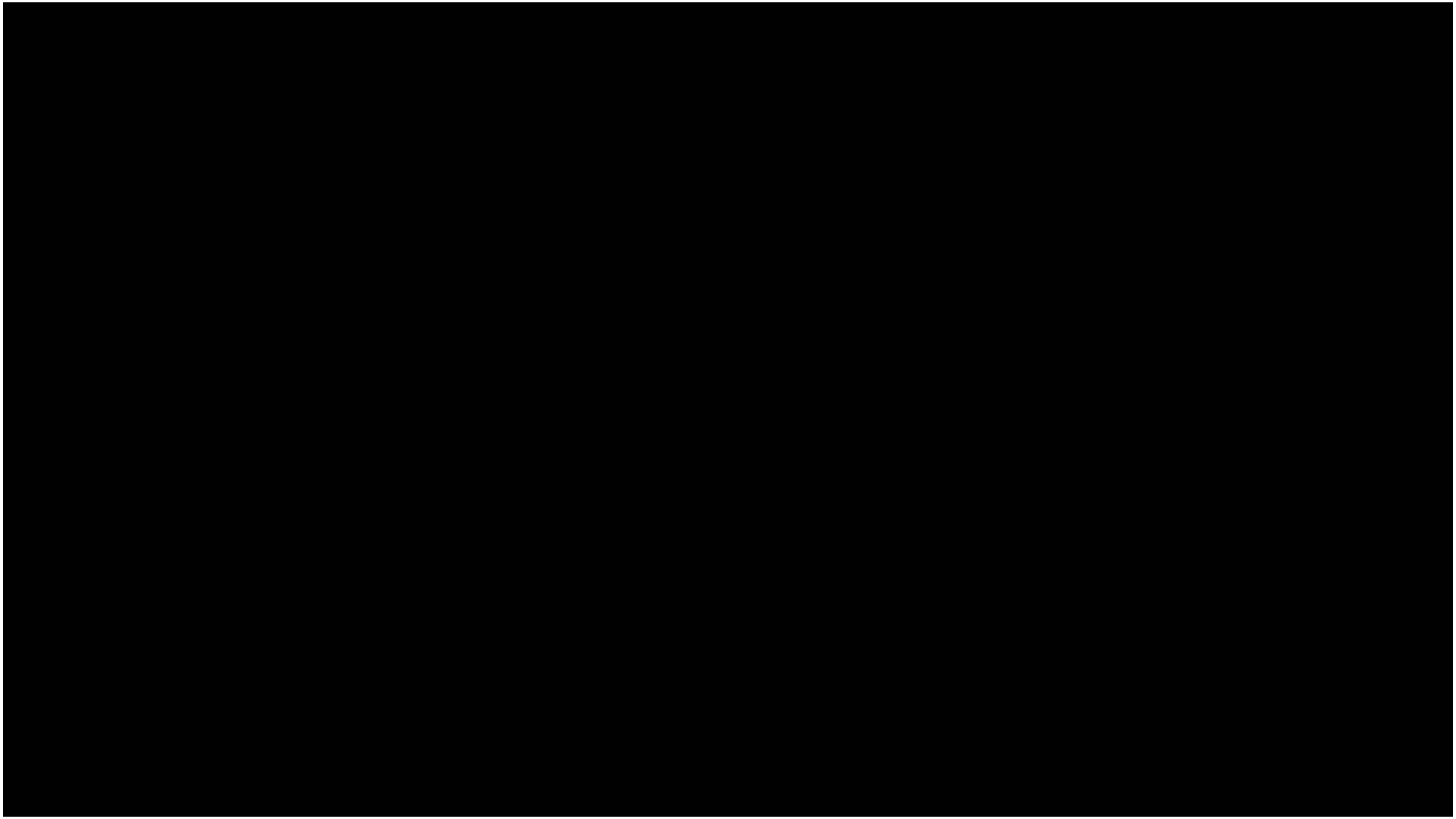
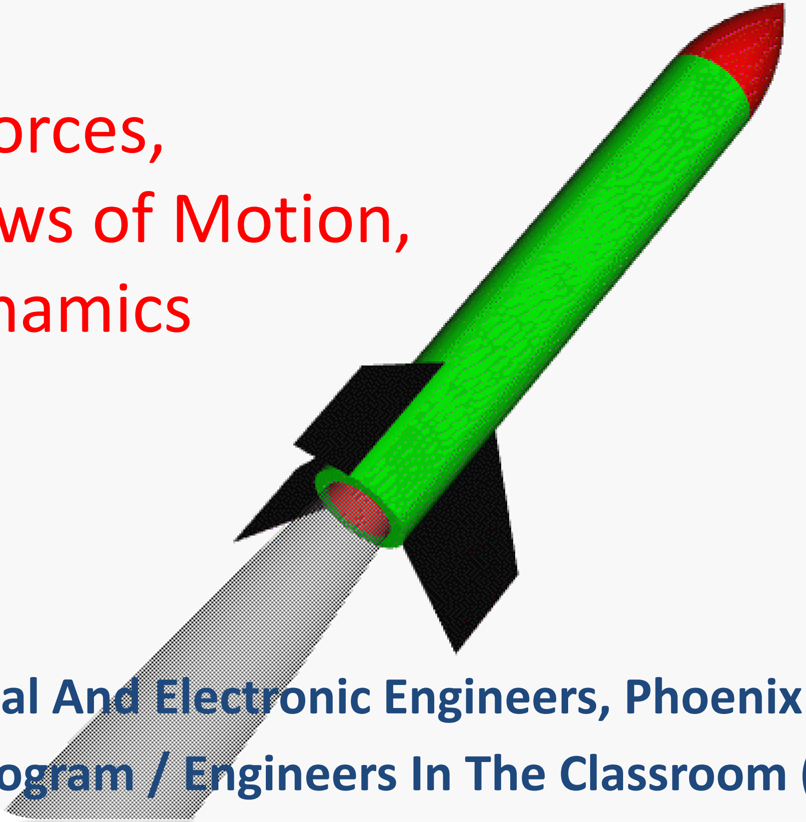
Space Travel



<u>Rockets</u>

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!

Our Objectives

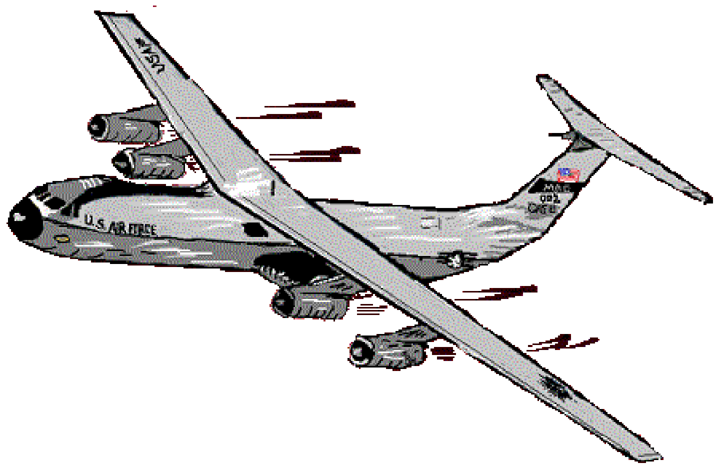
- Learn the science, engineering, and technology of Rockets!
- Experience the engineering process and design, build, test, and launch a model rocket!
- Learn to work together as a team!
- Have fun!

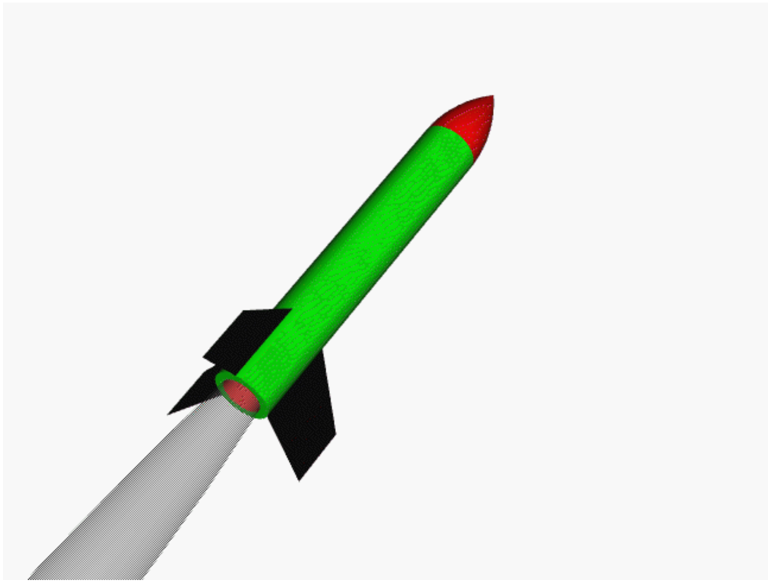
A Real Rocket Launch – With Astronauts Onboard

A Real Airplane Takeoff– With People Onboard

Rockets

- What is the difference between a rocket and an airplane?





Wings **Fins**

Air **Oxygen**

Rocket Science

- **Galileo** (1564-1642):
  - Experimental Physicist, Father of observational astronomy
- **Sir Isaac Newton** (1643-1727):
  - Theoretical Physicist and Mathematician
- **Robert Goddard** (1882-1945):
  - Father of modern rocketry
  - First liquid fuel rocket flew March 16, 1926

Rocket Science

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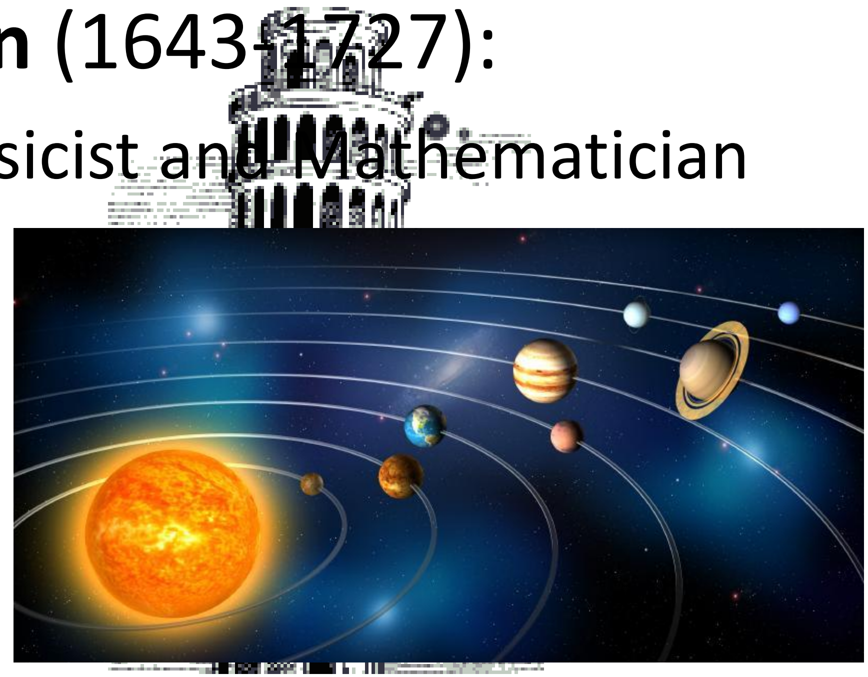

Sir Isaac Newton

Rocket Science

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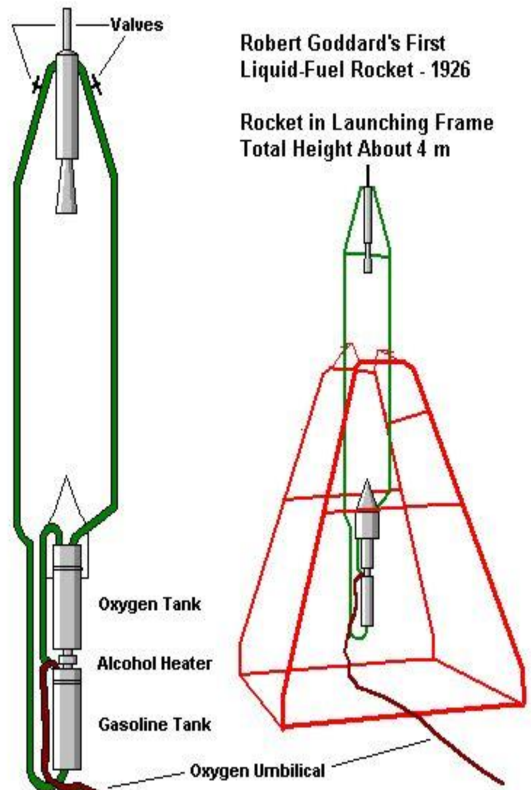


History of Rockets

- Hero's engine: 60 BC

Hero Engine

Chinese Fireworks and Fire Arrows

For many centuries rockets were primarily used for warfare.

