Rockets

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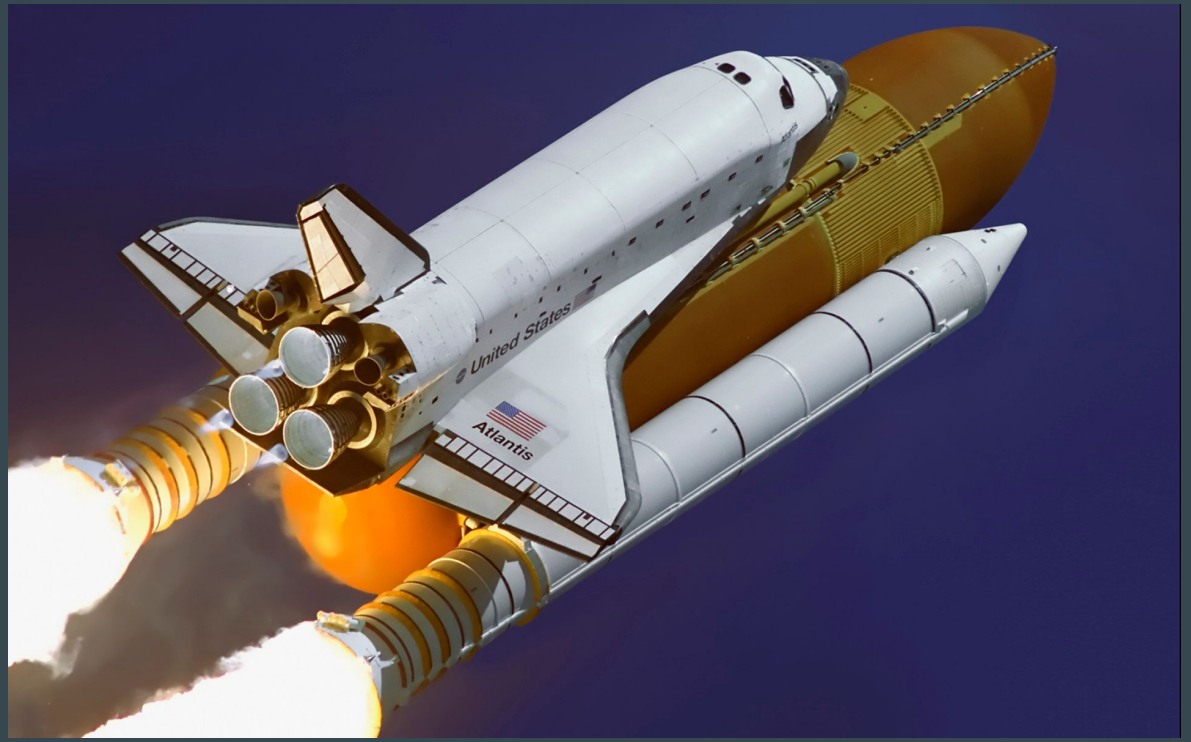
What is a Rocket?

Rockets use Newton's third law of motion. Matter is forcefully ejected from a system, producing an equal and opposite reaction on what remains.



Equations of Rockets

- Acceleration:

