Surface-Lander Interactions on Small Bodies

Cecily Sunday, Naomi Murdoch, Claudia Valeria Nardi, Sara Morales Serrano, and David Mimoun

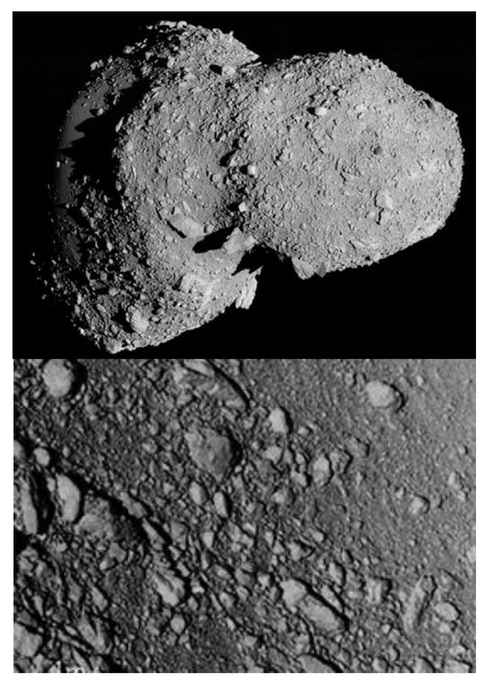
Institut Supérieur de l'Aéronautique et de l'Espace

Overview and Motivation

Goal: To study low-velocity collisions into granular materials under reduced gravity conditions

Application: Previous ground-based observations and space missions have shown that small bodies such as comets and asteroids are covered by loose regolith. Understanding how this granular material behaves in low-gravity conditions is useful for the design and operations of future surface-landers, in addition to being important for studies of the geophysical evolution of the asteroid surfaces

Motivation: The experiment is designed based on the parameters of the 2014 Hayabusa-2 JAXA mission to near-Earth-asteroid 1999 JU3



Surface images of Asteroid Itokawa, as taken by Hayabusa-1 [2]

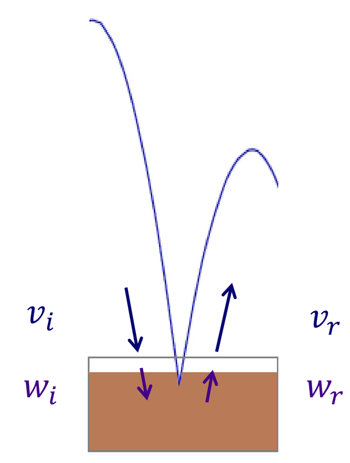
Artist rendition of Hayabusa-2 and MASCOT (Photo Credit: DLR)

- One of the surface packages that Hayabusa-2 will deploy is the 10 kg lander, MASCOT (DLR/CNES). MASCOT will impact the asteroid's surface at 10 – 20 cm/s [1]
- MASCOT will assist in-situ science investigations at 3 different sites [1]. In order to succeed in its operations, the lander cannot be in rebound during the entirety of its life

Objectives

1. Measure coefficient of restitution as a function of surface gravity for a projectile impacting a granular material at a collision velocity of 10 – 20 cm/s
2. Obtain the projectile's acceleration profile as a function of surface gravity as it is decelerated and restored during the collision by the granular material

Theory



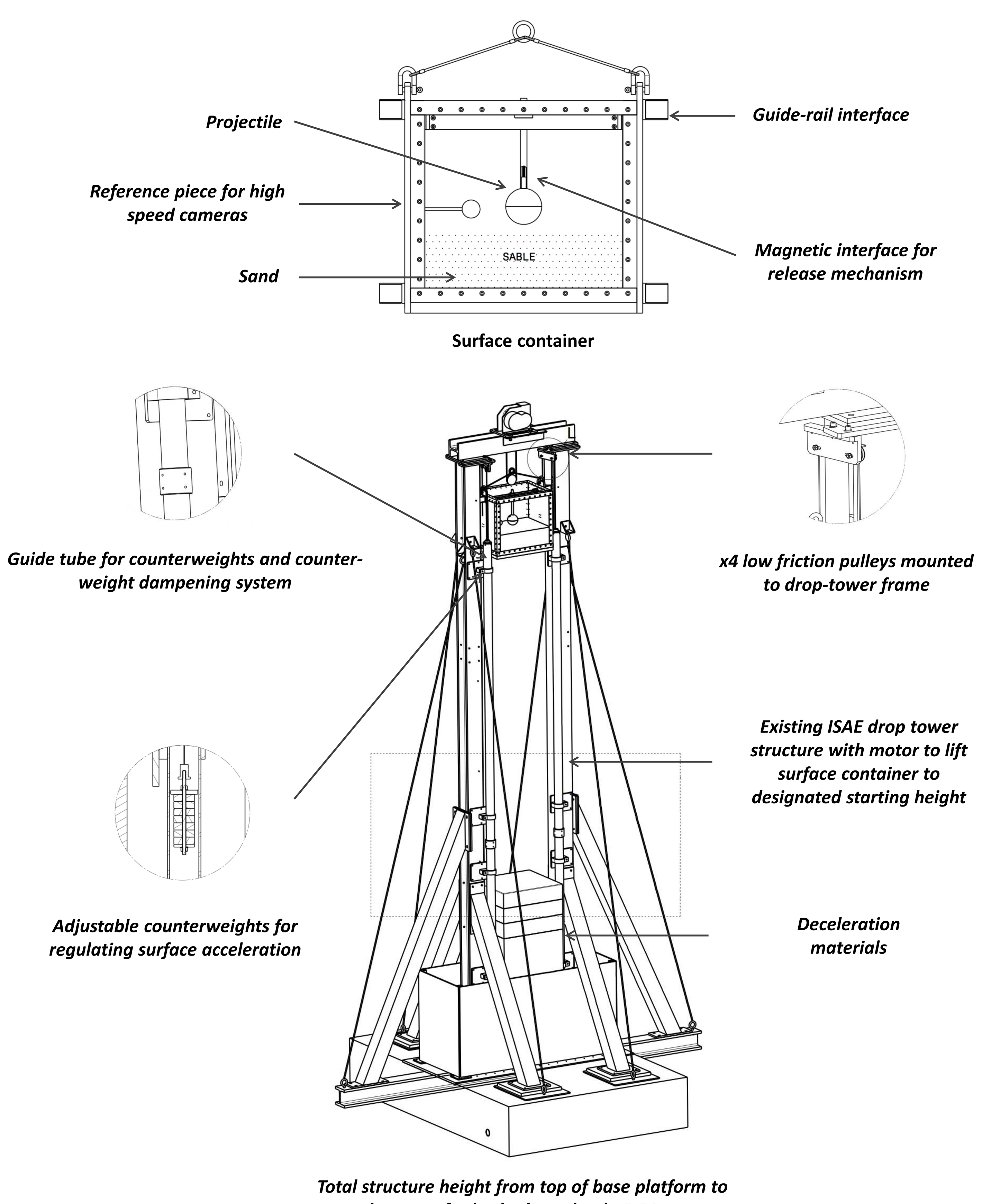
$$CoR = \frac{v_r}{v_i} = \sqrt{\frac{w_r}{w_i}}$$

v_i = Projectile impact velocity
v_r = Projectile rebound velocity
w_i = Work done to bring projectile to rest
w_r = Work done to restore projectile to flight

- The coefficient of restitution (CoR) provides a measure of amount energy lost during a collision
- Energy can be lost during granular collisions due to inelastic collisions between grains, friction between grains, and lifted material [3, 4]
- Energy losses during granular-surface impacts are not well understood for low gravity environments because the reduced weight of the particles allows for forces like cohesion to have a greater effect on granular interactions than they do on Earth [5]