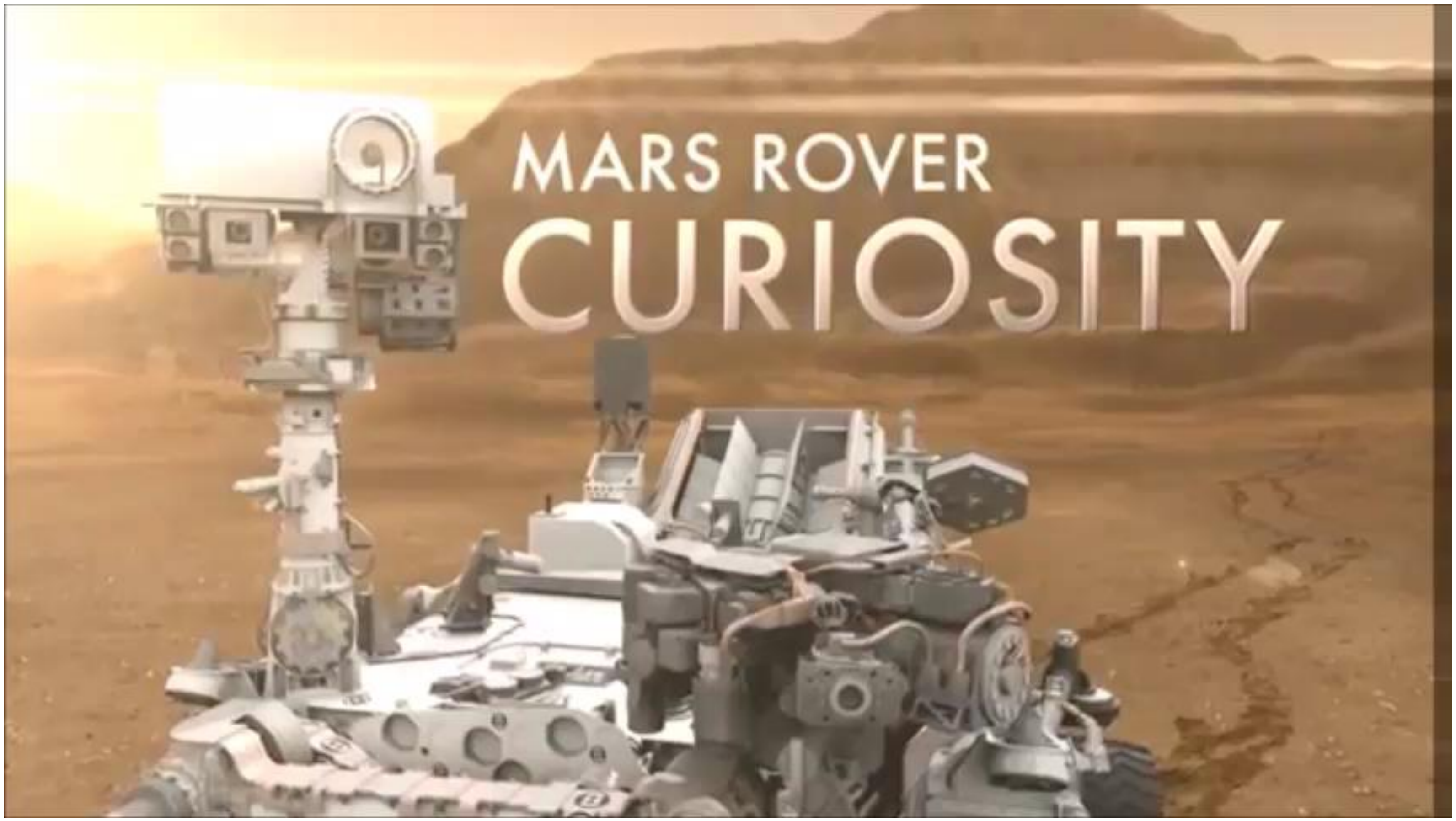
German V-2 Rocket Launch

Rocket Uses

- For many centuries rockets were primarily used for warfare.
- Currently, rockets still used for warfare but also for defense and peaceful purposes:
  - Launch Satellites for GPS, Communication, and Weather
  - Launch and maintain International Space Station
  - Space Exploration to other planets

Rocket Uses

Exploration to other planets like Mars Rover



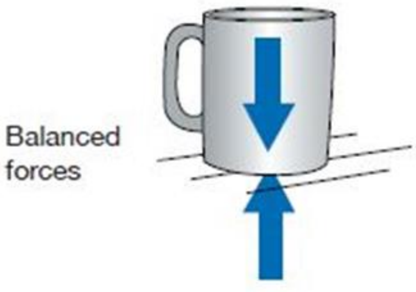
Sir Isaac Newton
&
The Laws of motion

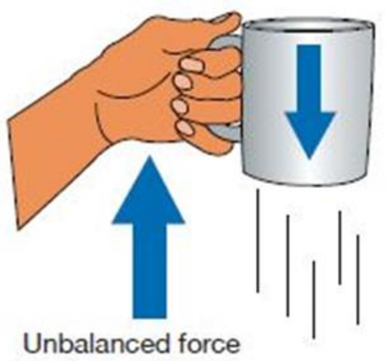
- English scientist in physics, mathematics, and astronomy, 1643-1727.
- One of the most influential people in human history.

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

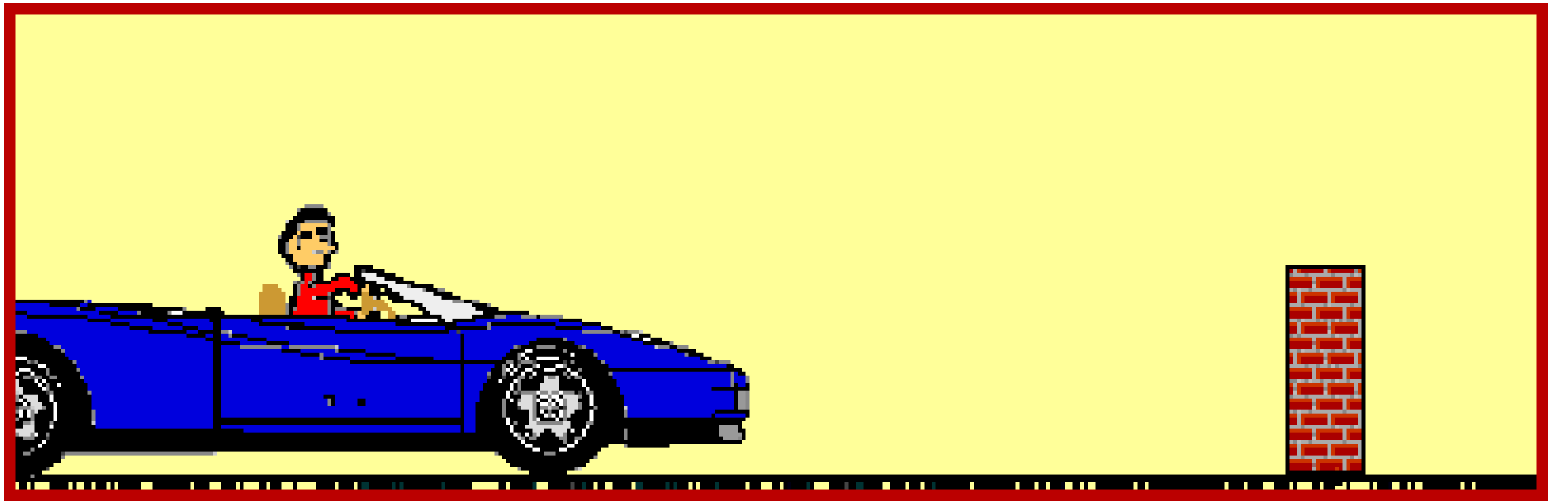
Newton's First Law of Motion

- **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:



