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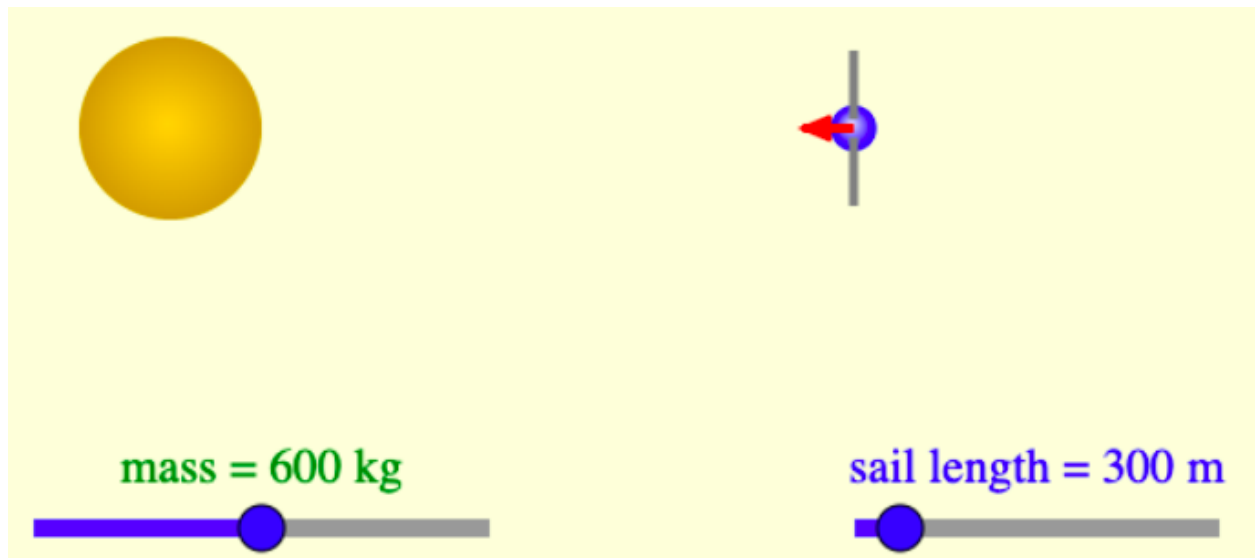
Solar sail

Link to the simulation: https://physics.bu.edu/~duffy/HTML5/solar_sailboat.html

Play with the simulation for a couple of minutes, to explore what it does.

The simulation shows the Sun, on the left, and then a blue space probe (the solar sail) with a large square sail. This is a side view, so the sail looks just like a gray line. There are sliders that can be used to adjust the mass of the probe and the length of each side of the square sail.

Here's a screenshot of the initial situation.



Two forces act on the solar sail. One is the force of gravity. This is given by Newton's universal law of gravitation:

$$F_g = \frac{GmM}{r^2}$$

where G is a constant, m is the mass of the solar sail, M is the mass of the Sun, and r is the distance from the center of the Sun to the solar sail. The solar sail is attracted toward the Sun by the force of gravity.

The second force is associated with radiation pressure - light from the Sun that reflects off the sail exerts a force on the solar sail that is directed away from the Sun. It can be shown that this force is given by:

$$F_{rp} = \frac{2(Power)A}{4\pi r^2 c}$$

where P is the power (the light energy per second) emitted by the Sun, A is the area of the solar sail, c is the speed of light in vacuum, and r is the distance from the center of the Sun to the solar sail. Again, this force on the sail is directed away from the Sun.

1. In the simulation, there is a red arrow attached to the solar sail. What does this arrow represent?

☐ the velocity of the solar sail ☐ the acceleration of the solar sail

☐ the force associated with radiation pressure ☐ the gravitational force

How do you know?

2. If the distance between the center of the Sun and the solar sail is halved (that is, reduced by a factor of 2), what happens to the magnitude of the gravitational force acting on the solar sail? That force goes from F to ...

☐ F/4 ☐ F/2 ☐ F ☐ 2F ☐ 4F

How do you know?

3. If the distance between the center of the Sun and the solar sail is halved (that is, reduced by a factor of 2), what happens to the magnitude of the force associated with radiation pressure acting on the solar sail? That force goes from F' to ...

☐ F'/4 ☐ F'/2 ☐ F' ☐ 2F' ☐ 4F'

How do you know?

4. For this question we give three masses in the table (increasing by a factor of 2 from one to the next) and you need to fill in the length of each side of the sail (that's the value of the length slider) that gives the solar sail a net force of zero.

Mass (kg)	Sail length to balance the forces (m)
200	?
400	?
800	?

If we quadruple the mass, the sail length to balance the forces increases by a factor of:

☐ 2 ☐ 4 ☐ 8 ☐ 16

Explain why that is: