

USING BLENDER AS CONTACT DYNAMICS ENGINE FOR CUBESAT LANDING SIMULATIONS WITHIN IMPACT CRATER ON DIMORPHOS

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Introduction

Landing on small-bodies is a hectic task that requires high degrees of autonomy, robustness to various uncertainties and fast close-loop iterations. Milani is a 6U CubeSat that will be launched as payload for the Hera mission and will be deployed in the Didymos binary system. As an end-of-life strategy, the CubeSat will attempt to land on an artificial crater generated by the DART mission on the surface of Dimorphos: the smaller body on the Didymos binary system. Due to mission constraints, Milani's descent trajectory will be ballistic. Because of that, the attitude with which the CubeSat will impact the surface of the asteroid is the only control variable that could be used to modify the final trajectory.

In the current landing simulation scene, contact dynamics tools play a fundamental role. Developing them is a very complex task, however several options used in the video-game and VFX are available. In this work, a study is performed exploiting the contact physic engine in Blender to simulate the bounce-off trajectories followed after impact on different areas around the crater.

Dimorphos

Dimorphos is the secondary body of the Didymos system. Its shape model is currently modelled as a triaxial ellipsoid with the major axis of 170 m. The exact shape of the body is still unknown and will only be partially resolved once the DART spacecraft visits the system in October 2022. Dimorphos orbits about the barycenter of the system in a circular orbit of 1.2 km radius and an orbital period of 11.9 hours. The orbit is coplanar with the equatorial plane of Didymos. Similarly to the Earth-Moon system, Dimorphos is tidally locked, always exhibiting the same face to the primary.

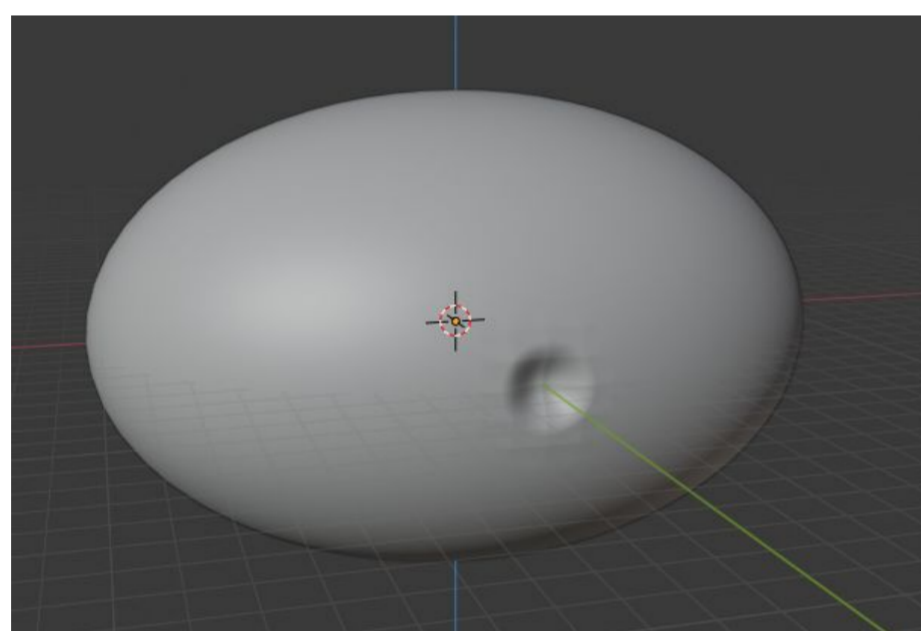


Figure 1: Shape model of Dimorphos with an artificial crater.

In order to slow down Dimorphos and change its orbital period, DART will impact the secondary at the center of the face in the anti-velocity direction, generating an artificial crater. The key characteristics of the crater such as shape, size and depth have large uncertainties associated to it. For the purpose of this work, a regular crater 20 m wide and 4 m deep is considered, corresponding, thus, to an aspect ratio of 0,2. The crater is generated on the shape model using a proportional deformation tool in Blender. The mesh's resolution has been increased over the crater region, while it has remained low for the remaining shape model regions.

