Movement of An Object in Microgravity Environments

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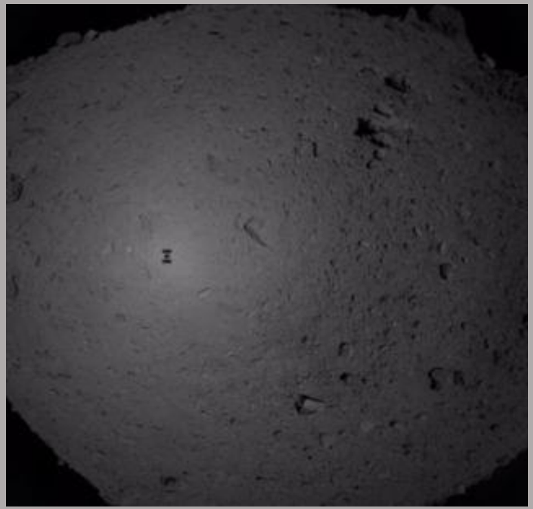
Problem Statement

- Select the smallest sized asteroid allowable to land the probe
- Develop a method to land a small probe on the asteroid with minimal amount of bouncing
- Develop a spring that will allow the device to hop without generating thrust
- Make sure the probe does not bounce too high as to escape the gravitational field on the asteroid



https://www.space.com/japanese-asteroid-probe-lands-ryugu.html

Assumptions Made

- There exists no air resistance because space is a vacuum and there is no atmosphere surrounding the asteroid.
- The distance from the main-lander to the surface of the asteroid is known.
- Due to the shape of the asteroid, the gravitational pull will vary around the asteroid. It was determined that the probe would not be traveling around the asteroid, therefore the acceleration due to gravity is negligible.

Dimensions of the Probe

- Each probe was disk-shaped
  - measuring 7 inches wide
  - 2.8 inches tall
  - mass = 2.4 lb.

- A goal of the probe is that it is expected to remain in the air for up to 15 minutes after a single hop before landing, and to move up to 50 ft horizontally.