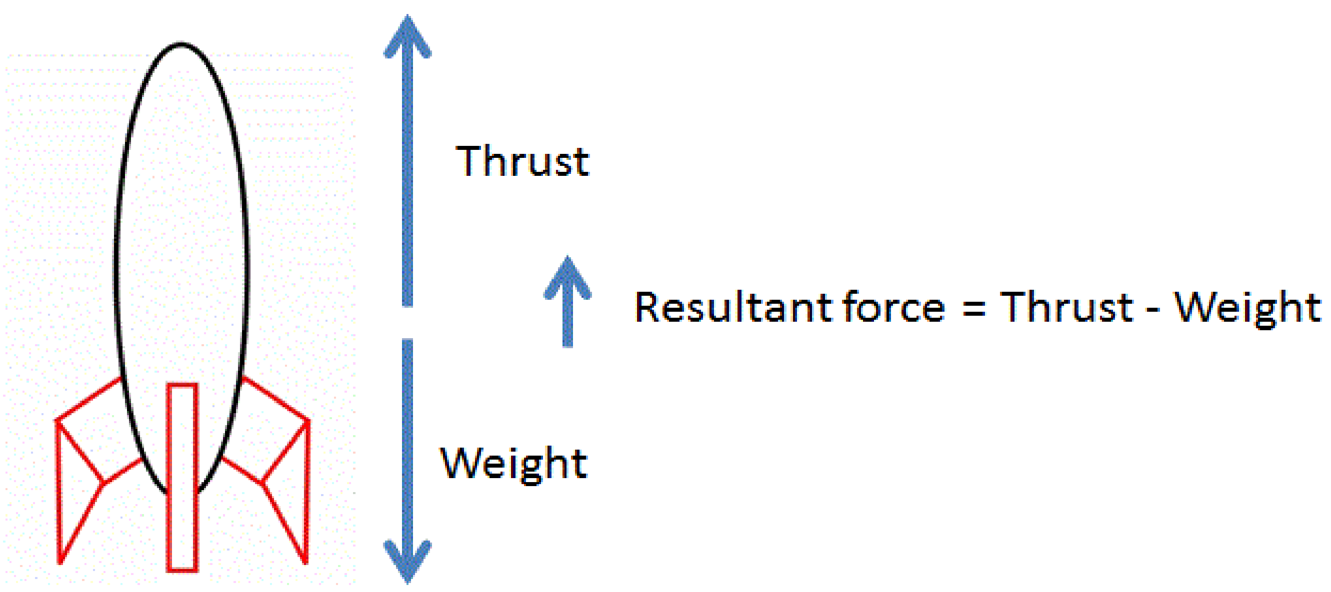


Newton’s First Law - Example



Newton's 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



Newton's Second Law of Motion

<u>Force</u> equals <u>mass</u> times <u>acceleration</u>: $F = m * a$

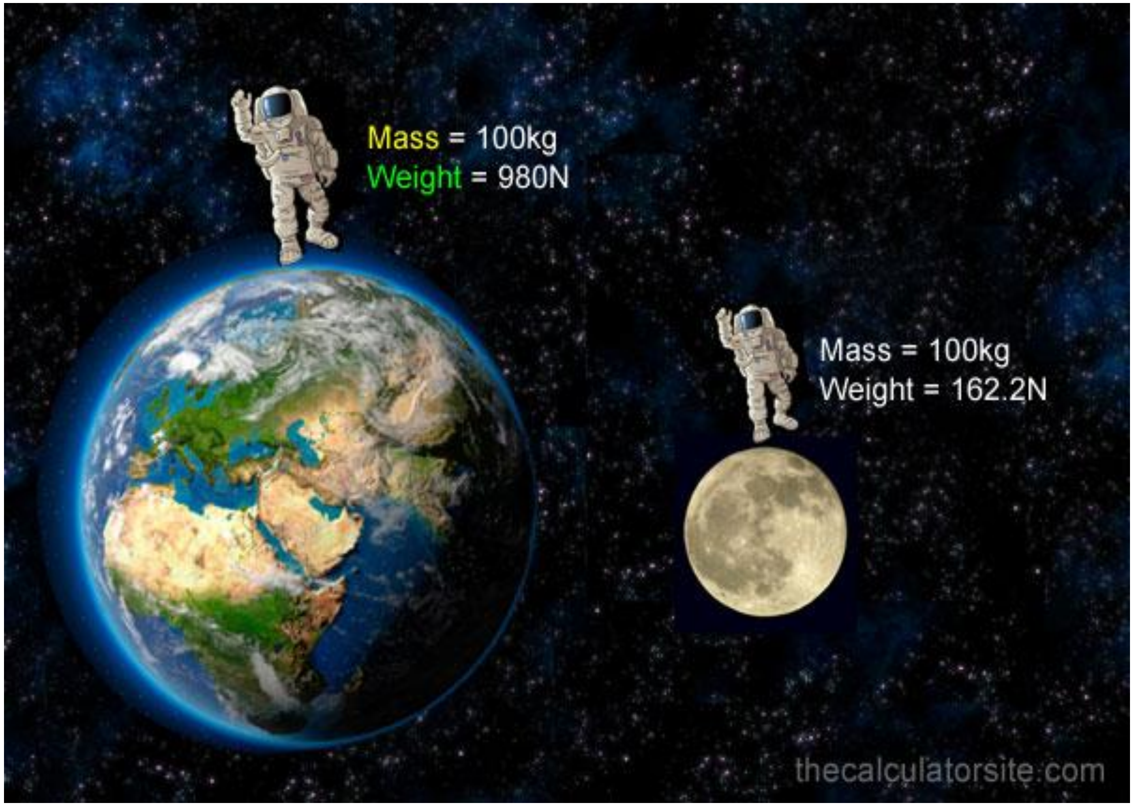
- <u>Force</u> is a push or pull exerted on an object.
- <u>Mass</u> is the amount of matter in an object.

- *<u>Mass</u> is not weight, mass is the same no matter where an object is!*
- <u>Acceleration</u> is a **<u>change</u>** in motion, i.e. increasing speed or changing direction

Mass vs. Weight

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

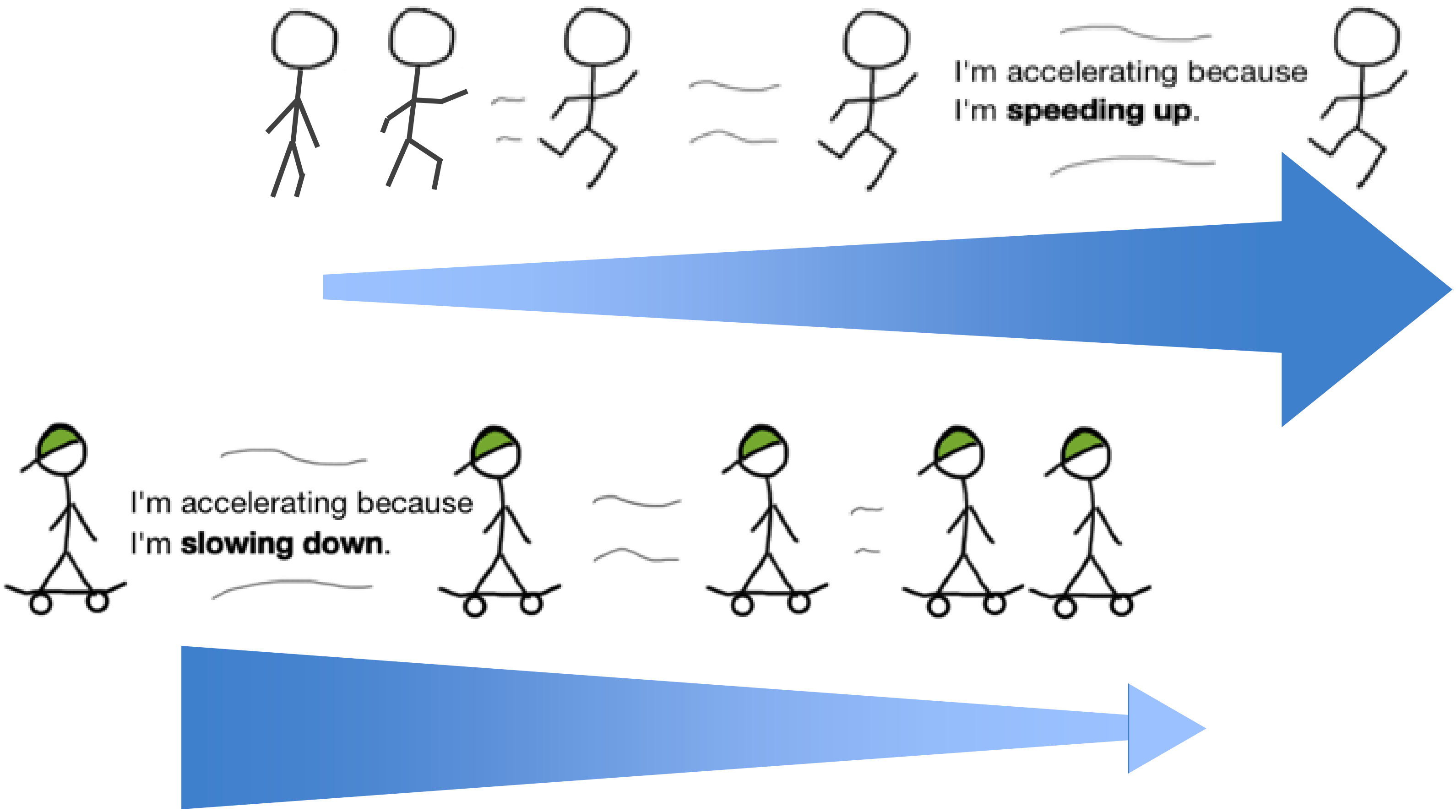
- **Weight is the gravity force, W=m * g**
- At sea level: acceleration due to gravity (**g**) is 9.807 meters/second/second – a constant!
- Weight (in Newtons) = mass * 9.807
- Weight varies depending on the gravity force, the mass of an object is always the same!



Official Kilogram

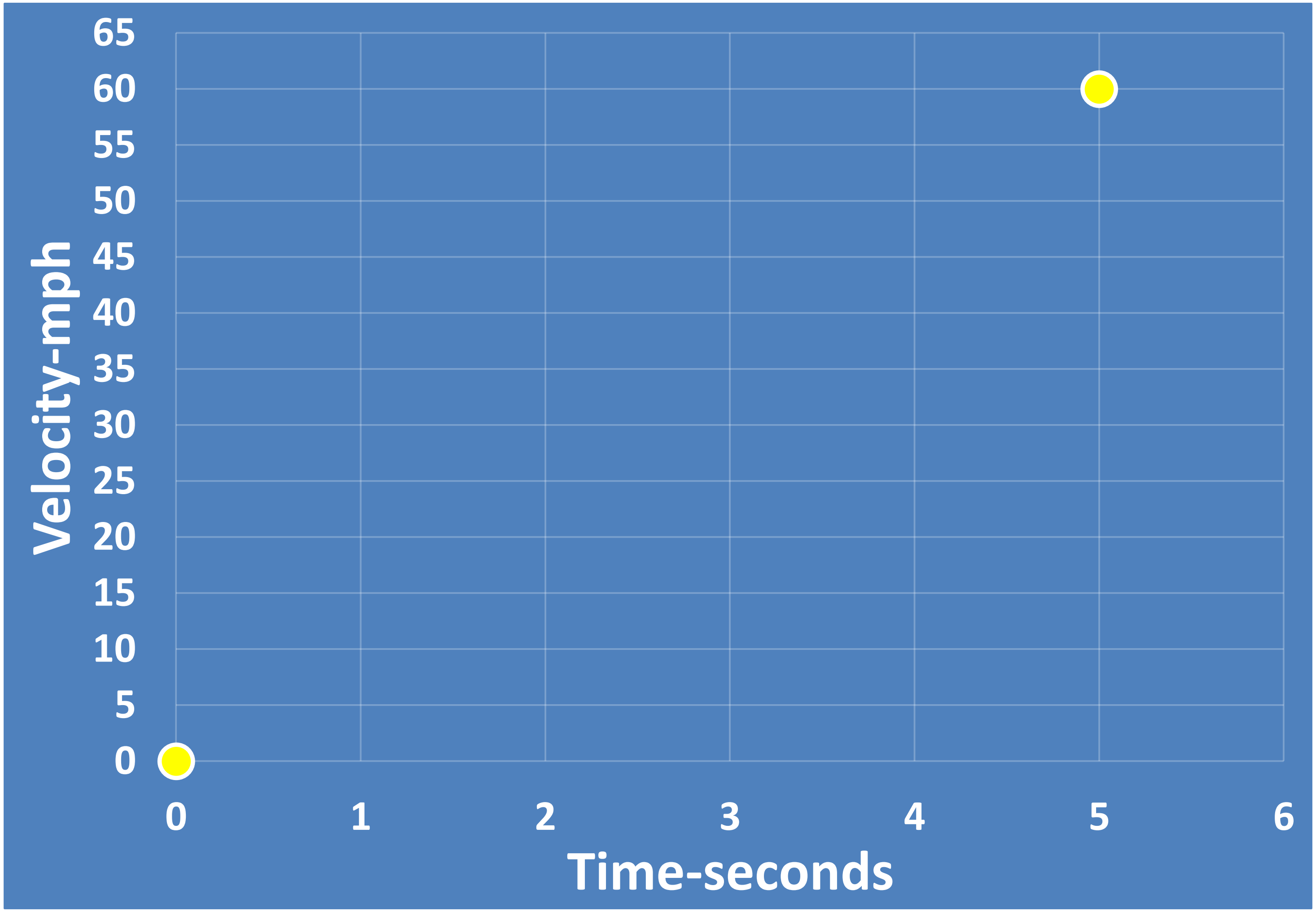
Acceleration

Acceleration is the <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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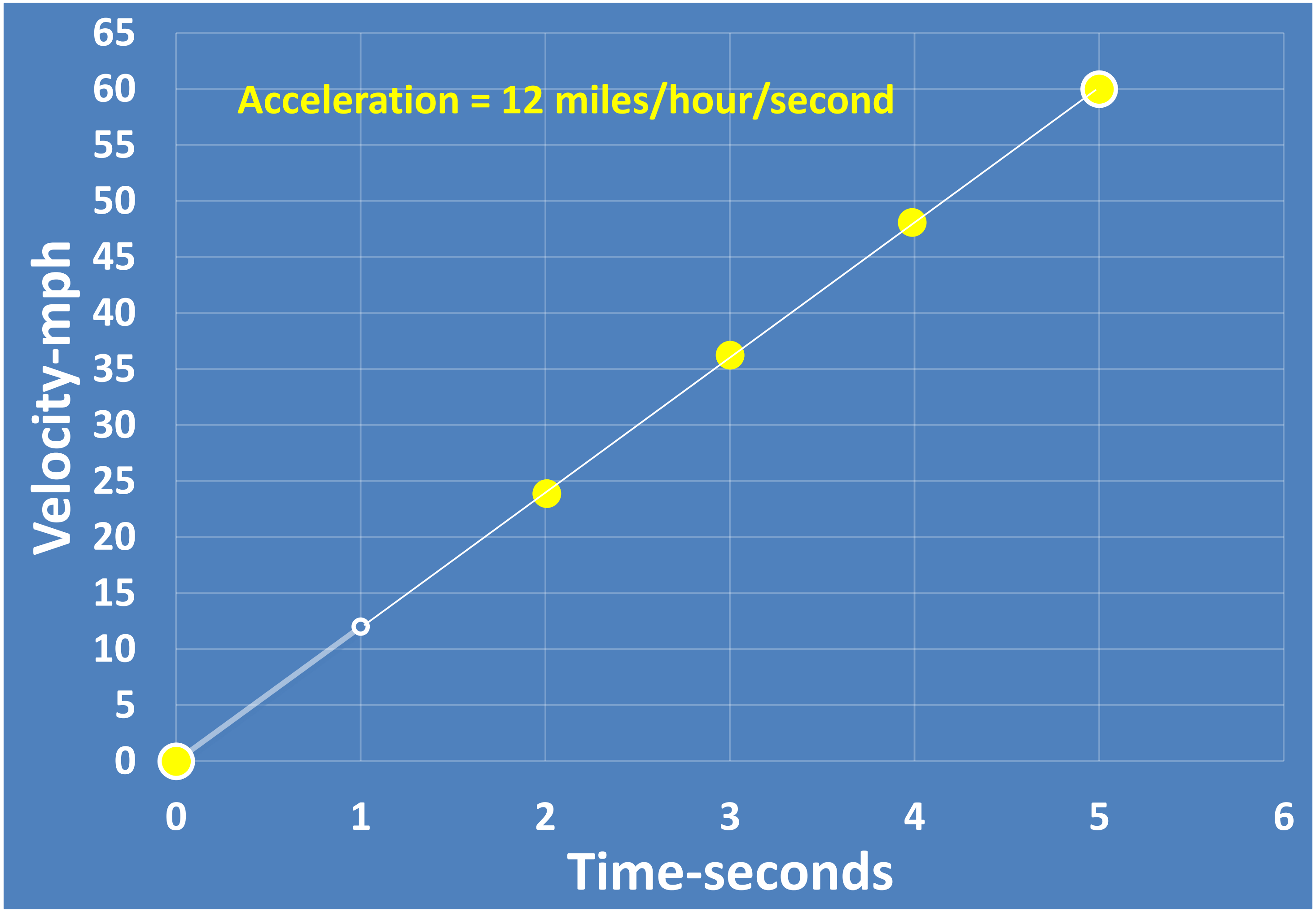


