SIMIODE 2019

Problem B:
Movement of an Object in a Microgravity Environment

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Challenges I

1. **Determine the range of dimensions for the smallest asteroids which can be used to land a probe.**
2. **Develop a method to land a small probe on the asteroid.**
3. **Develop a way to move the probe to a predetermined position using a spring that will allow the probe to hop in a given direction.**

Challenges II

1. **Provide guidance concerning the limits of moving the probe using a minimal number of jumps under a wide variety of situations.**
2. **Provide a detailed description of the mathematical models that describe the movement of the probe under different conditions.**
3. **The analysis should include guidance on choosing an asteroid with respect to the possible dimensions.**

Assumptions

1. There is no air resistance on the surface of the asteroid.

2. There is no horizontal acceleration of the probe.

3. The motion of the probe can be modeled as a bouncing ball.

4. This bouncing ball during contact with the surface makes the airbag-probe system behave like a mass atop a spring.

5. The asteroid's initial landing spot is not a ravine or a cliff, rather a rugged horizontal plane.

6. When the probe bounces, we do not account for its spin.

Conditions

1. **Asteroids can have high aspect ratios and are generally not round.**
2. **The surface of the asteroid is coarse.**
3. **Probe may have to jump into a ravine or along the side of a steep cliff.**
4. **The amount of bouncing should be minimized as to avoid damage to the probe.**

Method of Selection I

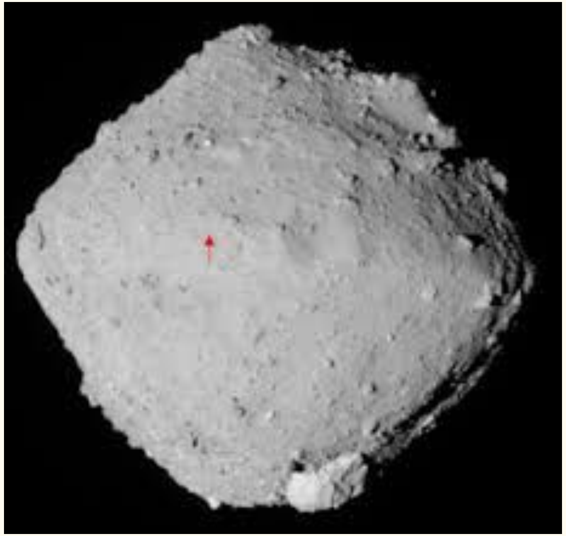
- To determine an appropriate asteroid to land on, use the following three-parameter model.
- Density (rho), Volume (V), Velocity (v_0)

$$R = \frac{2G\rho V}{{v_0}^2}$$

- If the asteroid is nearly spherical, then the above equation becomes a 4 parameter model. We add the drop distance d and the radius of the probe r.

$$\frac{8\pi}{3} G\rho R^3 - {v_0}^2 R - {v_0}^2 (d + r) = 0$$

- Let density be that of spherical asteroid Ryugu & the speed of the probe as reported in the sources provided to us, then calculated R is 474.8 m. The actual radius is 450 m.

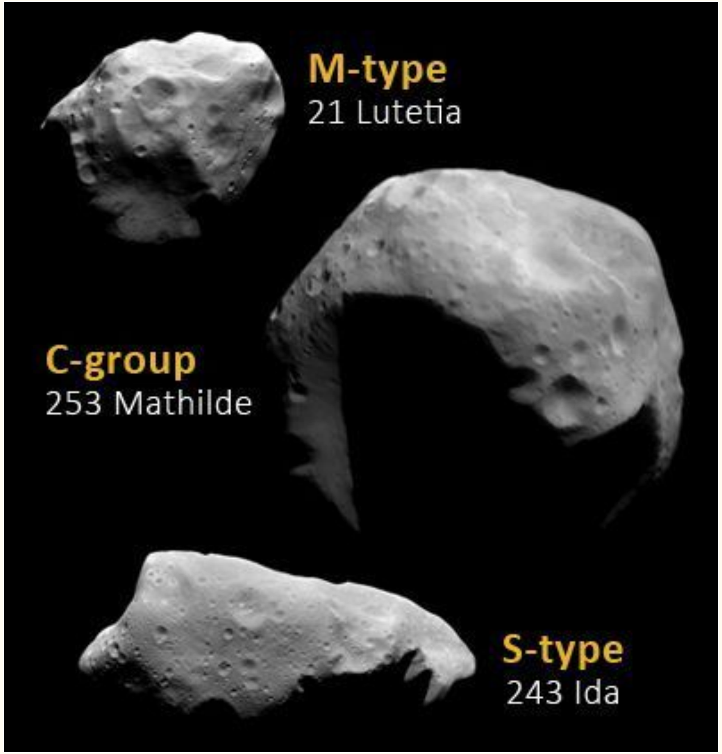


RYUGU

Method of Selection II

- 3 types of asteroids: C-type, S-type, and M-type asteroids (as classified by their spectroscopy).
- The mean density of the asteroids are
  - C-Type: 1380 kg per m cubed
  - S-Type: 2710 kg per m cubed
  - M-Type: 5320 kg per m cubed

- If asteroids are spherical, and the probe's velocity is 0.38m per seconds squared, then the corresponding radii are
  - C-Type: 456.3 m
  - S-Type: 331.8 m
  - M-Type: 242.5 m



Method of Landing I

- Probe with airbag
- Modeled as a spring when in contact
- Modeled with projectile motion otherwise
- Loses kinetic energy with each consecutive bounce
- We model the airbag-probe system as a bouncing ball

Method of Landing II

- When the equation is in free-flight, i.e., not in contact with the surface it can be modeled by

