US Army PEO STRI 2013 Summer Engineering Internship

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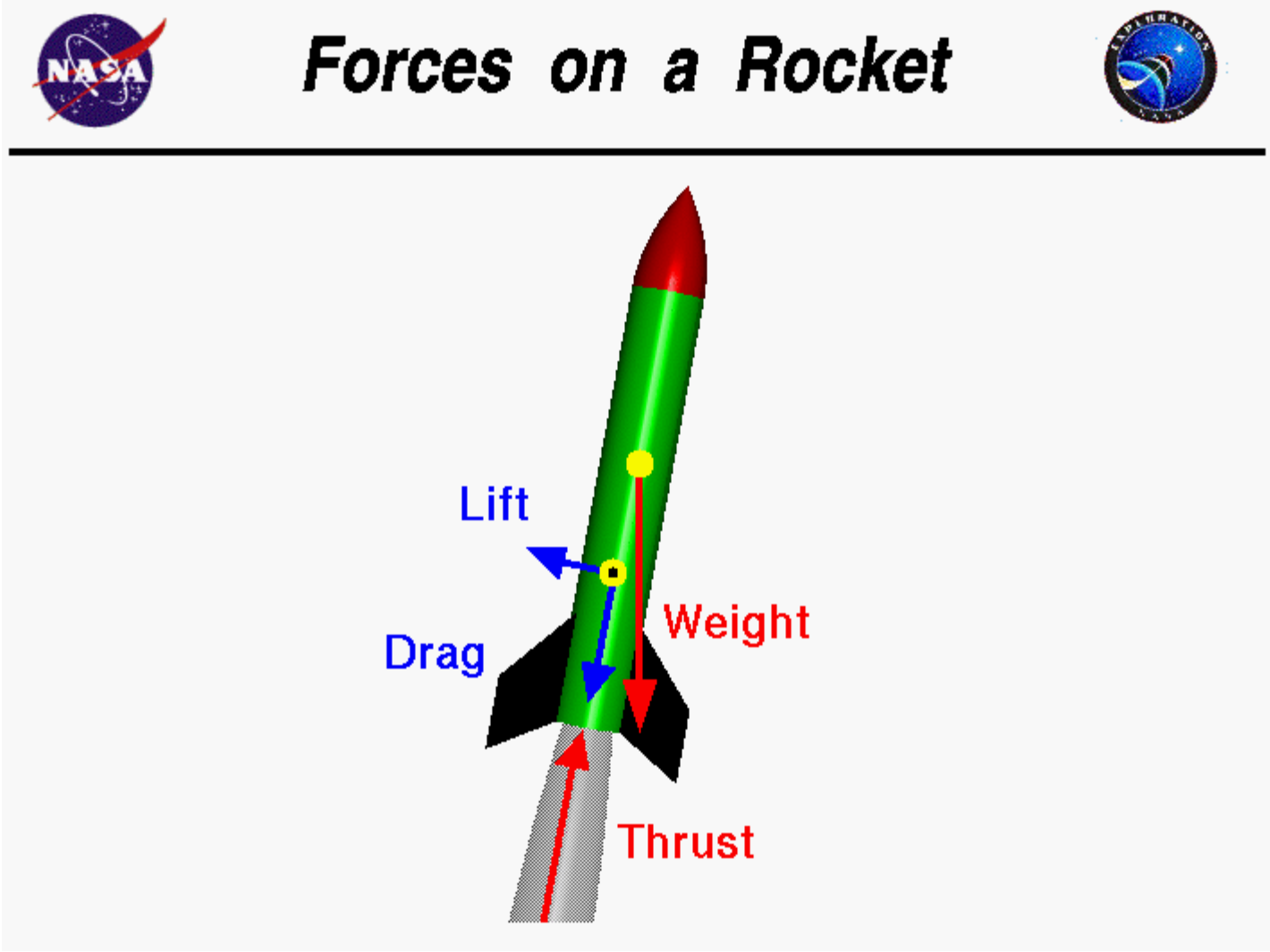
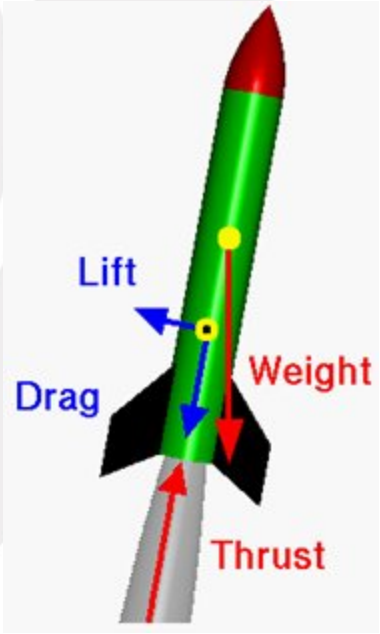
Forces on a Rocket



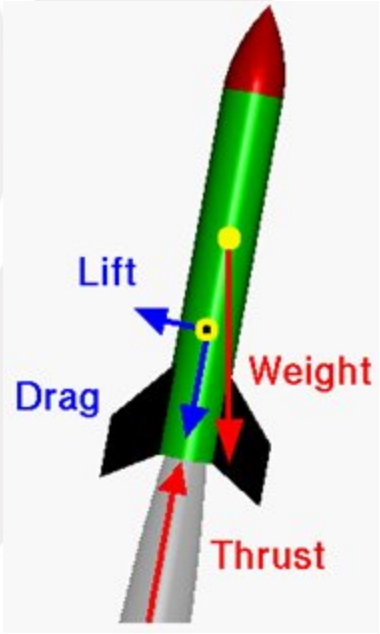
Forces on a Rocket

- Four forces
  - Weight
  - Thrust
  - Aerodynamic lift
  - Aerodynamic drag



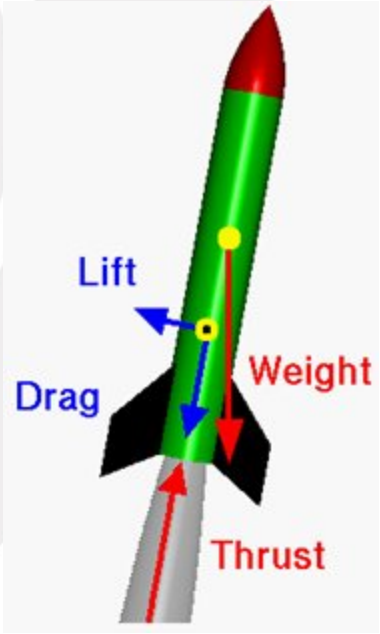
Forces on a Rocket

- Weight
  - Directed towards the center of the earth
  - Acts through the center of gravity (yellow dot)



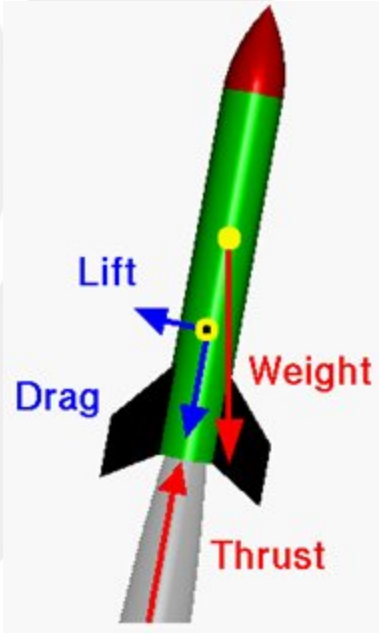
Forces on a Rocket

- Thrust
  - Depends on the mass flow rate through the engine and on the velocity and pressure at the exit of the nozzle
  - Acts along the longitudinal axis of the rocket and therefore acts through the center of gravity (yellow dot)



Forces on a Rocket

- Aerodynamic forces (lift and drag)
  - Depend on the shape, size, and velocity of the rocket and on properties of the atmosphere
  - Act through the center of pressure* (black and yellow dot)



*Center of Pressure – the point on the body about which the aerodynamic moment is zero.