The Force Equation

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

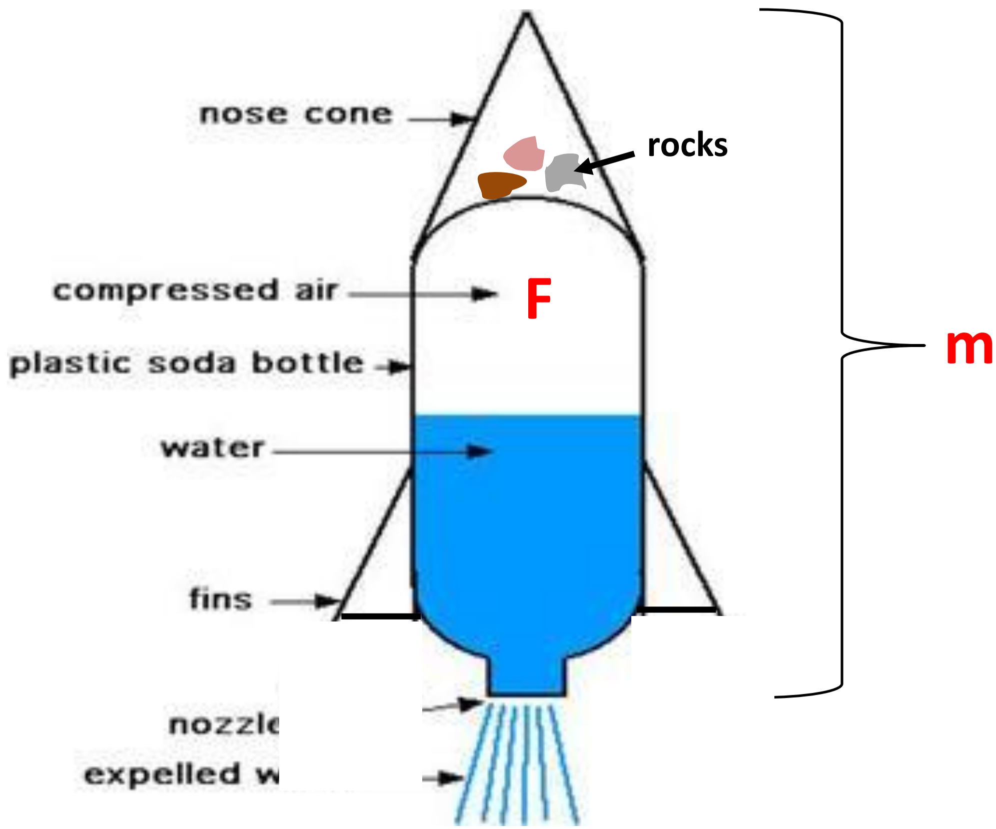
  or

  acceleration = Force/mass

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

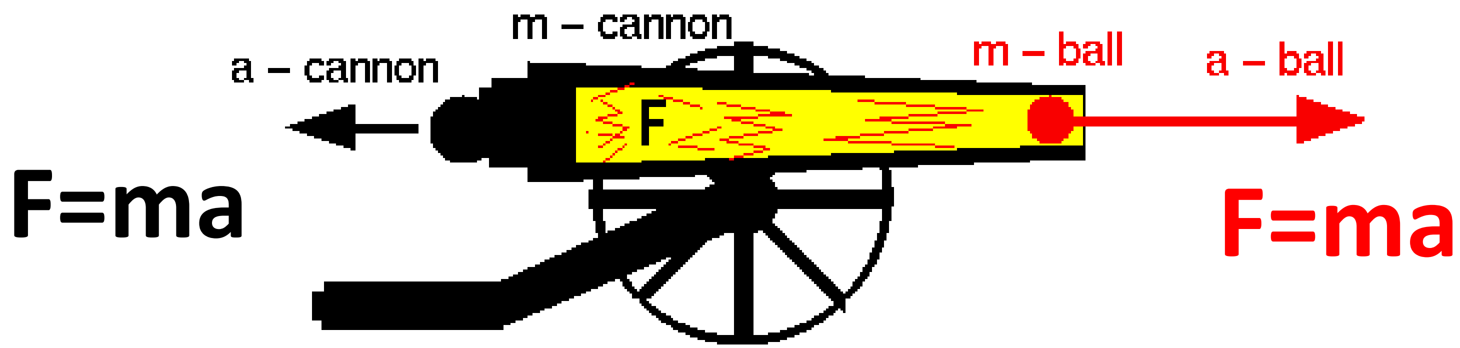
- **Acceleration of an object is:**
  - **directly proportional to the net force applied and**
  - **inversely proportional to its mass.**

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



Newton's Third Law

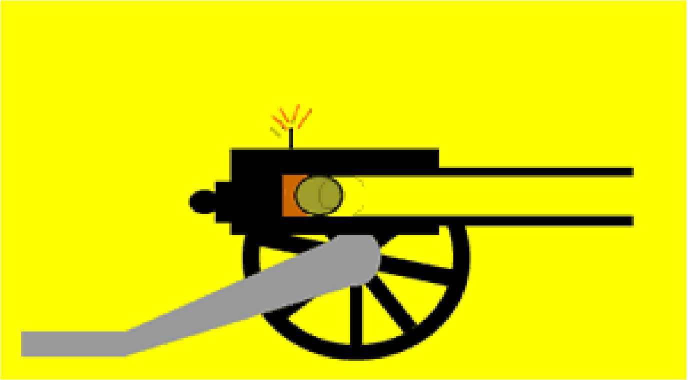
For every action there is an equal and opposite reaction



- 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 action

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

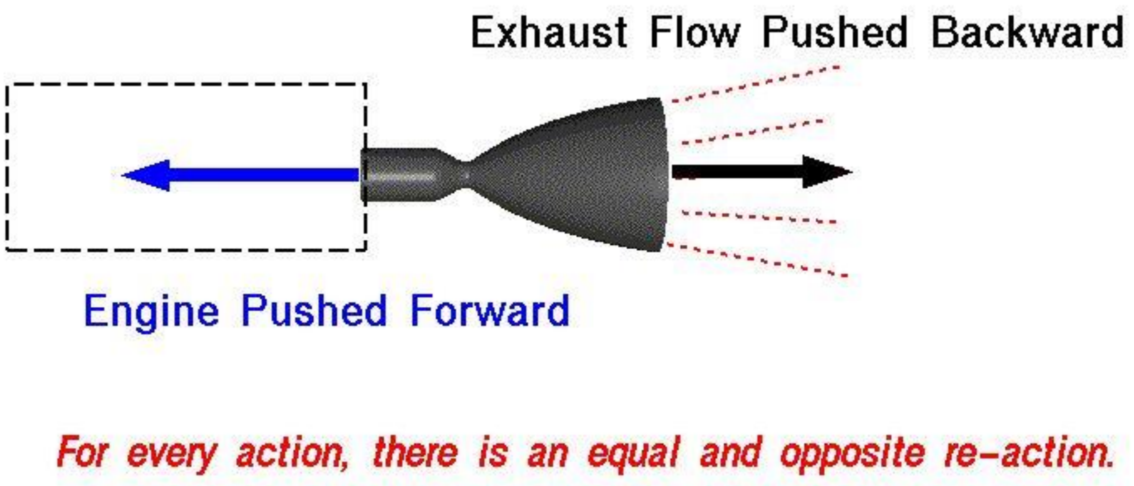
- Actions and reactions happen simultaneously



Newton's 3rd Law Applied to Rockets

- **The chemical rocket engine force =**
  the mass of the gas produced during the fuel burn times the acceleration of that gas out of the rocket nozzle.

- The more propellant consumed at any moment and the greater the acceleration of that gas out of the nozzle, the greater the engine force or thrust.



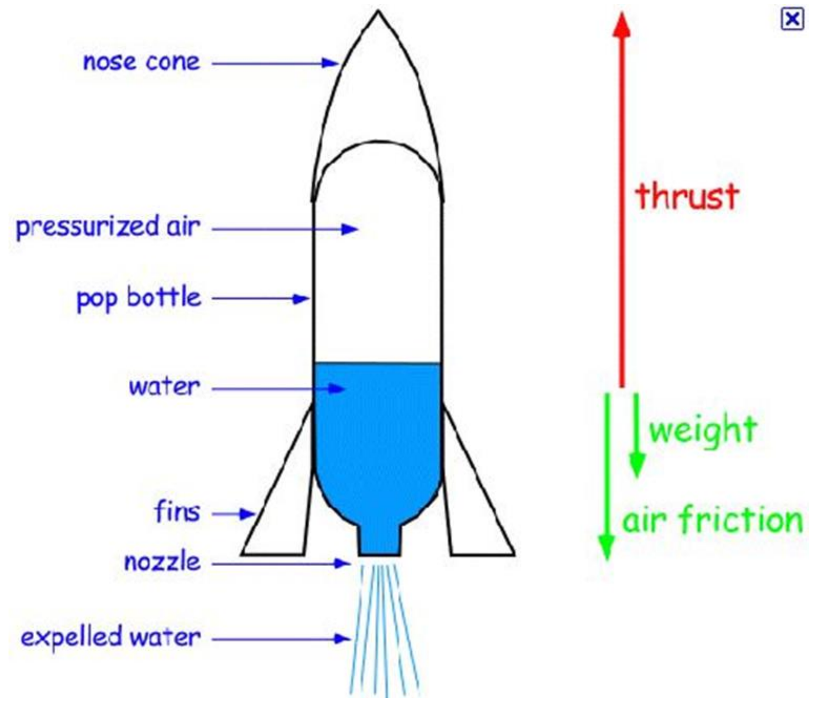
The Three Newton Laws

- All three laws work together for rockets:
  - **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.

