Rockets

Turn off all electronic devices

Observations about Rockets

Rockets seem to ride torch-like flames

Rockets can accelerate straight up

Rockets can go very fast

The flame only touches the ground initially

Rockets can apparently operate in empty space

Rockets usually fly nose-first

6 Questions about Rockets

1. What pushes a rocket forward?
2. How does the rocket use exhaust gas to obtain thrust?
3. What keeps a rocket pointing forward?
4. What limits a spaceship's speed, if anything?
5. Once in space, does a spaceship have a weight?
6. What makes a spaceship orbit the earth?

Question 1

Q: What pushes a rocket forward?

A: It's gaseous exhaust pushes it forward

A rocket's momentum is initially zero

That momentum is redistributed during thrust

- Ship pushes on fuel; fuel pushes on ship
- Fuel (now exhaust) acquires backward momentum
- Ship acquires forward momentum

Rocket's total momentum remains zero

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

Rocket Propulsion

The ship and fuel have opposite momentums

The ship's final momentum is

$$\begin{aligned}\text{momentum}_{\text{ship}} &= -\text{momentum}_{\text{fuel}} \\ &= -\text{mass}_{\text{fuel}} \cdot \text{velocity}_{\text{fuel}}\end{aligned}$$

The greater the fuel mass and backward velocity, the greater the ship's forward momentum

Question 2

Q: How does the rocket use exhaust gas to obtain thrust?

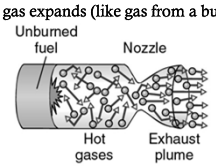
A: Redirects gas's thermal motion into a directed jet

Combustion produces hot, dense, high-pressure gas

This gas speeds up in a de Laval nozzle (like water in a nozzle)

Gas reaches sonic speed in the nozzle's throat

The now-supersonic gas expands (like gas from a burst firecracker)



Question 3

Q: What keeps a rocket pointing forward?

A: That depends on where the rocket is located

On the ground, a rocket needs static stability

In the air, a rocket needs aerodynamic stability

- Its center of aerodynamic forces must be behind its center of mass

In space, a spaceship is a freely rotating object

- Its orientation is governed by angular momentum
- Small rockets or spinning wheels are used to exert torques on spaceship
- The spaceship's orientation doesn't affect its travel

Question 4

Q: What limits a spaceship's speed, if anything?

A: The rocket's fuel to spaceship ratio

Spaceship's ultimate speed increases as

- the ratio of fuel mass to ship mass increases
- the fuel exhaust speed increases

If all the fuel were released at once with the rocket at rest,

$$\text{velocity}_{\text{ship}} = -\frac{\text{mass}_{\text{fuel}}}{\text{mass}_{\text{ship}}} \cdot \text{velocity}_{\text{fuel}}$$

But because the rocket accelerates forward as it releases of fuel,

$$\text{velocity}_{\text{ship}} = -\log_e\left(\frac{\text{mass}_{\text{ship}} + \text{mass}_{\text{fuel}}}{\text{mass}_{\text{ship}}}\right) \cdot \text{velocity}_{\text{fuel}}$$

Question 5

Q: Once in space, does a spaceship have a weight?

A: Yes, but less than at ground level

Earth's acceleration due to gravity

- is approximately constant for small changes in height at ground level
- but decreases at large altitudes

The actual weight of a spaceship at any altitude is

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

Law of University Gravitation

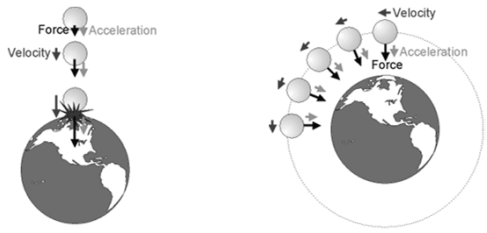
Two masses attract one another with gravitational forces equal in amount to the gravitational constant times the product of their masses, divided by the square of their separation.

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

Question 6

Q: What makes a spaceship orbit the earth?

A: An orbiting spaceship falls, but misses the earth



Orbits

An object that starts with a sideways velocity

- can miss the earth as it falls
- follows a trajectory called an orbit

Orbits can be

- closed loops: circles and ellipses
- open arcs: parabolas and hyperbolas

Minimum speed for low-earth orbit

- is about 28,000 km/h (17,400 mph)
- requires far more thrust than merely reaching space

Summary About Rockets

- A rocket's fuel (as exhaust) pushes it forward
- Total rocket impulse is basically the product of exhaust speed times exhaust mass
- Rockets can be stabilized aerodynamically
- Rockets can be stabilized by thrust alone
- After engine burn-out, spaceships can orbit