Newton’s Laws

- The resulting motion of the rocket is described by Newton's laws of motion.
- Formally, Force equals the rate of change of momentum

$$F = \dot{p} = \frac{dp}{dt}$$

Newton's Laws

Newton's Laws of Motion

"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

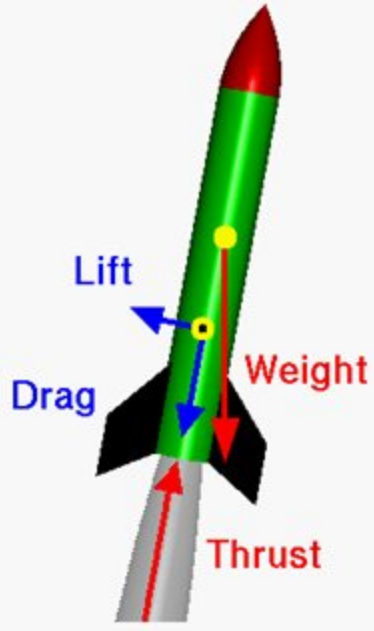
"Force is equal to the change in momentum (mV) per change in time. For a constant mass, force equals mass times acceleration."

$$F = m\ a$$

"For every action, there is an equal and opposite re-action."

Airplane Comparison

- On an airplane, the lift force (the aerodynamic force perpendicular to the flight direction) is used to overcome the weight.
- On a rocket, thrust is used in opposition to weight.
- On many rockets, lift is used to stabilize and control the direction of flight.

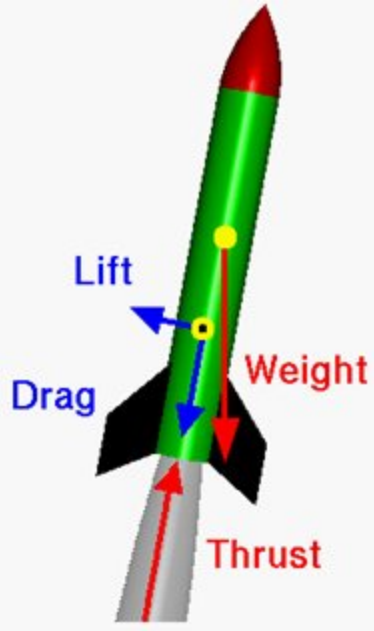


Airplane Comparison

- On an airplane, most of the aerodynamic forces are generated by the wings and the tail surfaces.
- For a rocket, the aerodynamic forces are generated by the fins, nose cone, and body tube.
- For both airplane and rocket, the aerodynamic forces act through the center of pressure (black and yellow dot) while the weight acts through the center of gravity (yellow dot).

Airplane Comparison

- While most airplanes have a high lift to drag ratio, the drag of a rocket is usually much greater than the lift.
- While the magnitude and direction of the forces remain fairly constant for an airplane, the magnitude and direction of the forces acting on a rocket change dramatically during a typical flight.