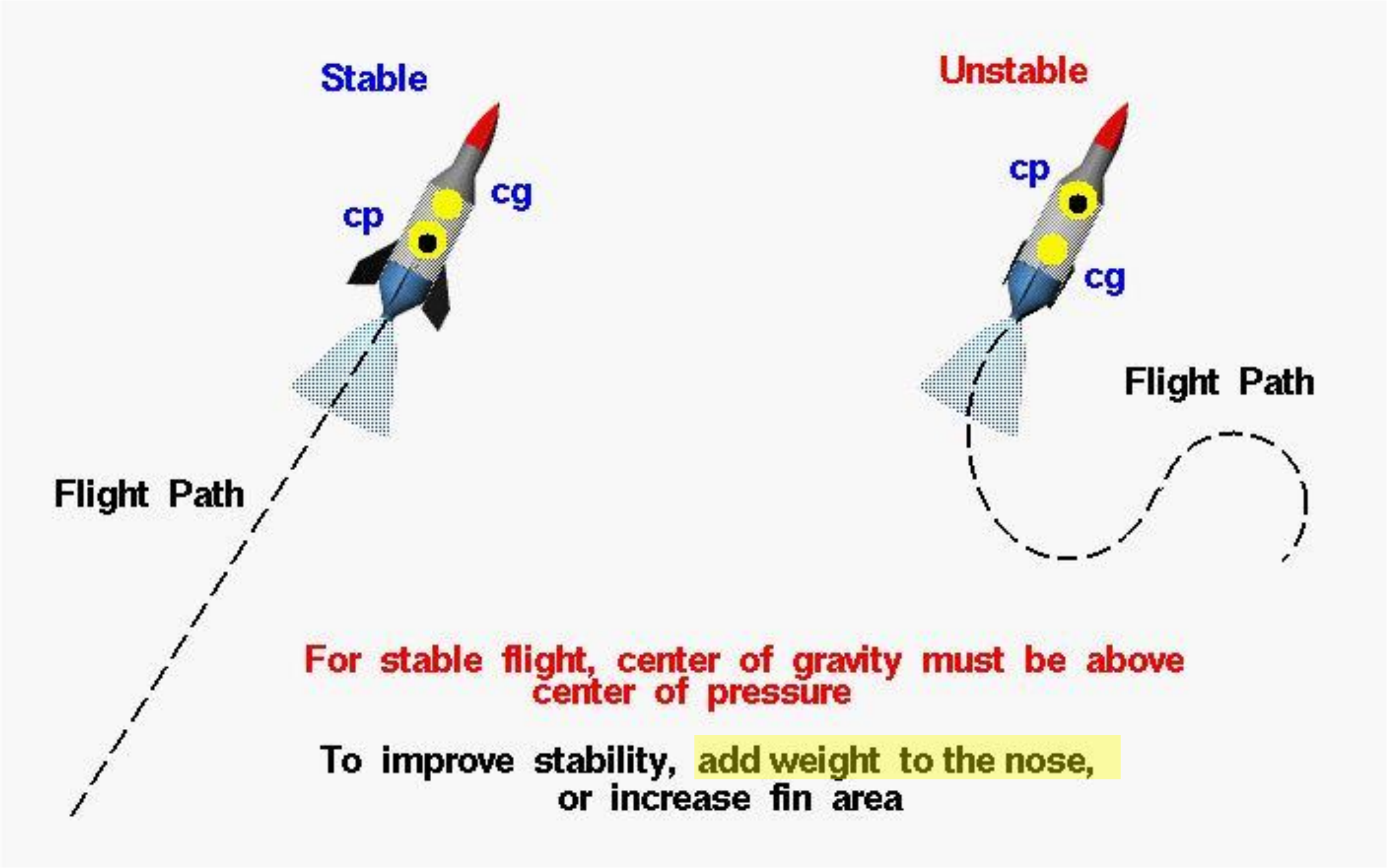
Rocket weight vs. engine thrust

- 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.

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

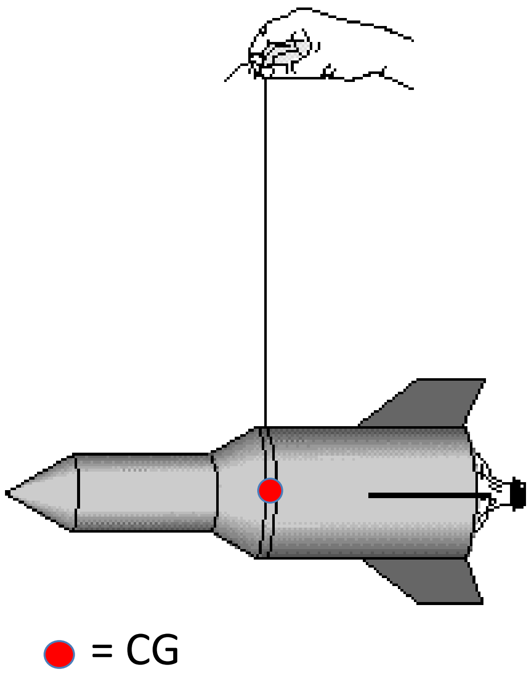


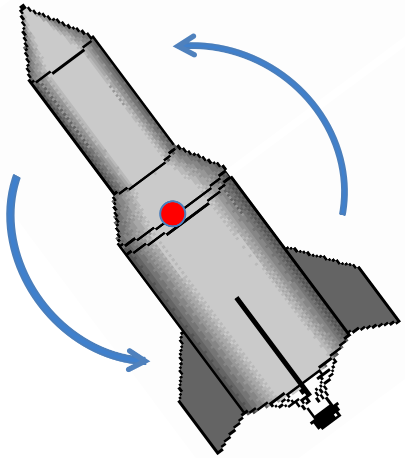
Rocket Stability



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 object's weight balances at the CG point

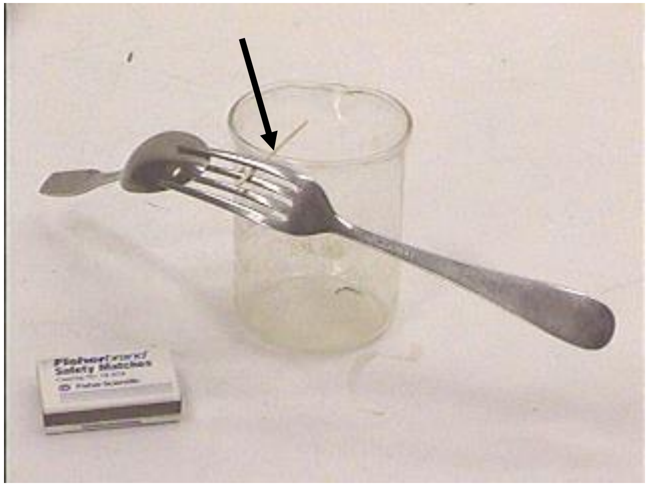




- The CG is the point about which an object will rotate
- For a rocket, end-over-end rotation about the CG is to be avoided for a safe, efficient, tumble-free flight

Center of Gravity, (Center of Mass)

All objects have a Center of Gravity

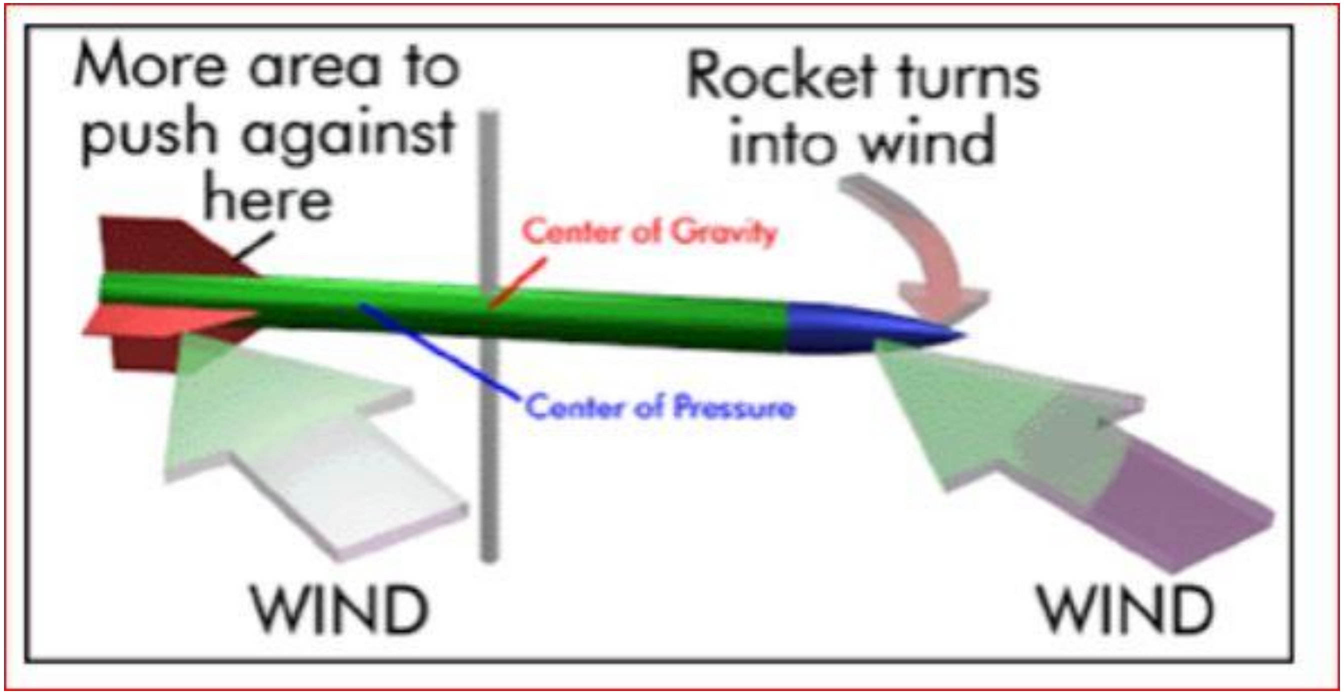


Where is the center of gravity in each of these examples?

Aerodynamic Forces

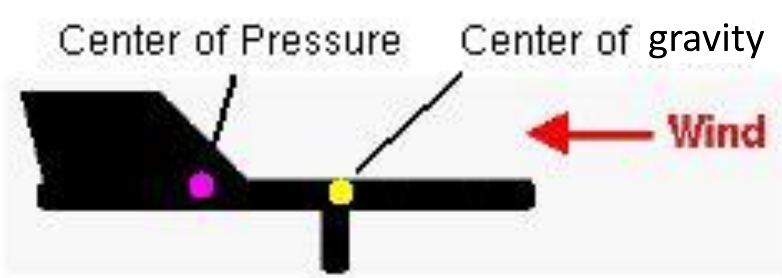
- Aerodynamic forces act through the "Center of Pressure" of the rocket.

Center of Pressure

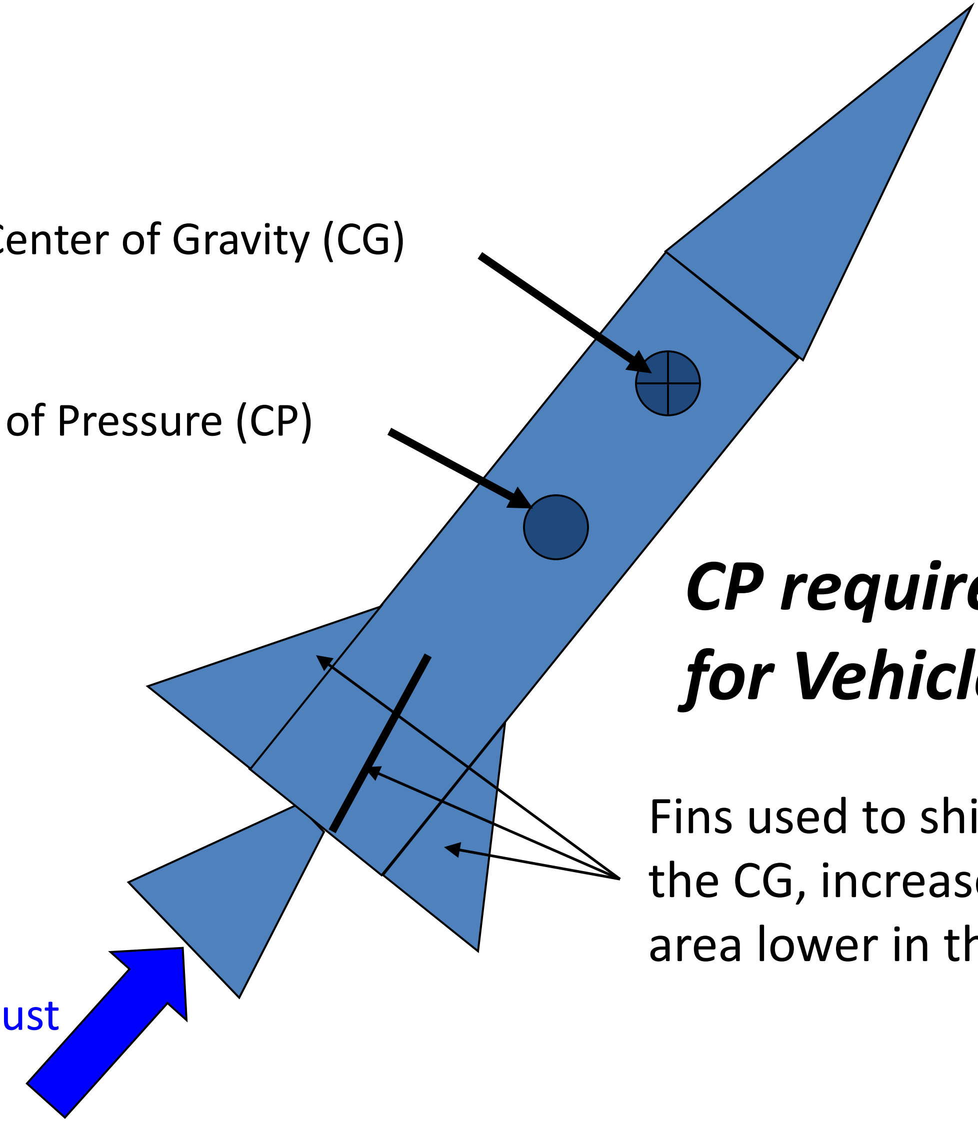


Rocket Stability

- 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.**



Unguided Vehicle Stability

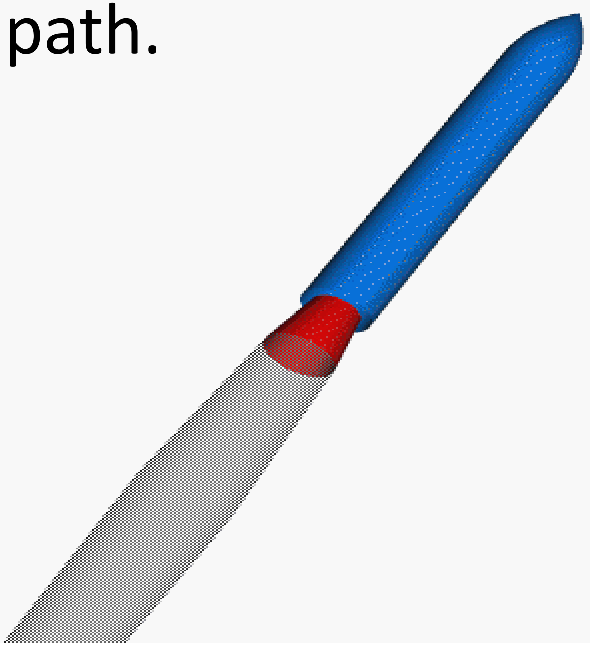


CP required to be below CG for Vehicle Stability!

Rocket Control

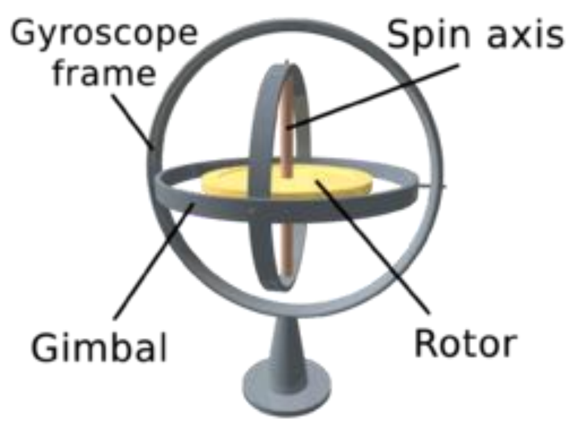
Gimbal Mount Exhaust

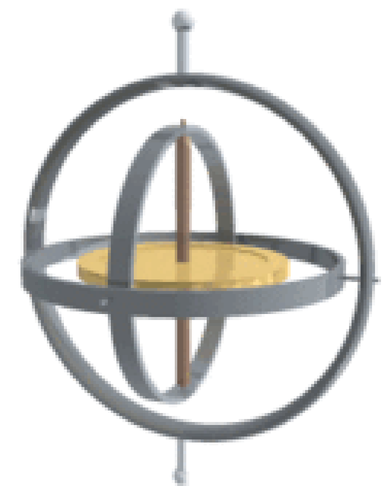
- In real rockets, complex guidance systems, **gyroscopes**, and swivel mount nozzles guide the rocket on its path.



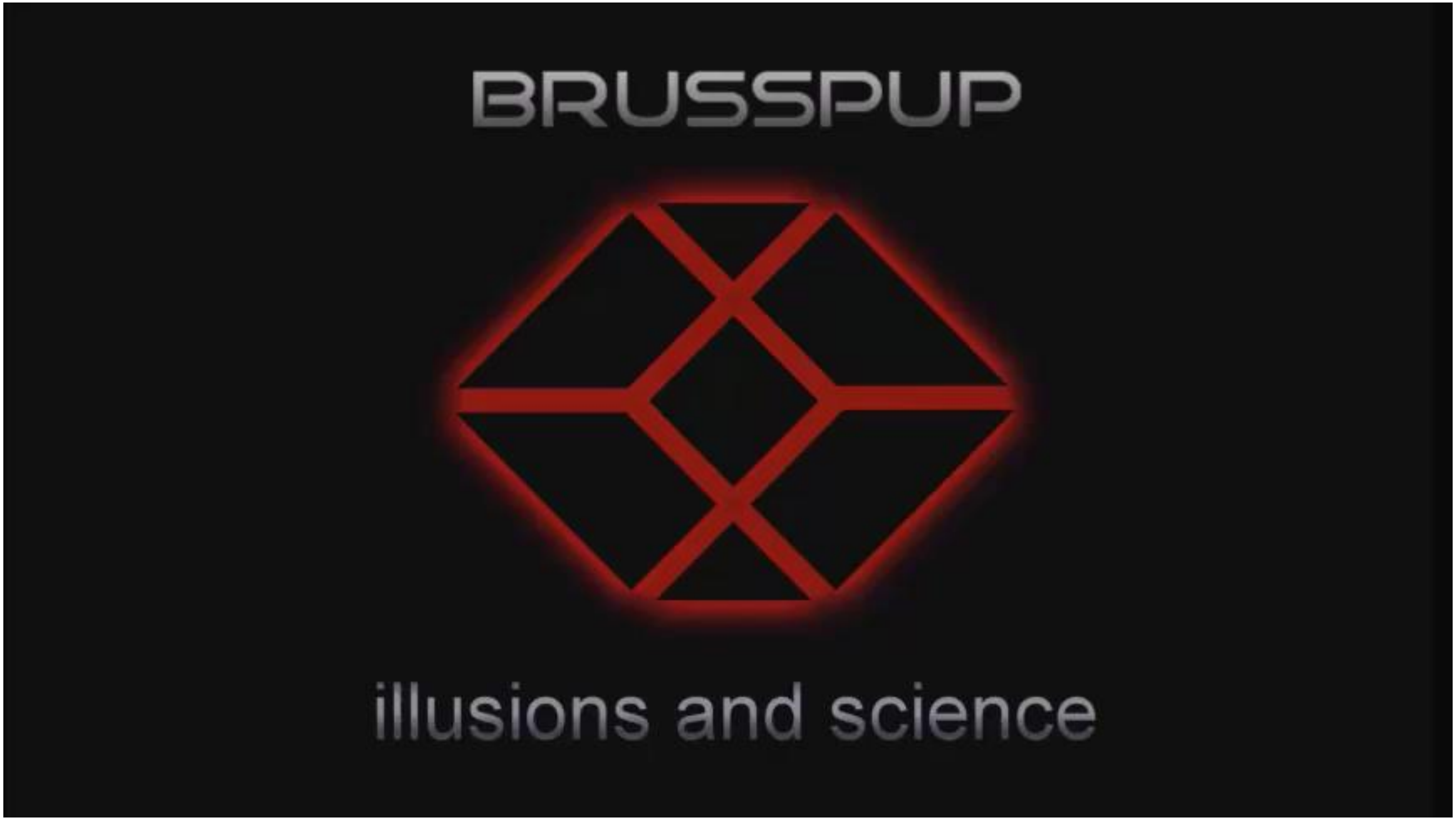
Gyroscope

- 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 Demos

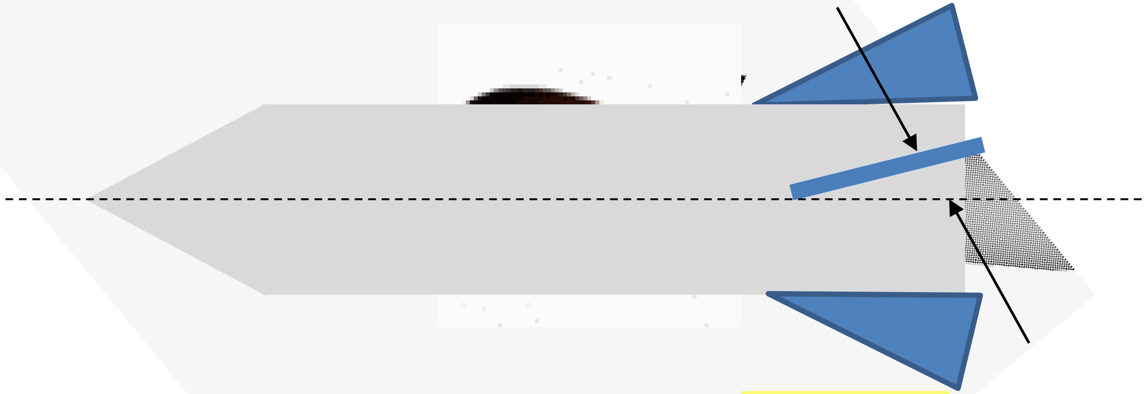


Rifling

- 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

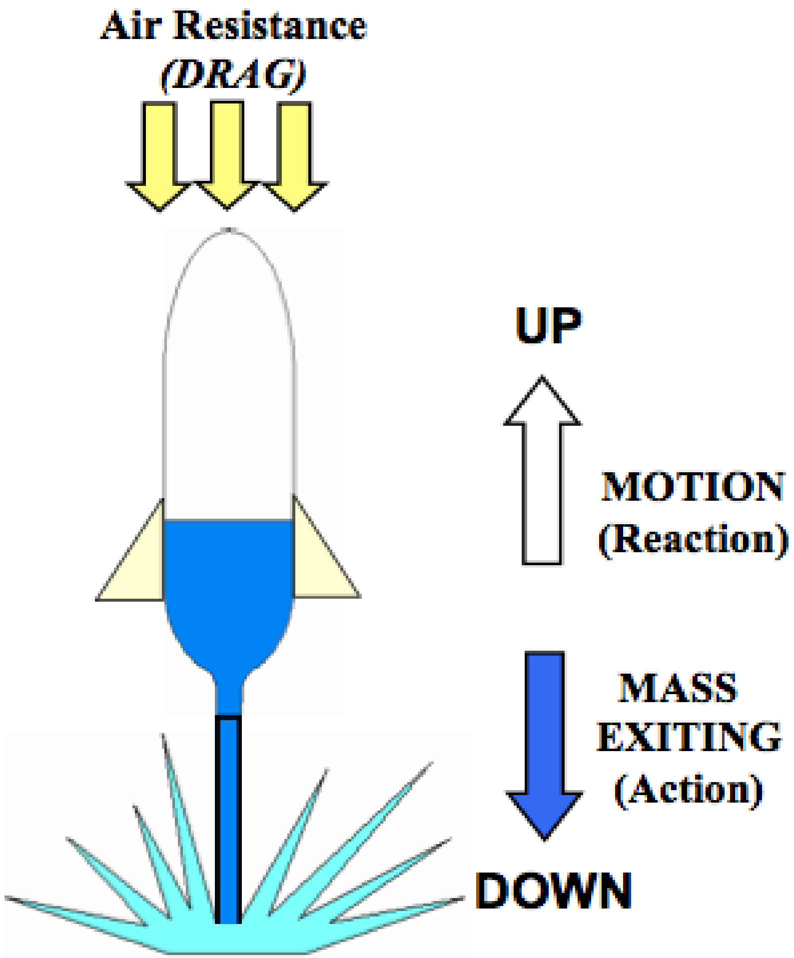
- For unguided rockets and projectiles, spinning them gives them "gyroscopic stiffness".



