This IS Rocket Science -
A Teaching Module
Adaptable K – 12

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Background & Contents

➢ Background: This presentation was initially developed for a K-12 Science Fair

➢ Adapting to different age groups:
  • For the younger students, go lighter on the history and physics, with more emphasis on the demonstrations, or
  • For the older, high school students, can go into all the history, physics, and demonstrations.

➢ A comprehensive approach to Rocket Science, starts with history, then the physics of propulsion and stability, and finally demonstrations using balloons, finger rockets (missiles), and bottle rockets.

➢ Instructions are included so that teachers and older students can build and fly bottle rockets and finger missiles.
Scope

➢ Introduction to Rocket Science
   • History
   • Physics
     ▪ Newton’s Laws
     ▪ Thrust & propellants
     ▪ Stability

➢ Launch Demos
   • Balloon rockets
   • Finger/Bungee missiles
   • Bottle rockets: high pressure air, high pressure air + water
   • Chemical rockets: low temp chemical reactions, using vinegar and baking soda, or Mentos and Coke, can also be used, but messier, and less repeatable.

➢ Definitions:
   • Rocket: a cylinder-shaped object that moves very fast by forcing out high pressure gas (usually hot, but not today).
   • Missile: an object that can be projected toward a target.
Brief History of Rockets & Missiles

➢ Who invented rockets?
   • The Chinese developed the first gunpowder rockets in the Song Dynasty in the 13th century

➢ Who developed the science/physics?
   • Sir Isaac Newton published his Laws in 1687 – next page

➢ Who developed the first digital computer, which was used to calculate ballistic trajectories?
   • ENIAC was developed at University of Pennsylvania in early 1940’s (WWII), used vacuum tubes, filled an entire room

➢ Who was the Father of American rocketry?
   • Dr Robert Goddard launched the first liquid fueled rocket in 1926

➢ Who developed the first rocket that went into space?
   • Werner von Braun and his German team developed the V-2 rocket in the early 1940’s (WWII)
   • Werner von Braun (with JFK) and his German team helped the U.S. send the first men to the Moon

ENIAC

We’re going to the Moon! Way up there?

arc.osu.edu
Physics – Newton’s Laws – 1687

**First law:** In an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.

**Second law:** In an inertial reference frame, the vector* sum of the forces, \( F \), on an object is equal to the mass, \( m \), of that object multiplied by the acceleration, \( a \), of the object:

\[
F = ma
\]

*A vector (shown as a bold letter) has magnitude and direction – see Forces On Rocket diagram - next*
Forces on Rocket
Equations of Motion

➢ Start with $F = ma$, so the acceleration $a = F/m$

➢ The forces, $F$, are $T$, thrust, pushing the rocket forward, $D$, drag due to air resistance, and $W$, weight due to gravity.

➢ Let’s take the simple case of a rocket going straight up (all of the vectors align in the vertical direction). The acceleration of our rocket is now:
  • $a = (T – D – W)/m$

➢ Making it simpler still, for a rocket in space, there is no air drag, $D = 0$, and
  • $a = (T – W)/m$ when/if this $a = constant$, the velocity,
    $$v = (T – W) \frac{t}{m}, \text{where } t = \text{time},$$
  • Distance, $x = (T – W) \frac{t^2}{2m}$
Specific Impulse

Rocket Thrust Equation
\[ F = \dot{m} V_e + (p_e - p_o) A_e \]
where \( p \) = pressure, \( V \) = velocity, \( A \) = area, \( \dot{m} \) = mass flow rate, \( F \) = thrust

Define: Equivalent Velocity
\[ V_{eq} = V_e + \frac{(p_e - p_o) A_e}{\dot{m}} \]

Define: Total Impulse
\[ I = F \Delta t = \int F \, dt = \int \dot{m} V_{eq} \, dt = \dot{m} V_{eq} \]

Define: Specific Impulse
\[ I_{sp} = \frac{I}{\dot{m} g_o} = \frac{V_{eq}}{g_o} \quad \text{units} = \text{sec} \]
\[ I_{sp} = \frac{F}{\dot{m} g_o} \]
Rocket Propellants and Specific Impulse

- Specific impulse, Isp, is a key metric for the efficiency of a propellant, it’s basically thrust per pound (weight) – so the higher the better
- Liquid propellants have higher specific impulses than solids, some examples:
  - Estes solid (black powder) model rocket Isp = 80 sec
  - Space Shuttle solid booster Isp = 250 sec
  - Liquid oxygen/liquid hydrogen rocket Isp = 450 sec
Propulsion

- Real world: solid or liquid propellants
  - Solid: ready to go, used in weapons and Space Shuttle
  - Liquid: higher performance, need loading time prior to launch, used for satellite launches

- Model rockets: High pressure gas with liquid (H2O), or solid
  - High pressure air: use tire pumps (inside or outside)
  - Solid: Estes makes small solid rockets for models, can reach altitudes ~ 1,000+ ft
  - Liquid: chemical reactions; low and high temperature options
    - Low temp – Mentos and Coke, baking soda and vinegar
    - High temp – gasoline or kerosene = too dangerous - don’t attempt

High pressure air is recommended for class room or outside
Stability of Rocket

➢ Why do regular (round) balloons not go straight after being released?