Experiment Design Features

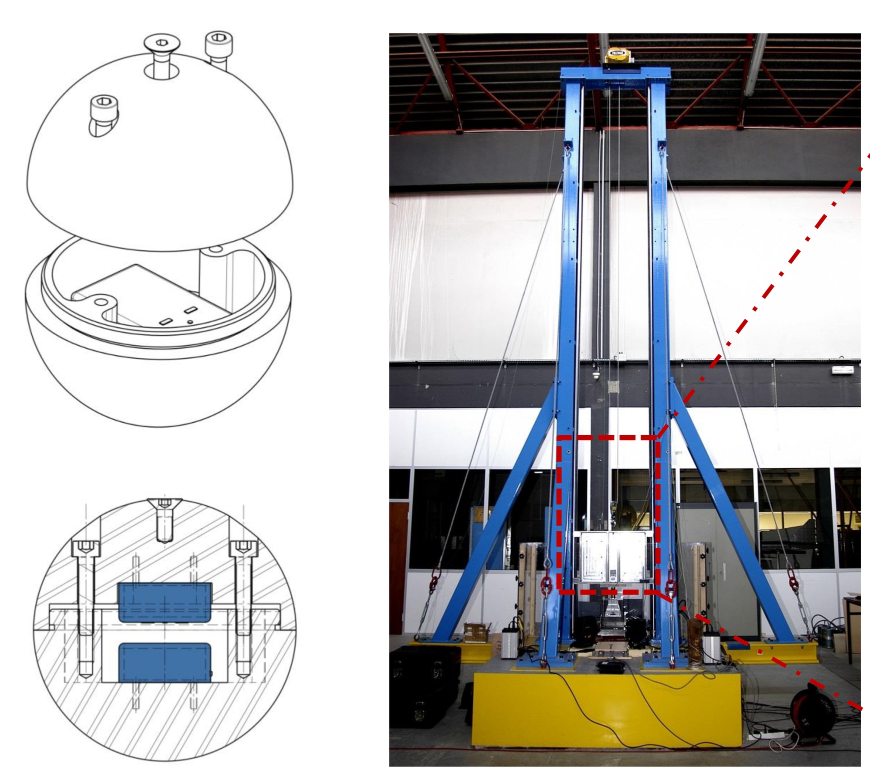
1. The granular surface is provided a constant downward acceleration using an Atwood machine, or a system of pulleys and counterweights, so that the surface experiences reduced gravity conditions at the time of the collision
2. The projectile and surface container are simultaneously released from rest using a magnet and mechanical hook assembly
3. The starting height of the surface container and the initial separation distance between the projectile and surface are variable, so that collision velocity and effective acceleration can be controlled

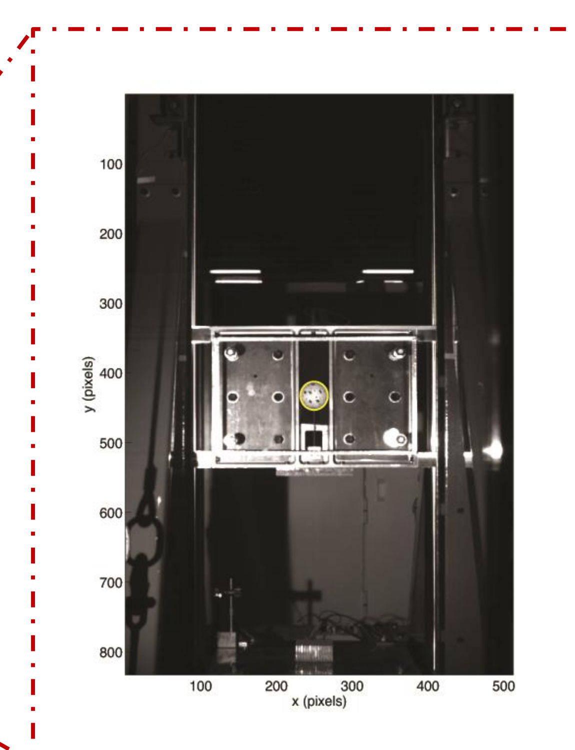


Projectile shape	Sphere
Projectile diameter	100 mm
Surface sample material	1 – 2.5 mm quartz sand
Depth of sample material	150 mm
Horizontal cross-section of container	650 mm x 430 mm
Maximum drop height	2.5 m
Maximum speed of surface container	7 m/s
Minimum counterweight mass	TBD based on pulley friction
Maximum counterweight mass	6.75 kg