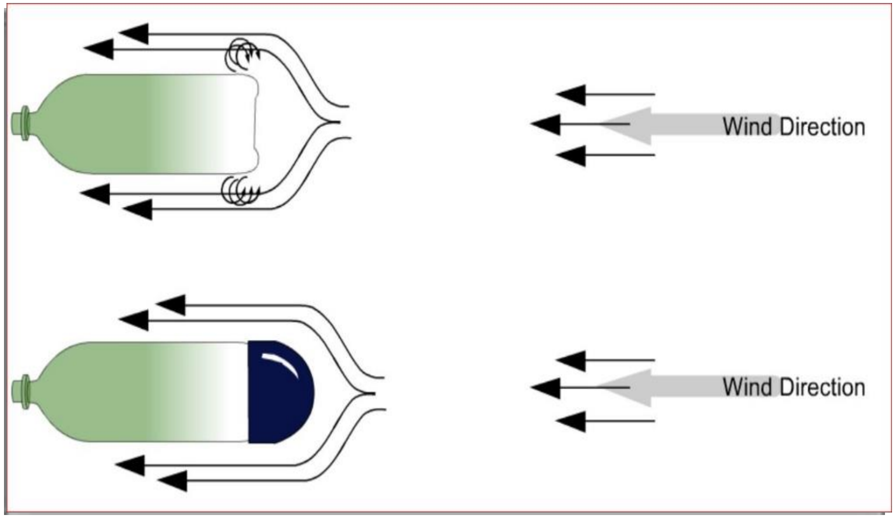
- For our rockets we use **tilted** fins to spin the rocket.
- Like the football, the rocket resists changes in its direction.

Aerodynamic Drag

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



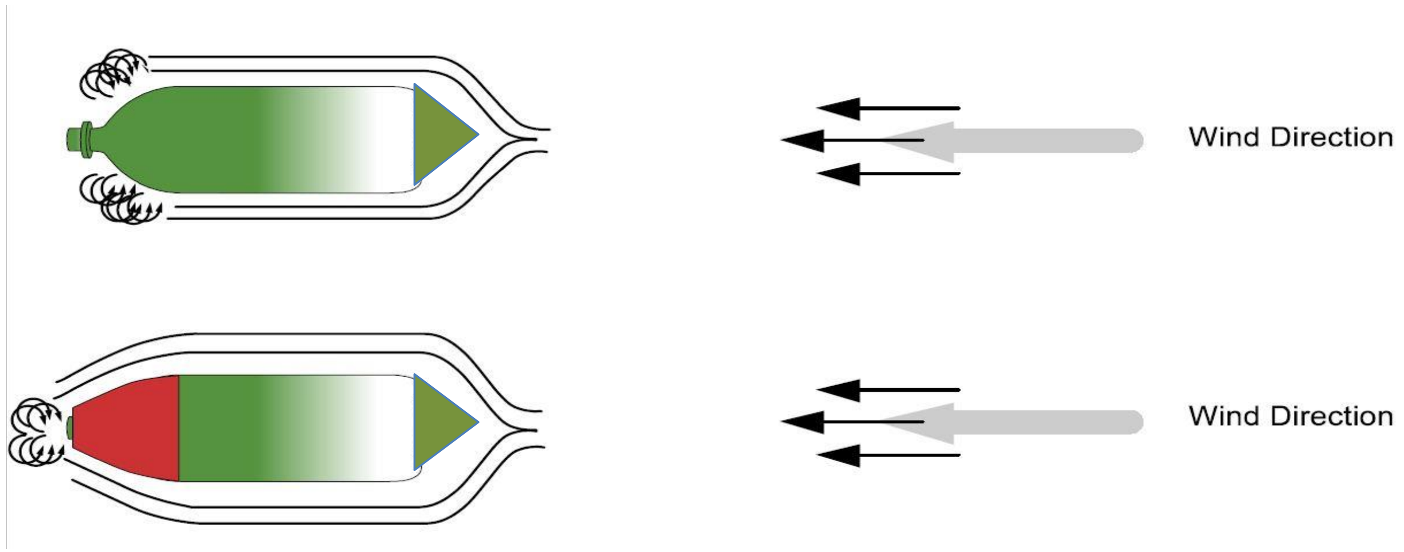
Rocket Aerodynamics



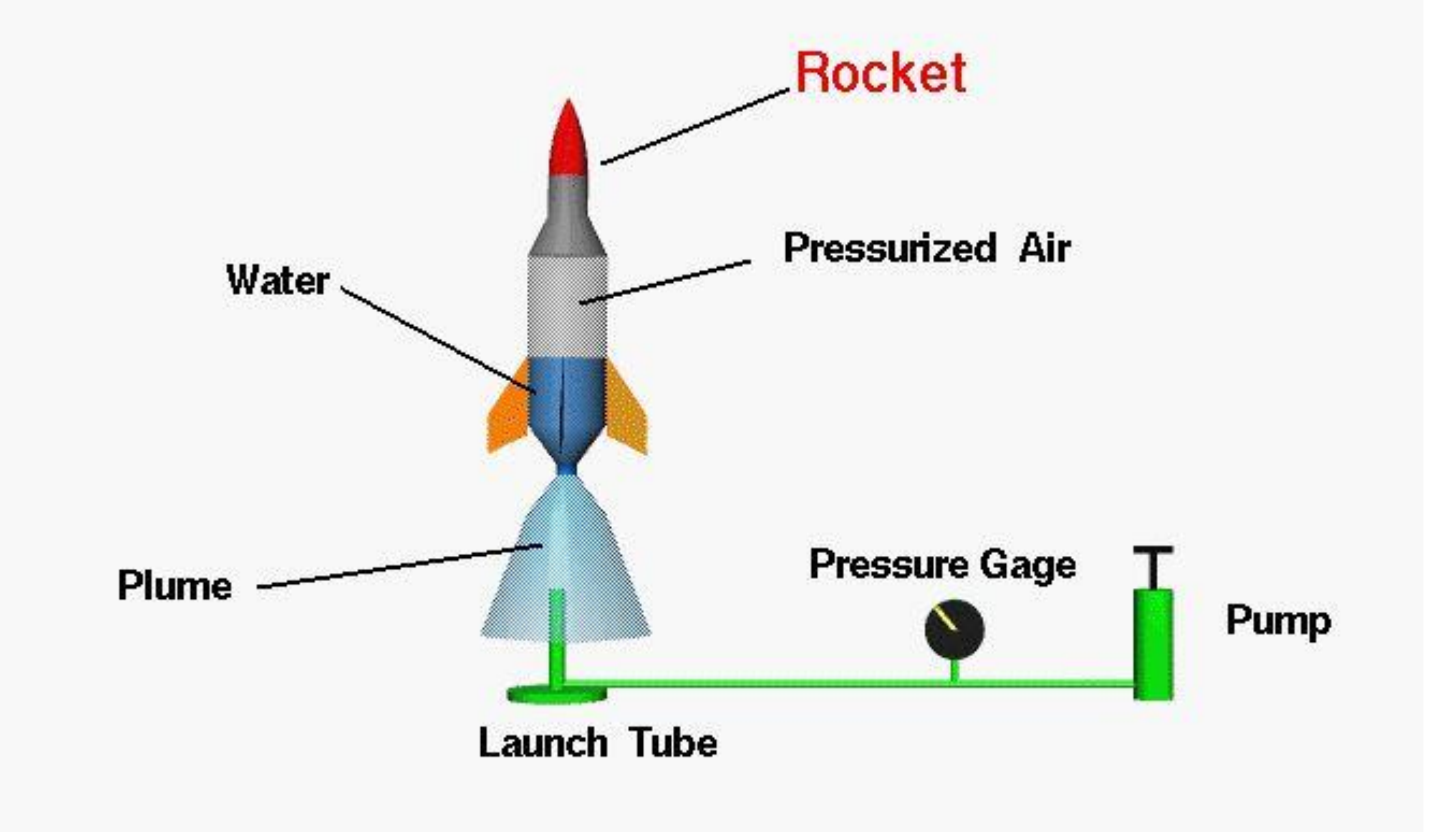
- The shape of an object greatly affects its air resistance (drag)
- A nose cone is very effective at reducing air resistance

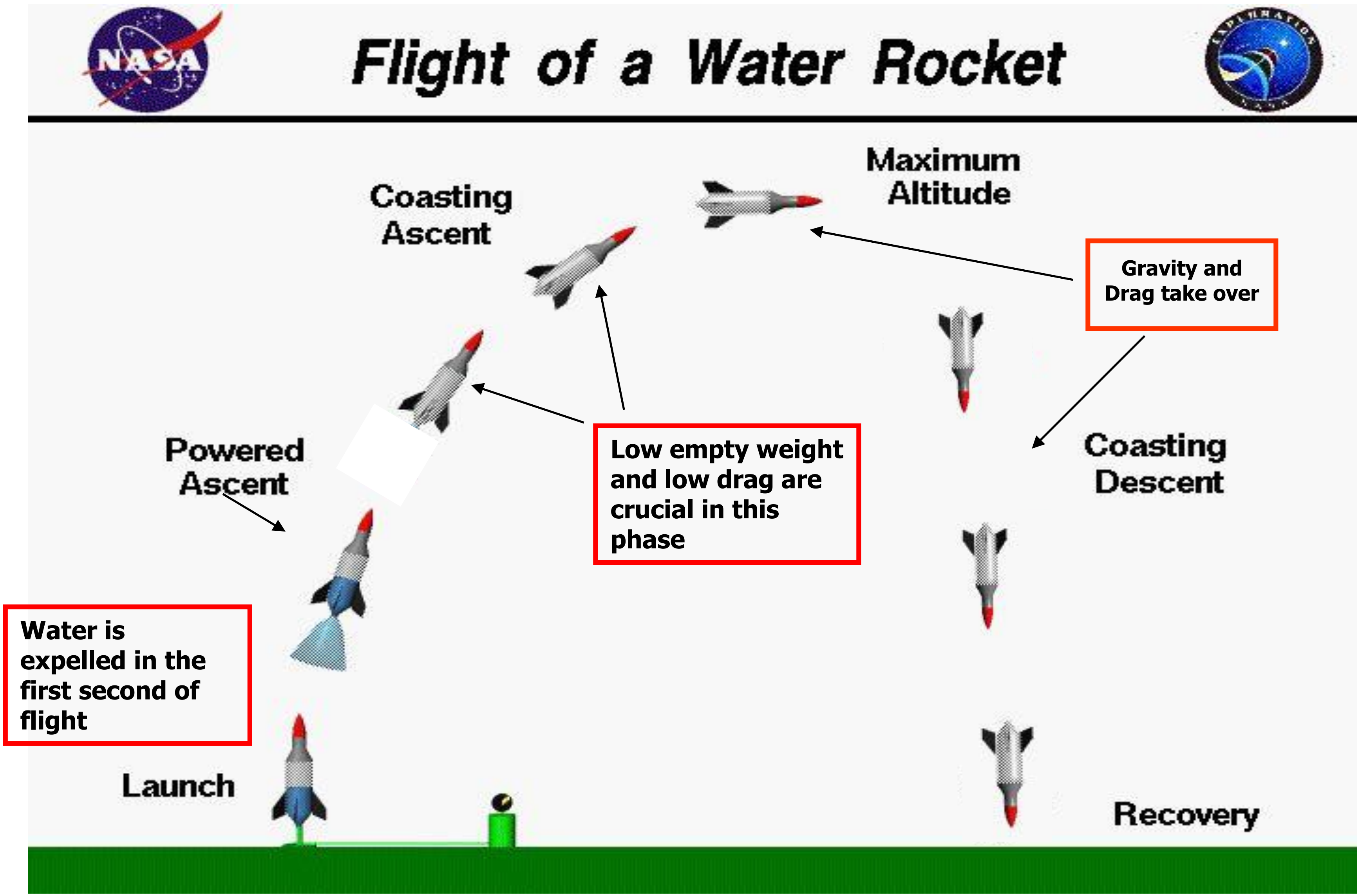
For our bottle rocket, a paper nose cone like this is simple and effective