The artificial crater will then be investigated in detail by the Hera mission and specifically by the Milani CubeSat, which will have a hyperspectral imager to characterize surface composition of both bodies and of the excavated material [1]. At the end of the Milani mission, an experimental phase is designed that will attempt to land the CubeSat within the crater for additional scientific investigations.

Blender

To simulate the contact dynamics for the simulated landing trajectory, a contact dynamics engine is required. Typically, the development of such environments is the most time-consuming and technically challenging part of these analyses.

The current scene regarding contact dynamics tools is very much linked to graphic design SW, typically used to create cinematics or video games. It is specially on these sectors, where the most powerful and renown tools are developed. In an attempt to make use of this great amount of resources available, some of these tools were screened for landing-design applications.

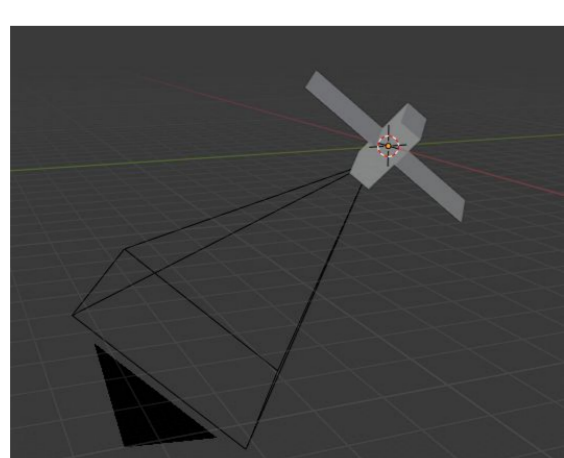


Figure 2: Milani CubeSat shape model.

After a thorough research, Blender was chosen mainly because of its open-use license and the strong community support. It also offers the option to initialise the simulations using Python scripts that are executed using the internal distribution that comes with its installation. Blender's core functionality as rendering engine can also be integrated in future works to generate images during the landing. This makes for a very organic way to link the simulations with the platform and the post-processing functionalities.

Methodology

The study case used as proof-of-concept for this method is based on an "entry-gate" landing technique [2], in which a gate is defined close to the landing spot. The mission profile then aims to arrive to this gate within a certain velocity threshold so that it is guaranteed the arrival point is within a certain region.

These initial velocity is set up by introducing "keyframes", i.e., way-points that fix the initial position and velocity of the spacecraft on the Blender simulation.

Other than kinematic properties of the scenario, it is also possible to introduce a dynamic environment in Blender by indicating the value of the acceleration at each simulation frame. Because this acceleration values depend on the position of the spacecraft at each frame, they need to be updated accordingly as the simulation goes. These acceleration values are computed using AstroSim, a GNC simulation tool developed internally at Deimos Space that includes the polyhedron dynamics, which are used for these analyses.

To keep the script as detached as possible from the GNC simulator, an interpolator for the acceleration values is created using an homogeneous spherical distribution (Fibonacci distribution). With a grid resolution of 10 m, concentric spheres are concatenated to guarantee that the simulation will not be outside the interpolated region.

Object physical properties are also set from the aforementioned script, including bounciness coefficients and frictional properties of the bodies involved in the simulation. Finally, the trajectory followed by the spacecraft, including the bounces, is integrated by the Blender's physic engine, complemented by the acceleration values obtained from the interpolator.

Validation

Blender is meant to be used as a graphic design tool, thus, the parameters included as properties are not always scientifically defined. For instance, the Coefficient of Restitution (CoR) is referred to as Coefficient of Bounciness (CoB), which may or may not be the same parameter that is usually applied in contact dynamics formulation. Since the way Blender manages the different parameters set up for each simulation is a black-box for the user, a set of validation tests has been performed.

The first test involved a plane and an icosahedron. The latter is dropped from a fixed height. By changing the CoB of the two objects, the CoR can be computed as the fraction between the magnitude of the velocity after and before the impact. From this simple test it is possible to determine that the physical CoR is the product of the bodies' CoB, as it is possible to see from the Figure 3.