Data Collection and Processing

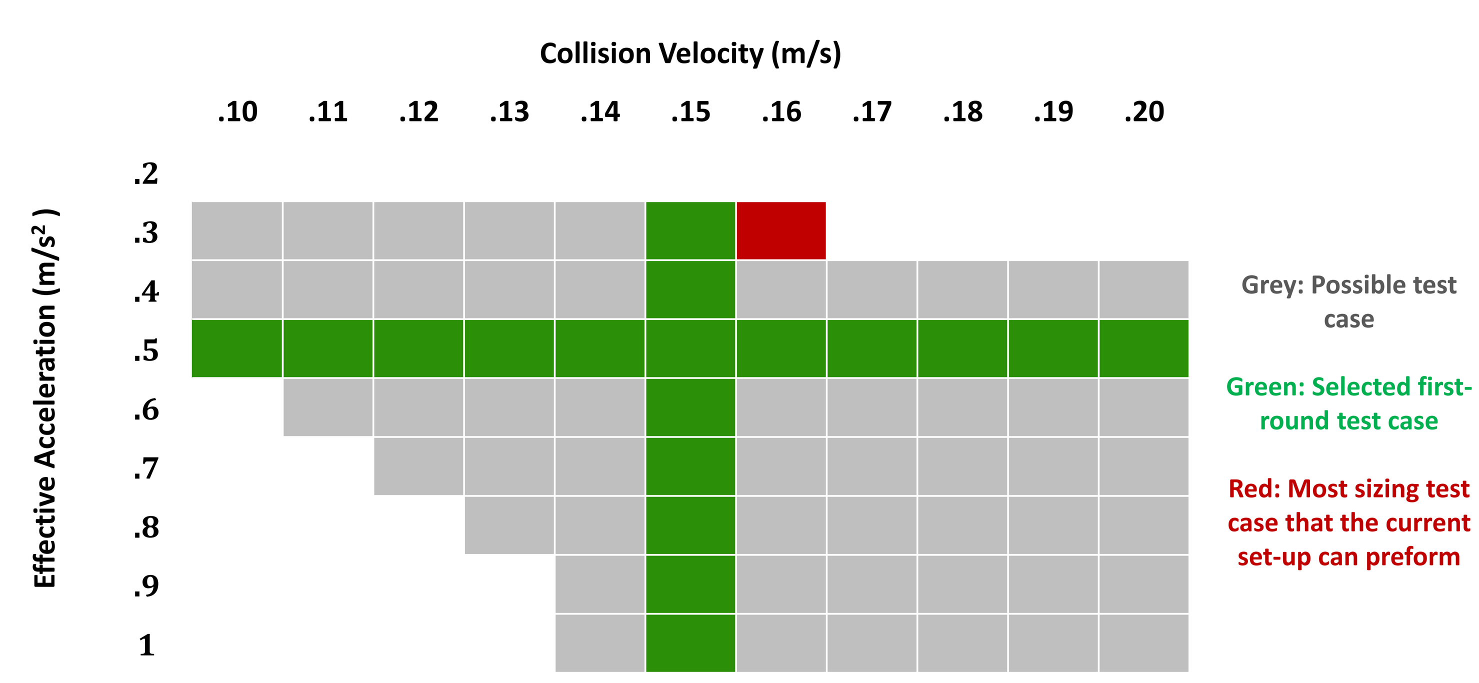
- 2 wireless, 3-axis accelerometers are mounted inside of the projectile. Data will be used for collision time, penetration depth, and work-based CoR calculations
- High speed cameras capture the collision at 1000 frames per second within a 1 meter filming window
- A particle tracking program in MATLAB is used to determine the velocities of the surface container and projectile before, during, and after the collision [6]





Planned Experimental Trials

Planned experimental trials and testing capabilities of current set-up:



The following parameters may be altered for future testing: Surface simulant material, size and shape of projectile, collision velocity, and effective acceleration

Acknowledgements

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References: [1] Kuninaka, Hitoshi et al. 2013. Hayabusa-2: A Carbonaceous Asteroid Sample Return Mission. The 10th IAA International Conference on Low-Cost Planetary Missions. Pasadena, California. [2] Yano, Hajime et al. 2006. Touchdown of the Hayabusa Spacecraft at the Muses Sea on Itokawa. Science 312, 1350. [3] Wu, Chuan-yu et al. 2003. Rebound behavior of spheres for plastic impacts. International Journal of Impact Engineering 28, 929–946. [4] Tsmiring, L. S., et al. 2005. Modeling of impact cratering in granular medium. Powders and Grains 2:1215, 1223. [5] D. J. Scheeres et. al. 2010. Scaling forces to asteroid surfaces: The role of cohesion. Icarus, 210: 968-984. [6] Crocker, J. & Grier, D. 1996. Methods of Digital Video Microscopy for Colloidal Studies. Journal of Colloid and Interface Science, 179, 298–310(13).