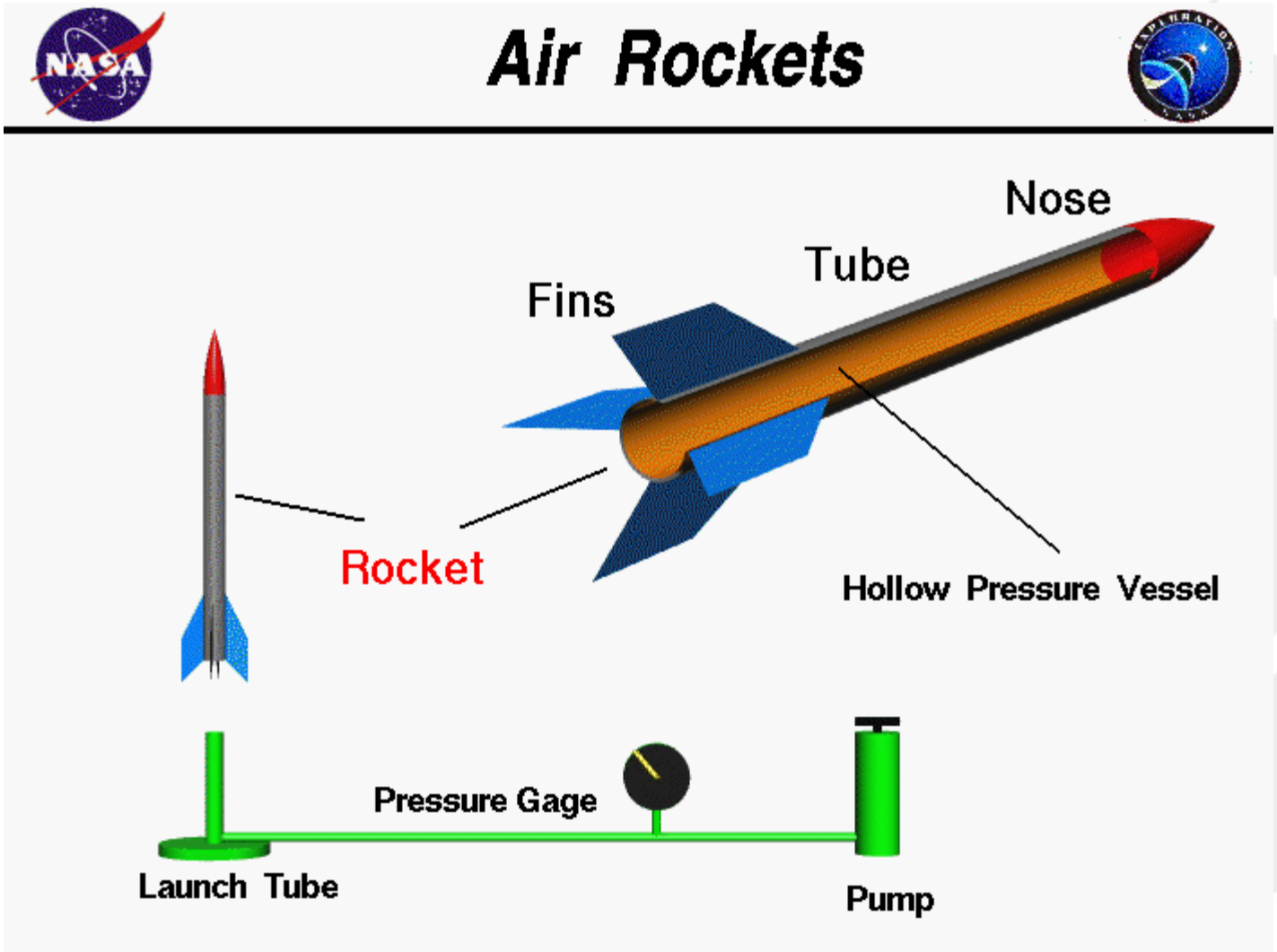


AIAA
The World's Forum for Aerospace Leadership

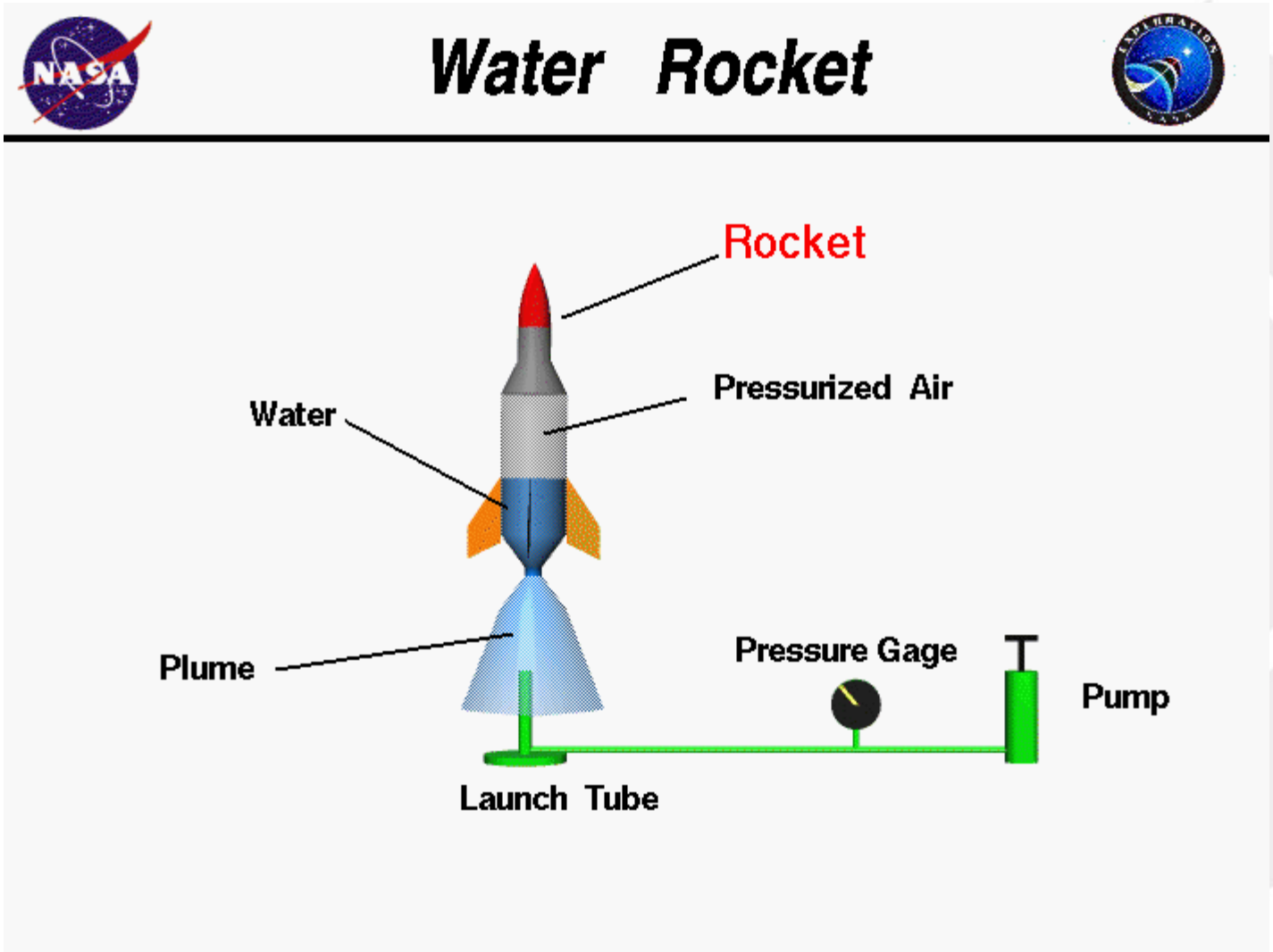
Types of Rockets

- Air Rockets
- Water Rockets
- Model Rockets
- Full-Scale Rockets

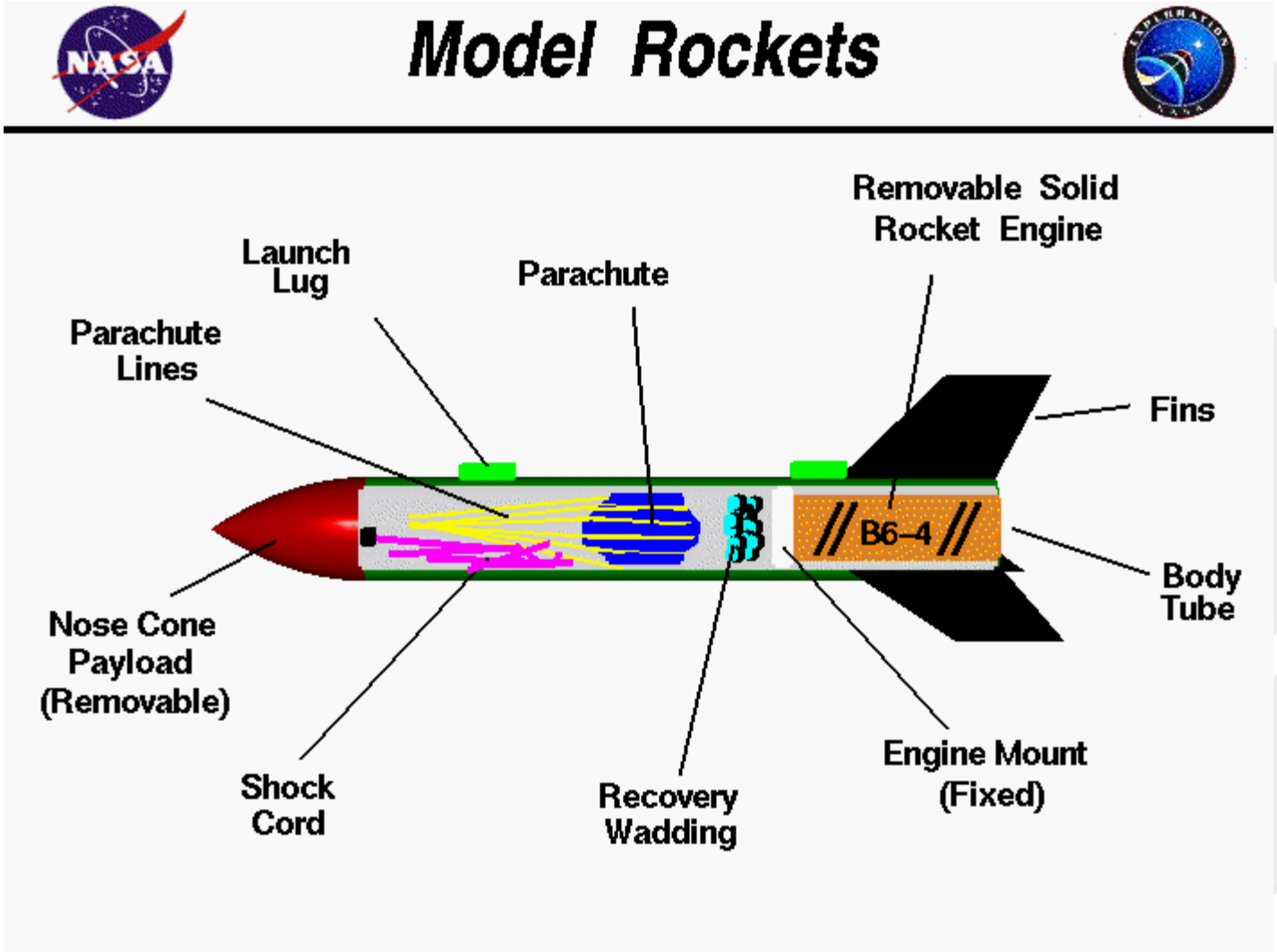
Air Rockets


Air Rockets
Nose
Tube
Fins
Rocket
Hollow Pressure Vessel
Pressure Gage
Launch Tube
Pump