➢ For a rocket to be stable the Center of Gravity (CG) must be in front of the Center of Pressure (CP) – see next chart

➢ How is this accomplished?
  • CG – add weight to nose = moves CG forward
  • CP – add fins = moves CP aft

➢ Answer: regular balloons don’t go straight because the CG is not in front of the CP!

➢ Some rockets don’t have fins – they use active control to maintain desired direction – see next chart
Examples of Controls

Movable Fins

Gimbaled Thrust

Vernier Rocket

Thrust Vane
Finger/Bungee Missile (not Rocket)

- Force, \( F \), and impulse, \( I \), generated by rubber band/bungee that acts like a spring:
  - \( F = k \Delta x \), where \( k \) = spring constant in lbs/inch, and \( \Delta x \) is amount stretched in inches
  - \( I = k \Delta x \frac{t}{2} \), where \( t \) = time for it to “unstretch” when released
- To launch, put loop on nose over tip of index finger, pointed in desired direction; grasp tail end with other hand, and pull back. Keep index finger very still and release grip on tail end.
- Retrieve and repeat, as often as possible
Bottle Rocket

- nose cone
- pressurized air
- pop bottle
- water
- fins
- nozzle
- expelled water

thrust

weight

air friction
Summary

➢ Rocket history goes back about 800 years
➢ Rockets going into space goes back 70 years
  • Man in space, in orbit, and to the Moon
  • Satellites that enable Worldwide communications, navigation, weather, and other surveillance
➢ Isaac Newton discovered the physics just over 300 years ago
➢ Rockets are propelled by mass flowing out nozzle
  • Model rockets use compressed air with water or chemical reactions
  • Large rockets use controlled burning of liquids or solids
➢ Rockets are stable
  • Due to fins making Center of Pressure be behind Center of Gravity
  • Or, by using active control of thrust vector
➢ You know enough to make your own bottle rocket or launch your own finger missile
Making a Bottle Rocket

➢ Start with a 1 or 2 liter plastic soda bottle – next page
➢ Need fins, nose cone, and launch loops
  • Cut fins out of foam core from hobby store, attach with duct tape
  • Use small foam football, cut in half, attach to nose with duct tape
  • Tape 2 plastic strips fore and aft to hang rocket on launch pole
➢ Use wine bottle cork, with very small hole drilled through it. Make sure cork is very tight fit, if not wrap with electrical tape until it is.
➢ Insert inflation needle (used to inflate footballs/basketballs) into cork and insert cork into bottle
➢ Attach inflation needle to tire pump (hand or battery powered)
➢ Hang from launch rod
➢ Initiate pumping, cork should pop out at 20-30 psi above ambient pressure
Materials Needed

➢ A. Plastic soda/water bottle
   • 0.5, 1, or 2 liter sizes
➢ B. Foam football (3”D)
➢ C. Foamcore for fins
➢ D. Regular & Rocket balloons
➢ E. Duct & electrical tapes
➢ F. Wine corks
➢ G. Inflation needle
➢ H. Plastic strips/cable ties
➢ I. Launch rod (not shown)
Demonstrations

➢ Stability: Releasing inflated balloons
  • Regular spherical balloons travel in spiral directions after release, as CP is not behind CG
  • “Rocket Balloons” (or a long balloon with a small weight attached to nose) travel relatively straight as CG is ahead of CP

➢ Finger Rockets (Missiles)
  • Fun for kids, except during class, not fun for teacher
Demonstrations - cont

➢ Propulsion: Launching bottle rockets with and without H2O
  • Inflate with tire pump, with air only, should launch around 20-30 psi, and travel 10-20 ft (30-40 deg launch angle)
  • Add ½ cup of H2O in bottle rocket, should travel 30-60 ft
Reference Material

➢ Youtube.com, search for “bottle rockets”
➢ Wikipedia, Specific Impulse and other topics https://en.wikipedia.org/wiki/Specific_impulse