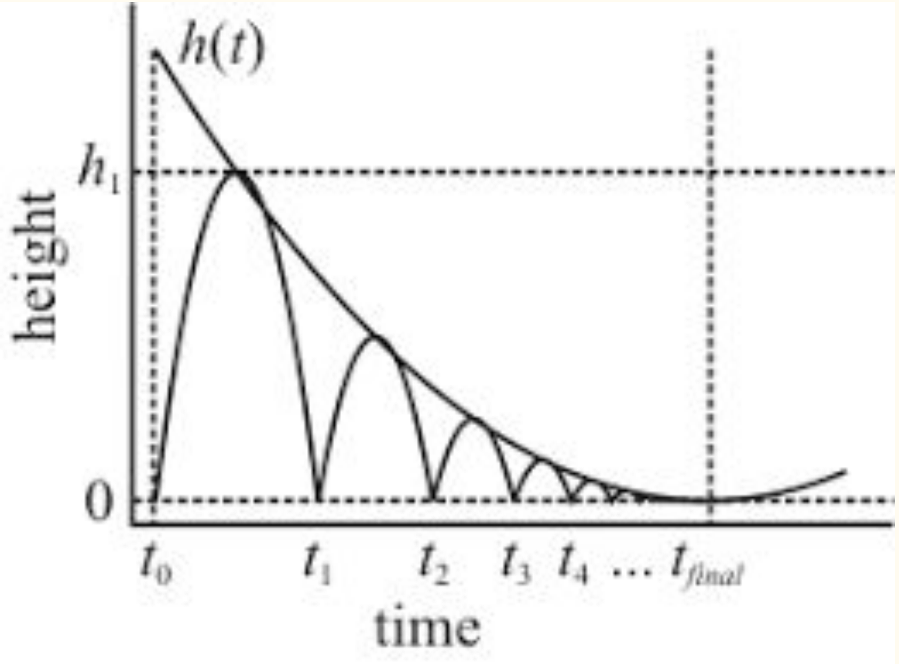
$$y''(t) = -g, \; x'(t) = v_{0x}$$

- When the equation is in contact with the surface it can be modeled by

$$my''(t) = k(L - y(t)) - mg,$$

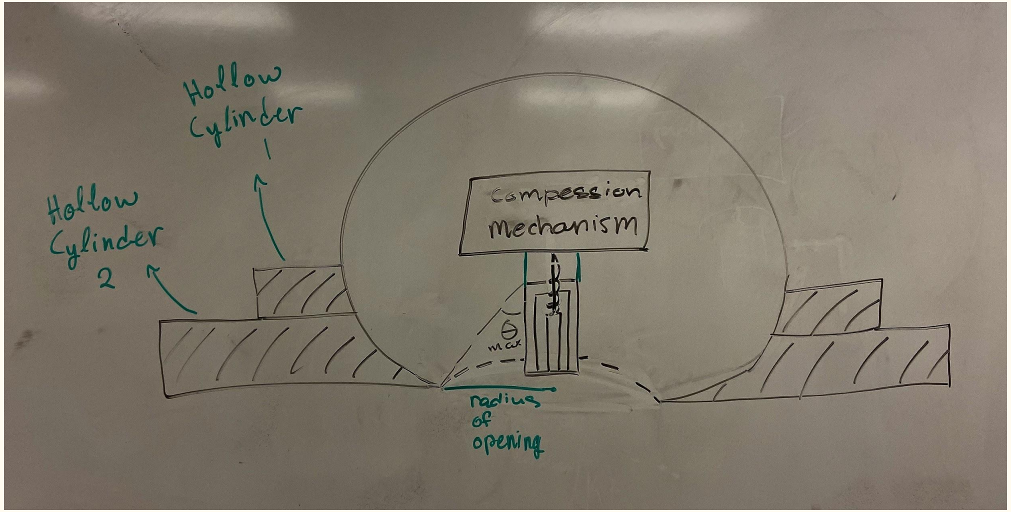
$$mx'(t) = -k_f(k(L - y(t)) + mg)$$

- To use equations, iterate them with new initial conditions.



Design of probe

- Open bottom
- Inward contracting spring launcher compressed by some mechanism
- Bottom heavy probe
- Two stacked hollow cylindrical stabilizers



Method of Traversal

1. Two-parameter model of projectile motion
2. Conservation of energy
3. Amount of energy and jumps predetermined
4. obstacles (Hills/Ravines)

$$\frac{1}{2}kc_i^2 = \frac{1}{2}mv_f^2$$

$$x(t) = v_{0x}cos(\Theta)t$$

$$y(t) = v_{0y}sin(\Theta)t - (1/2)gt^2$$

Where Θ is restricted to the radius of the opening

$$|v_0| = c\sqrt{\frac{k}{m}}$$

$$|v_0| < |v_{esc}|$$

Method of Selection Bonus Challenge

To determine size of asteroid, we use

$$R = \frac{2G\rho V}{{v_0}^2}$$

If the shape is a sphere, then V=V(R)

If the shape is not a sphere then V=V(R)

Where R is the distance from the center of the shapes (largest diagonal).

Original 4 parameter model goes unchanged.

You choose, the density of the asteroid, choose the shape, the radius of the probe, distance from the surface, and the velocity of the probe.

If the size of the asteroid changes, this will impact the amount of mass is lost by the asteroid,

- which affects the escape velocity of the asteroid.
    - which affects our choices for the spring constant k and the compression distance c of the spring
    - which affects the method maximum distance the probe can clear
    - thereby affecting the maximum circumference the probe can travel on the asteroid

Method of Traversal Bonus Challenge

- **How can your probe travel around the circumference of the asteroid as close to the path as possible?**
- Probe has inward contracting spring launcher that can extend in a cone shape of acute angle θ out the bottom.
- This angle is determined by the probe and can be adjusted after each successive launch and subsequent bounce as to correct the distance the probe has strayed away from the path around the circumference of the asteroid.
- The contraction of the spring prior to the ejection of the launcher can also be minimized which results in a small launch and subsequent small bounces, which minimizes the distance from the desired path
- This will require more launches to make it around the asteroid but will travel very closely to the path.

Method of traversal II bonus challenge

- What would happen if our probe rolled? (no stabilizers)
- We could model it as a solid sphere with a non-uniform density
- Our model would then have to take into account the angular velocity gained from projectile motion, inertia, and the friction between the probe and surface
- Final orientation of the probe after rolling

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