Rockets

Question:

- If there were no launch pad beneath the space shuttle at lift-off, the upward thrust of its engines would be
- approximately unchanged.
- approximately half as much.
- approximately zero.

Observations About Rockets

- Plumes of flame emerge from rockets
- Rockets can accelerate straight up
- Rockets can go very fast
- The flame only touches the ground initially
- Rockets operate fine in empty space
- Rockets usually fly nose-first

Momentum Conservation

- A rocket's momentum is initially zero
- The momentum redistributes during thrust
  - Ship pushes on fuel; fuel pushes on ship
  - Fuel acquires backward momentum
  - Ship acquires forward momentum
- Rocket's total momentum remains zero

Rocket Propulsion

- Neglecting gravity, then
  - rocket's total momentum is always zero

$$\text{momentum}_{\text{fuel}} + \text{momentum}_{\text{ship}} = 0$$

- The momentum of the ship depends on
  - the momentum of the ejected fuel, or
  - the speed of that fuel and
  - the mass of that fuel

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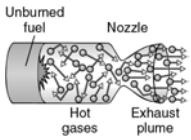
Rocket Engines

- Chemical reactions produce hot, high-pressure gas
- Gas speeds up in nozzle
- Gas reaches sonic speed in throat of de Laval nozzle
- Beyond throat, supersonic gas expands to speed up further



Stability and Orientation

- On ground, rocket needs static stability
- In air, rocket needs aerodynamic stability
  - Center of dynamic pressure behind c.o.m.
- In space, rocket is a freely rotating object
  - Orientation governed by angular momentum
  - Rocket can travel in any orientation

Ship's Ultimate Speed

- Increases as
  - ratio of fuel mass to ship mass increases
  - fuel exhaust speed increases
- If fuel were released with rocket at rest,

$$\text{speed}_{\text{ultimate}} = \frac{\text{mass}_{\text{fuel}}}{\text{mass}_{\text{ship}}} \cdot \text{speed}_{\text{exhaust}}$$

- Because rocket accelerates during thrust, ultimate speed is less than given above

Gravity Part 1

- The earth's acceleration due to gravity is only constant for small changes in height
- When the distance between two objects changes substantially, the relationship is:

$$\text{force} = \frac{\text{gravitational constant} \cdot \text{mass}_1 \cdot \text{mass}_2}{(\text{distance between masses})^2}$$

Gravity Part 2

- An object's weight is only constant for small changes in height
- When its height changes significantly, the relationship is:

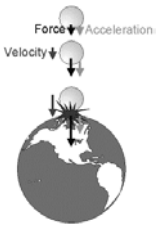
$$\text{weight} = \frac{\text{gravitational constant} \cdot \text{object} \cdot \text{earth}}{(\text{distance between centers of object and earth})^2}$$

Gravity Part 3

- An object high above the earth still weighs
- Astronauts and satellites have weights
  - weights are somewhat less than normal
  - weights depend on altitude
- Astronauts and satellites are in free fall

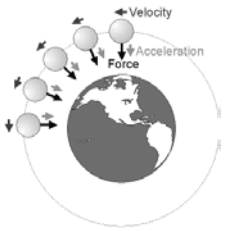
Orbits
Part 1

- An object that begins to fall from rest falls directly toward the earth
- Acceleration and velocity are in the same direction



Orbits
Part 2

- An object that has a sideways velocity follows a trajectory called an orbit
- Orbits can be closed or open, and are ellipses, parabolas, and hyperbolas



Summary
About Rockets

- Rockets are pushed forward by their fuel
- Total rocket impulse is the product of exhaust speed times exhaust mass
- Rockets can be stabilized aerodynamical
- Rockets can be stabilized by thrust alone
- After engine burn-out, rockets can orbit