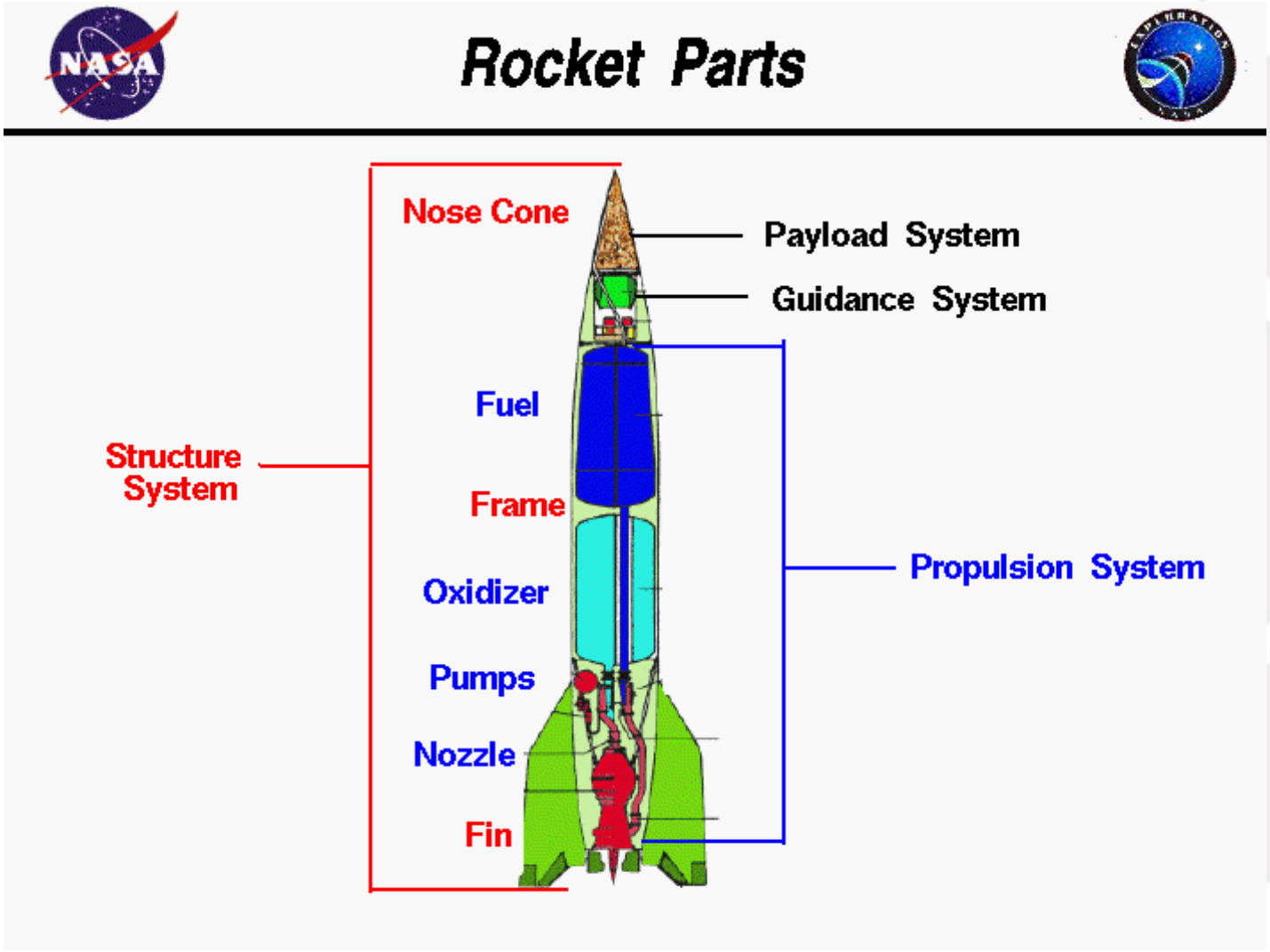
Water Rocket



Model Rockets



Full-Scale Rockets



Titan-IV

Rocket Systems

- Payload System
- Structural System
- Guidance System
- Propulsion System

Payload System

- The payload system of a rocket depends on the rocket's mission.
  - Communications
  - Weather monitoring
  - Spying
  - Planetary exploration
  - Observatories (Hubble Space Telescope)
  - Special rockets were developed to launch people into earth orbit and onto the surface of the Moon.

Structural System

- Made of strong/light-weight materials (Ti or Al)
- Long "stringers" from top-to-bottom connected to circumferential "hoops"
- “Skin" is attached to stringers and hoops to form basic shape of rocket
- Coated with thermal protection system
  - Keep out heat of air friction during flight
  - Keep in cold temperatures needed for fuels and oxidizers

Guidance System

- May include very sophisticated sensors, on-board computers, radars, and communication equipment to maneuver the rocket in flight.
- Different methods have been developed to control rockets in flight.
  - V2 guidance system included small vanes in the exhaust of the nozzle to deflect the thrust from the engine.