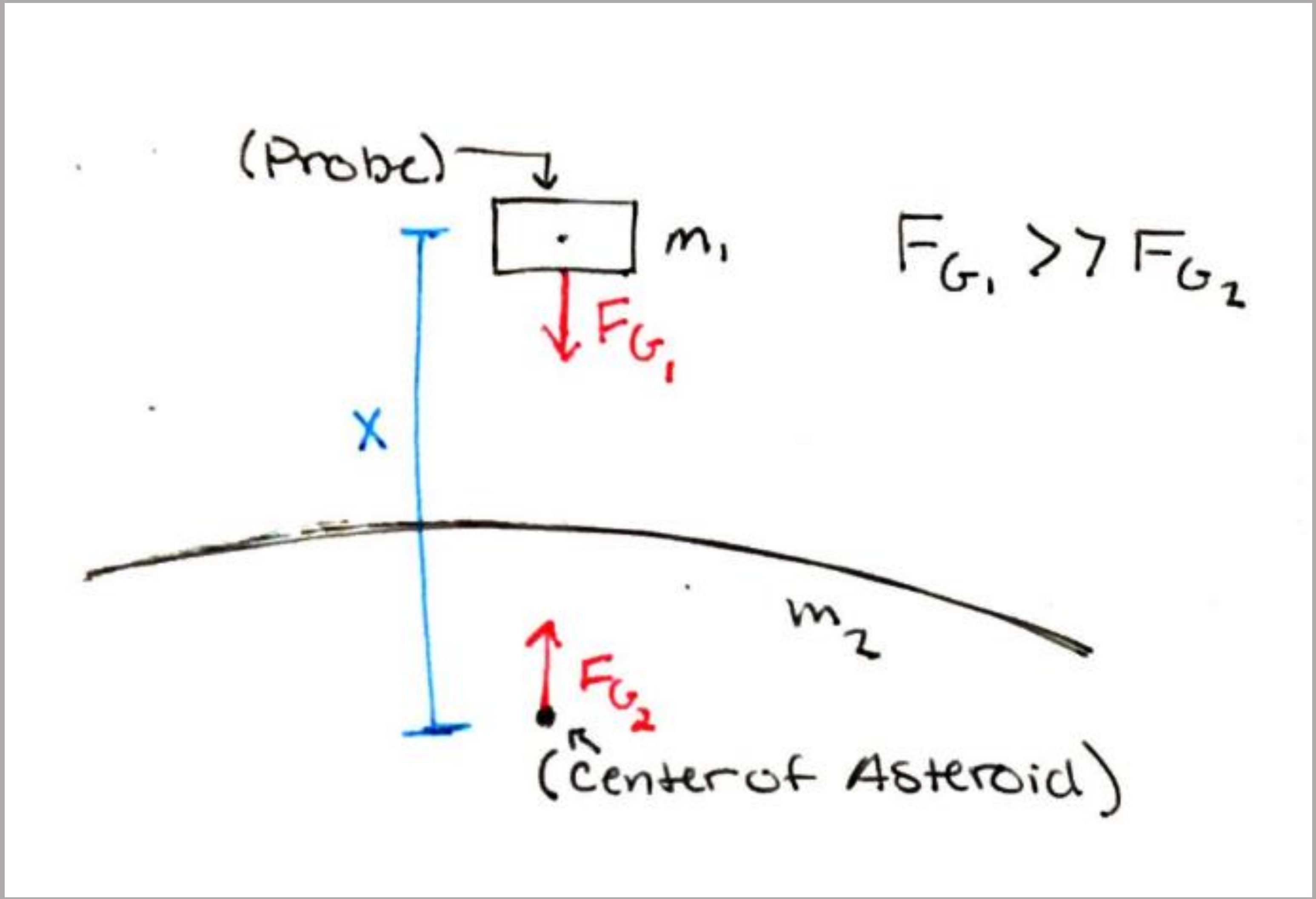
Selecting the Asteroid

- From Newton's universal law of gravitation a differential equation was determined. The differential equation allowed us to find smallest size the asteroid can be while having a large enough gravitational pull to keep the probe on the asteroid.

$$\frac{d^2x}{dt^2} = \frac{Gm_2}{x^2}$$

Note: $G = 6.67408 \times 10^{-11} \frac{m^3}{kg * s^2}$, m_2=mass of asteroid, x = distance of probe from asteroid center