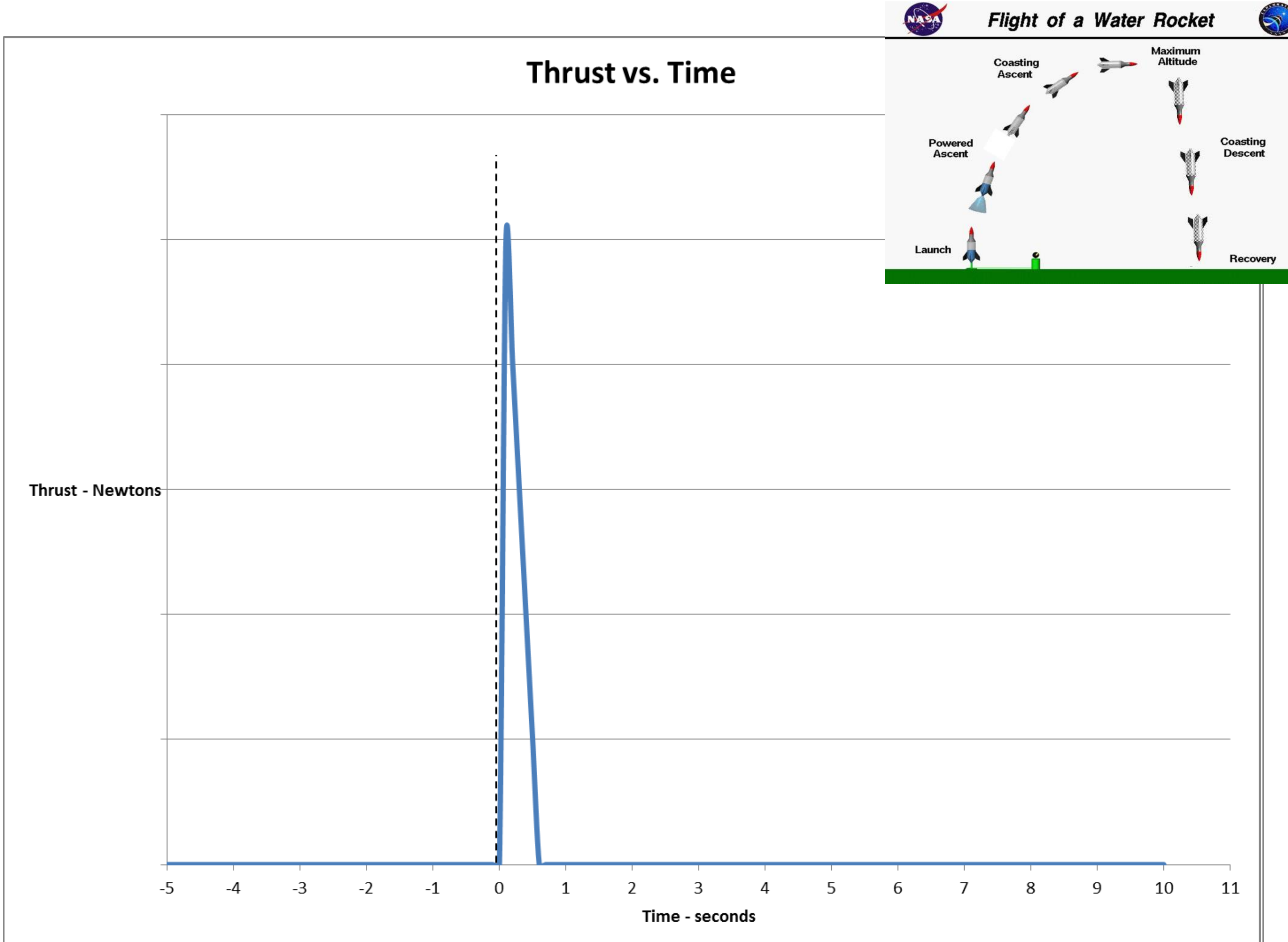
Air Flow Reaction to Fairing



Air/Water Rocket Launch Setup




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


Thrust vs. Time
Thrust - Newtons
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
Time - seconds
Flight of a Water Rocket
Coasting Ascent
Maximum Altitude
Powered Ascent
Coasting Descent
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.

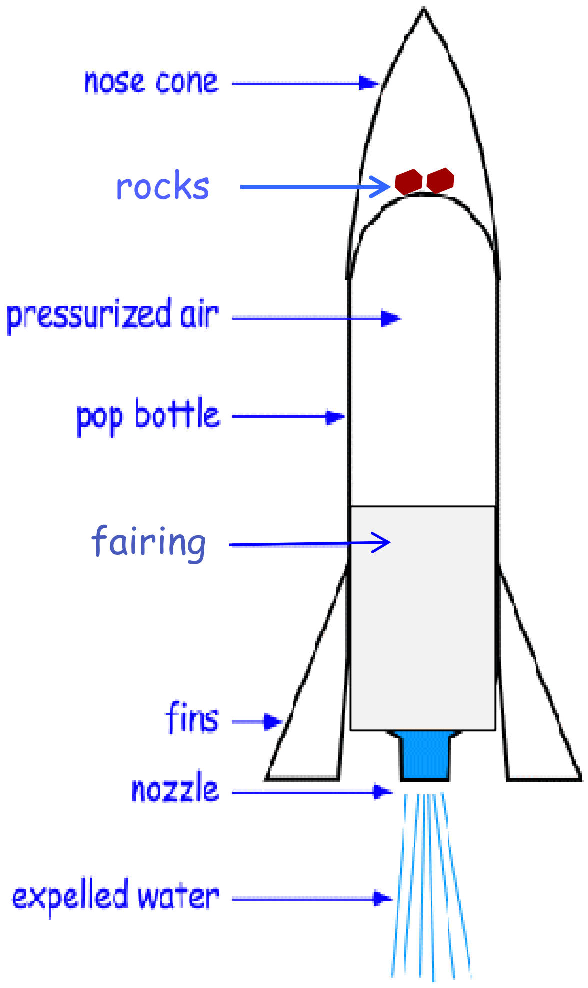
Building an Air/Water (Bottle) Rocket

- 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 positive in one design element may become a negative 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!

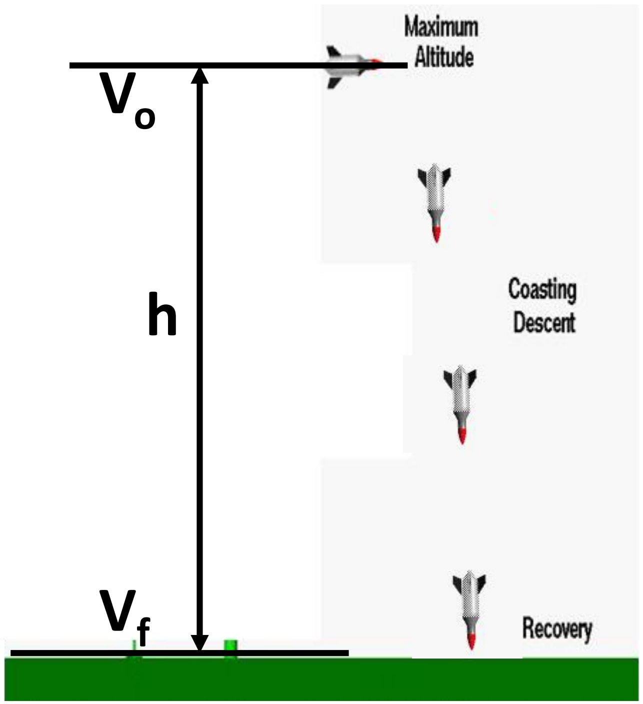
Rocket Failures – How We Learn!

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, $V_{avg} = (V_o + V_f)/2 = ½V_f$

therefore, $V_{avg} = ½\, g \cdot t$,

so, $h = (½\, g \cdot t) \cdot t$

or, $h = ½\, g \cdot t^2$

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

What did we learn today?

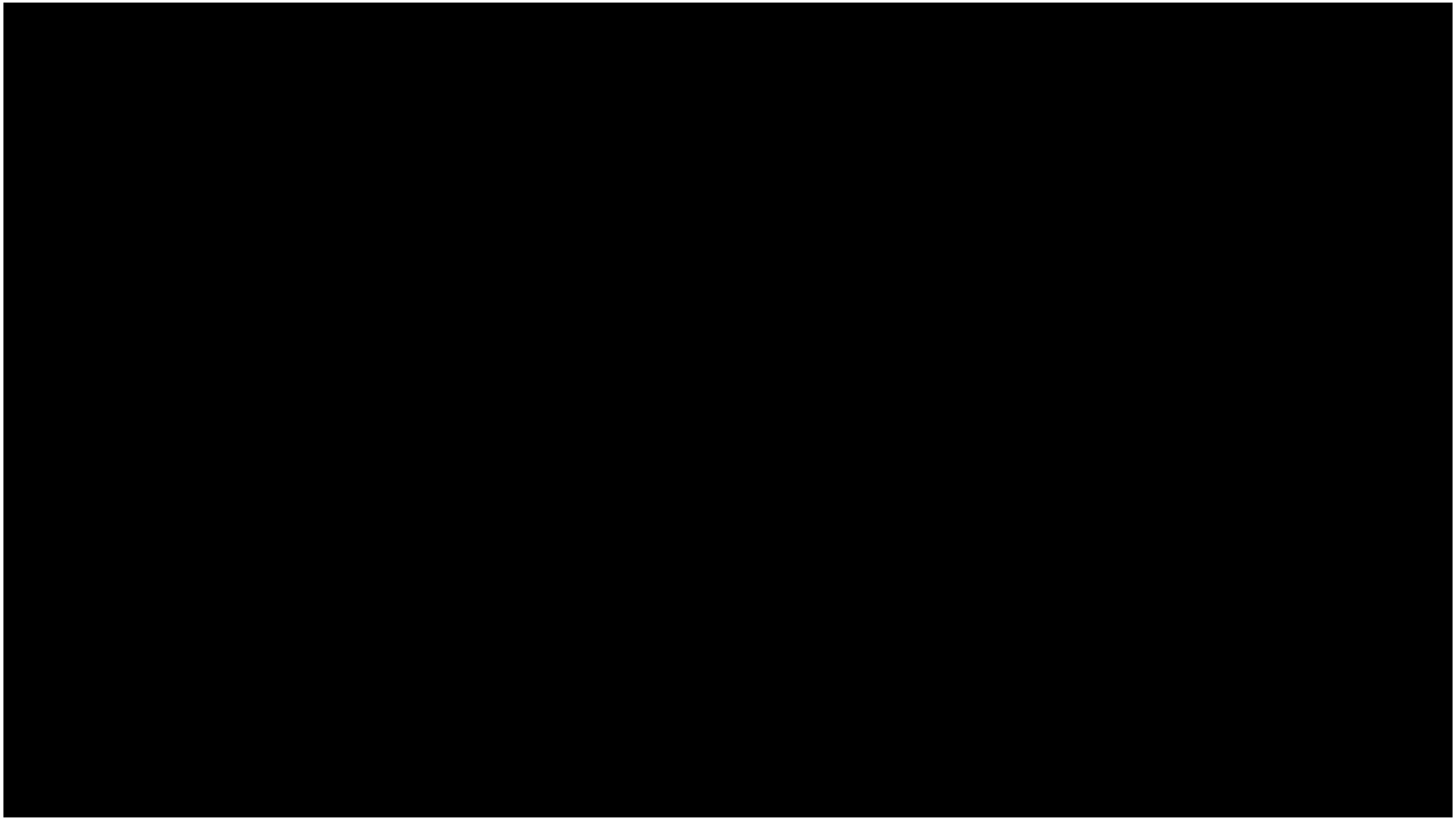
We explored the science, engineering, and technology of Rockets:

- 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!