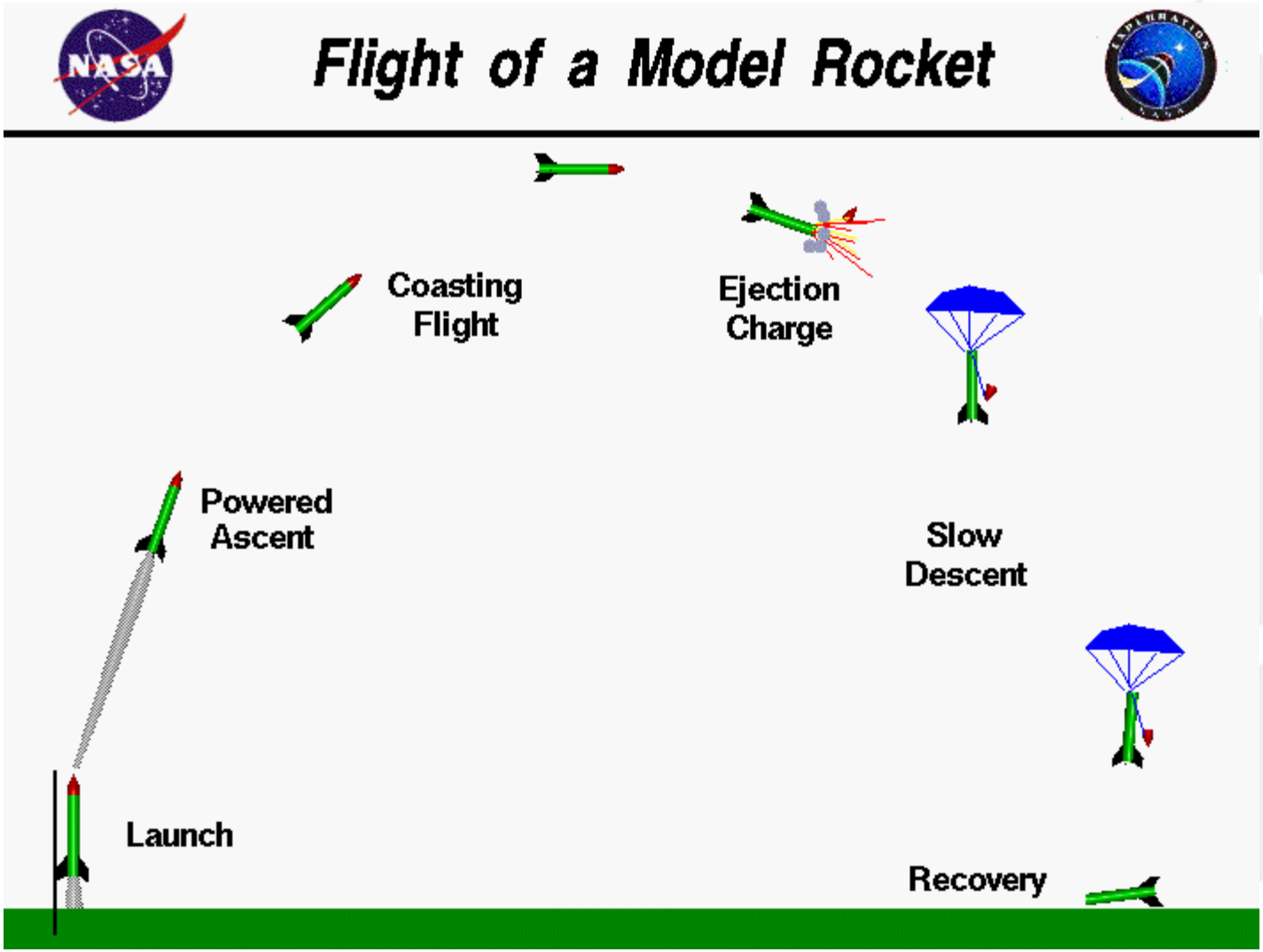
Guidance System

- Modern rockets typically gimbal the nozzle to maneuver the rocket.
- The guidance system must also provide some level of stability so that the rocket does not tumble in flight.
- Structurally…
  - Fins are attached to some rockets at the bottom of the frame to provide stability during the flight.

Propulsion System

- Most of a full scale rocket is propulsion system.
- Two main classes of propulsion systems
  - Liquid rocket engines
    - The V2 used a liquid rocket engine consisting of fuel and oxidizer (propellant) tanks, pumps, a combustion chamber with nozzle, and the associated plumbing
  - Solid rocket engines
    - The Space Shuttle, Delta II, and Titan IV all use solid rocket strap-ons.

Flight of a Model Rocket



Estes Rocket Engines

- 1/2A3-4T
  - 1/2A implies 0.626 Ns to 1.25 Ns of TOTAL Impulse
  - 3 implies 3 N od AVERAGE Thrust
  - -4T implies 4 sec delay until ejection charge

- Calculate the minimum and maximum AVERAGE burn time of the engine using Newton's 2nd Law

$$F = \dot{p} = \frac{dp}{dt}$$

RocketModeler.zip

- Click “Solid”
- Click “Design”
  - Tube/Fairing
    - Material
    - Length
    - Diameter
  - Click “GO”

RocketModeler.zip

- Click “Fuel”
  - Select “1 Stage”
  - Select Main Engine type
  - Click “GO”
- Click “Pad”
  - Select “Earth - Average Day”
  - Set “Altitude - ft” to 50 (with the slider)
  - Set “Wind fps” to current conditions (with the slider)
  - Click “GO”

RocketModeler.zip

- Click “Launch”
  - Click “Fire”
  - Note the maximum height and time of flight
  - Make note of these values and compare them with your actual launch.
  - Bring a stop watch to measure the flight time
  - Estimate height using trigonometry
  - …where H=Height and R=Range

$$\tan\theta = \frac{H}{R}$$