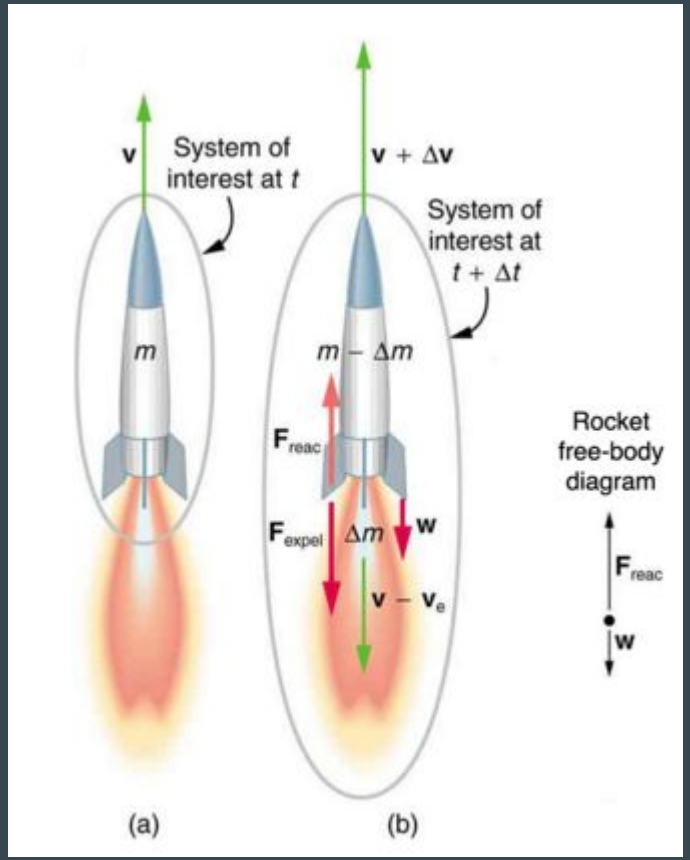
$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g,$$

- Velocity:

$$v = v_e \ln \frac{m_0}{m_r},$$

Free Body Diagram

a) This rocket has a mass m and an upward velocity v. The net external force on the system is −mg, if air resistance is neglected. (b) A time Δt later the system has two main parts, the ejected gas and the remainder of the rocket. The reaction force on the rocket is what overcomes the gravitational force and accelerates it upward.



Lab

- Google PHET Simulations
- Enter Lunar Lander in the search bar
- Start the simulation and turn on vectors

22. Professional Application

It is possible for the velocity of a rocket to be greater than the exhaust velocity of the gases it ejects. When that is the case, the gas velocity and gas momentum are in the same direction as that of the rocket. How is the rocket still able to obtain thrust by ejecting the gases?

- If you put the frame of reference on the rocket before expelling the exhaust, you would see that the exhaust flies backwards and the rocket flies forward after they separate. This is what you see. However, if you use earth as frame of reference, you might see everything flying in the same direction, as described above.
- The exhaust gases are applying a force to the mass of the rocket, resulting in an acceleration.

53. Professional Application

Antiballistic missiles (ABMs) are designed to have very large accelerations so that they may intercept fast-moving incoming missiles in the short time available. What is the takeoff acceleration of a 10,000-kg ABM that expels 196 kg of gas per second at an exhaust velocity of 2.50×10^3 m/s?

56. Professional Application

Ion-propulsion rockets have been proposed for use in space. They employ atomic ionization techniques and nuclear energy sources to produce extremely high exhaust velocities, perhaps as great as 8.00×10^6 m/s . These techniques allow a much more favorable payload-to-fuel ratio. To illustrate this fact: (a) Calculate the increase in velocity of a 20,000-kg space probe that expels only 40.0-kg of its mass at the given exhaust velocity. (b) These engines are usually designed to produce a very small thrust for a very long time—the type of engine that might be useful on a trip to the outer planets, for example. Calculate the acceleration of such an engine if it expels 4.50×10^{-6} kg/s at the given velocity, assuming the acceleration due to gravity is negligible.

59. Given the following data for a fire extinguisher-toy wagon rocket experiment, calculate the average exhaust velocity of the gases expelled from the extinguisher. Starting from rest, the final velocity is 10.0 m/s. The total mass is initially 75.0 kg and is 70.0 kg after the extinguisher is fired.

62. Unreasonable Results

Squids have been reported to jump from the ocean and travel $30.0\ \text{m}$ (measured horizontally) before re-entering the water. (a) Calculate the initial speed of the squid if it leaves the water at an angle of $20.0°$, assuming negligible lift from the air and negligible air resistance. (b) The squid propels itself by squirting water. What fraction of its mass would it have to eject in order to achieve the speed found in the previous part? The water is ejected at $12.0\ \text{m/s}$; gravitational force and friction are neglected. (c) What is unreasonable about the results? (d) Which premise is unreasonable, or which premises are inconsistent?