Free Body Diagram for Gravitational Force



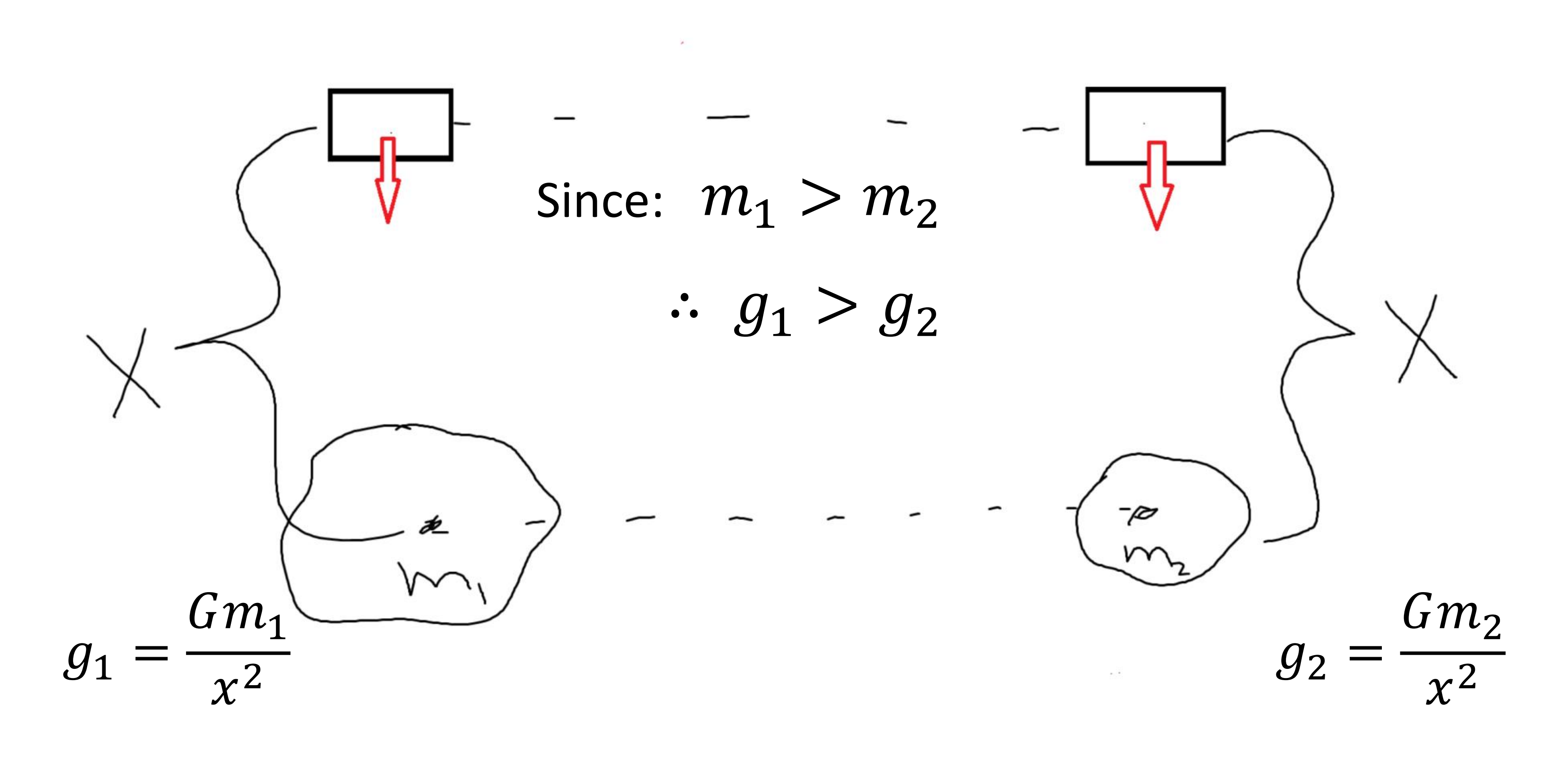
Role of Asteroid Size

- The asteroid's size affects the gravitational pull. The larger the asteroid, the greater the acceleration (due to gravity) of the probe to the asteroid's surface.

$$\frac{d^2x}{dt^2} = \frac{Gm_2}{x^2}$$

- Due to this change (say the asteroid in question is larger than the original problem)
  - The force that the probes hit the surface would be greater
  - The probes can be released from a greater distance

Free body diagram of the effects of the asteroid's size due to mass



Landing the Probe

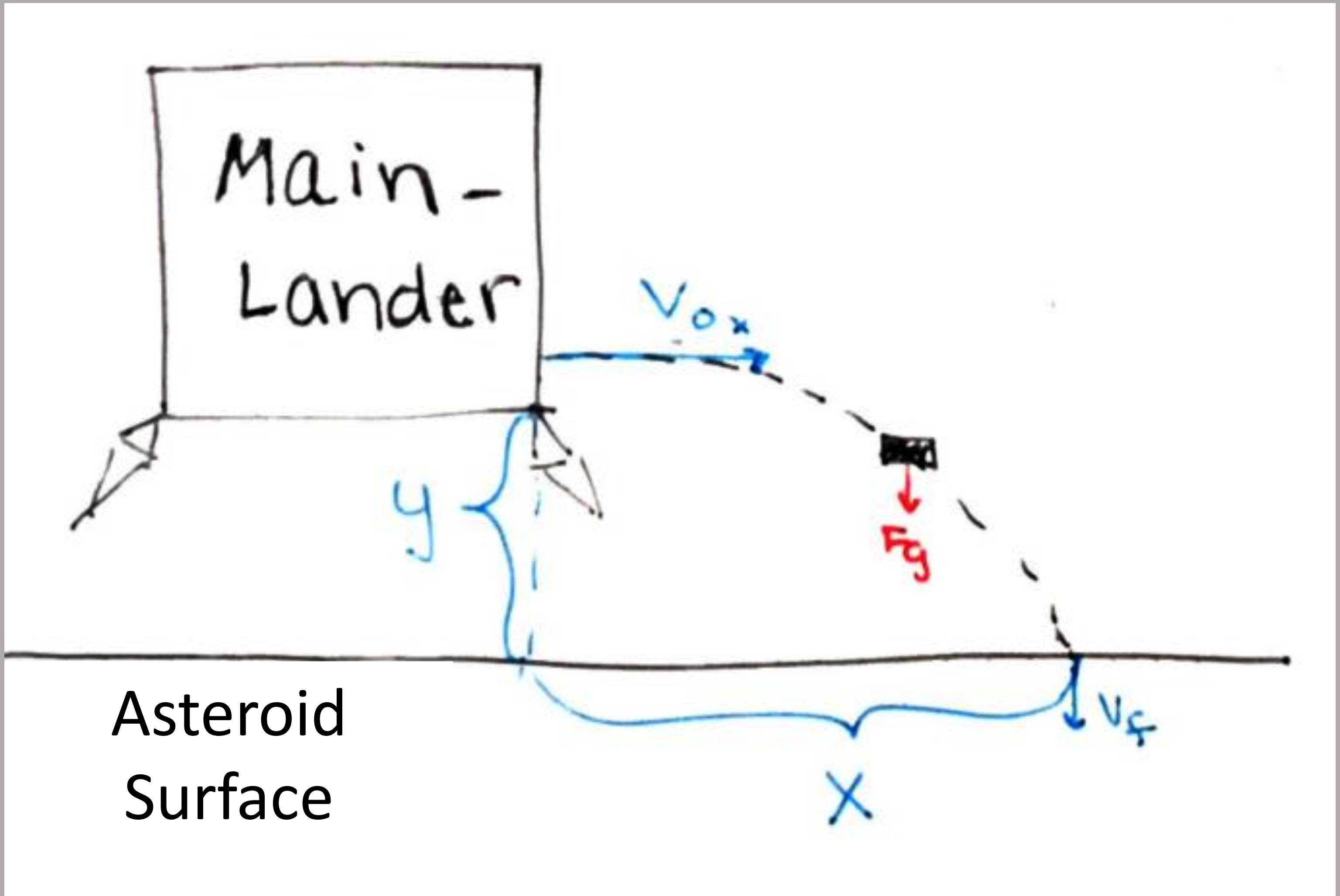
- Assume the probe is being released parallel to the surface of the asteroid.
- The equation for the x-component is used to determine the maximum distance the probe lands from the predetermined landing position.

$$V_{x,inital} = \frac{x}{t}$$

- In order to prevent damage from bouncing the final velocity in the y–component is minimized. The equation below shows how to calculate this velocity.

$$V_f = \sqrt{2gy}$$

Free body diagram of projectile motion of probe



Moving the Probe

- The spring force cannot exceed a force that would allow the probe to reach the escape velocity, so the force of the spring faces a constraint
- Using the equations below, a proper spring force and therefore spring can be solved through iterations.
- Assuming the acceleration due to gravity is known on the asteroid, kinematic equations and Hooke’s Law can be used:

$$\Delta X = V_o t + \frac{1}{2} a t^2$$

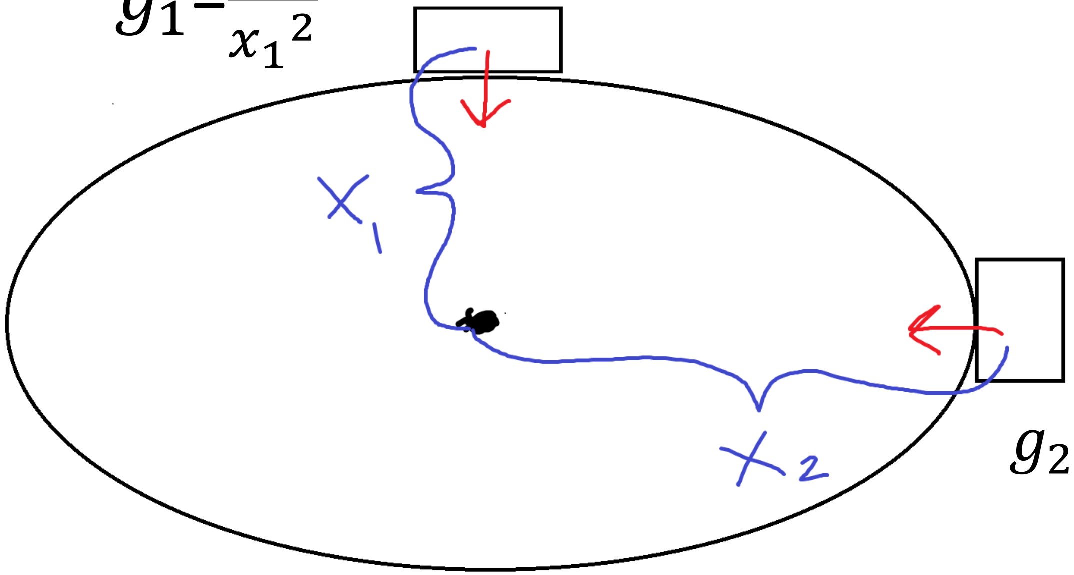
$$F_{spring} = -k\Delta X$$

Role of Asteroid Shape

- The asteroid shape affects the aspect ratio.
- For example, if the asteroid is more elliptical, the aspect ratio is larger
- Due to this change (say the asteroid in question is more elliptical than the original problem)
  - Originally, we assumed that the probe was not going to be moving a great distance and therefore, the aspect ratio was negligable
  - The force needed to get the probe to bounce is much greater in some areas than others. Therefore, the calculations need to take into account the fluctuation of the gravitational constant

Free body diagram of the effects of the asteroid's shape

$$g_1 = \frac{Gm}{{x_1}^2}$$



$$g_2 = \frac{Gm}{{x_2}^2}$$

Since: $x_2 > x_1$ $\therefore$ $\boldsymbol{g_2 < g_1}$

Effects of Changes

- Change in size
  - The original acceleration due to gravity will affect the force of the probe hitting the surface and the potential height it can drop from.
- Change in shape
  - As you move across the surface you have to aware of the gravitational constant change.
  - If you get to a point that is farther away from the center of the asteroid, you cannot use the same amount of force to hop across.

Special Thanks to Our Coach!

Dr. Suzzi Valli