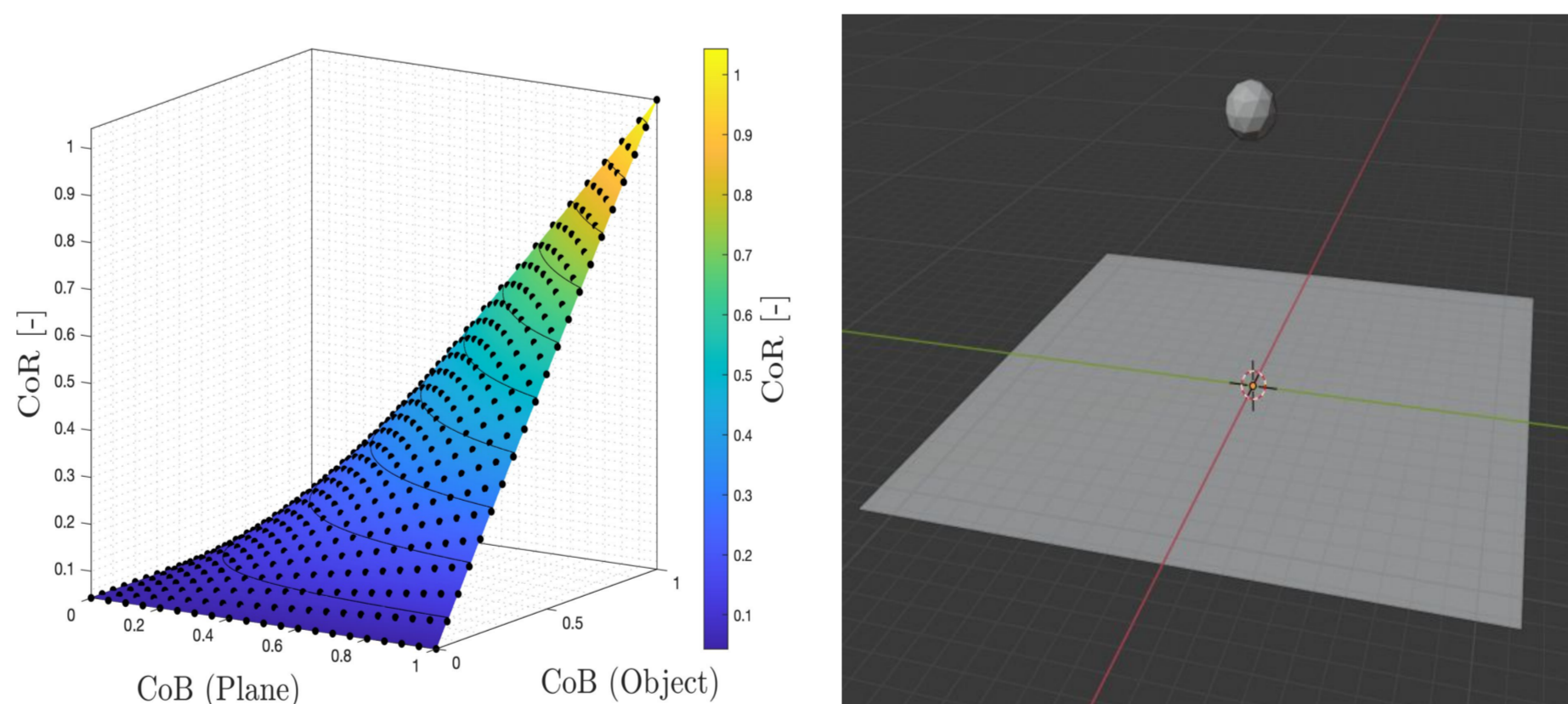


Figure 3: CoB-CoR validation test in Blender.

The other test was to perform an orbital propagation using the acceleration keyframes given by the gravitational interpolator previously created. The results show that the error after 4 hours of propagation stays below 10 m. This is acceptable for landing lasting around 20 minutes, since it translates into an error of 10^{-2} m.

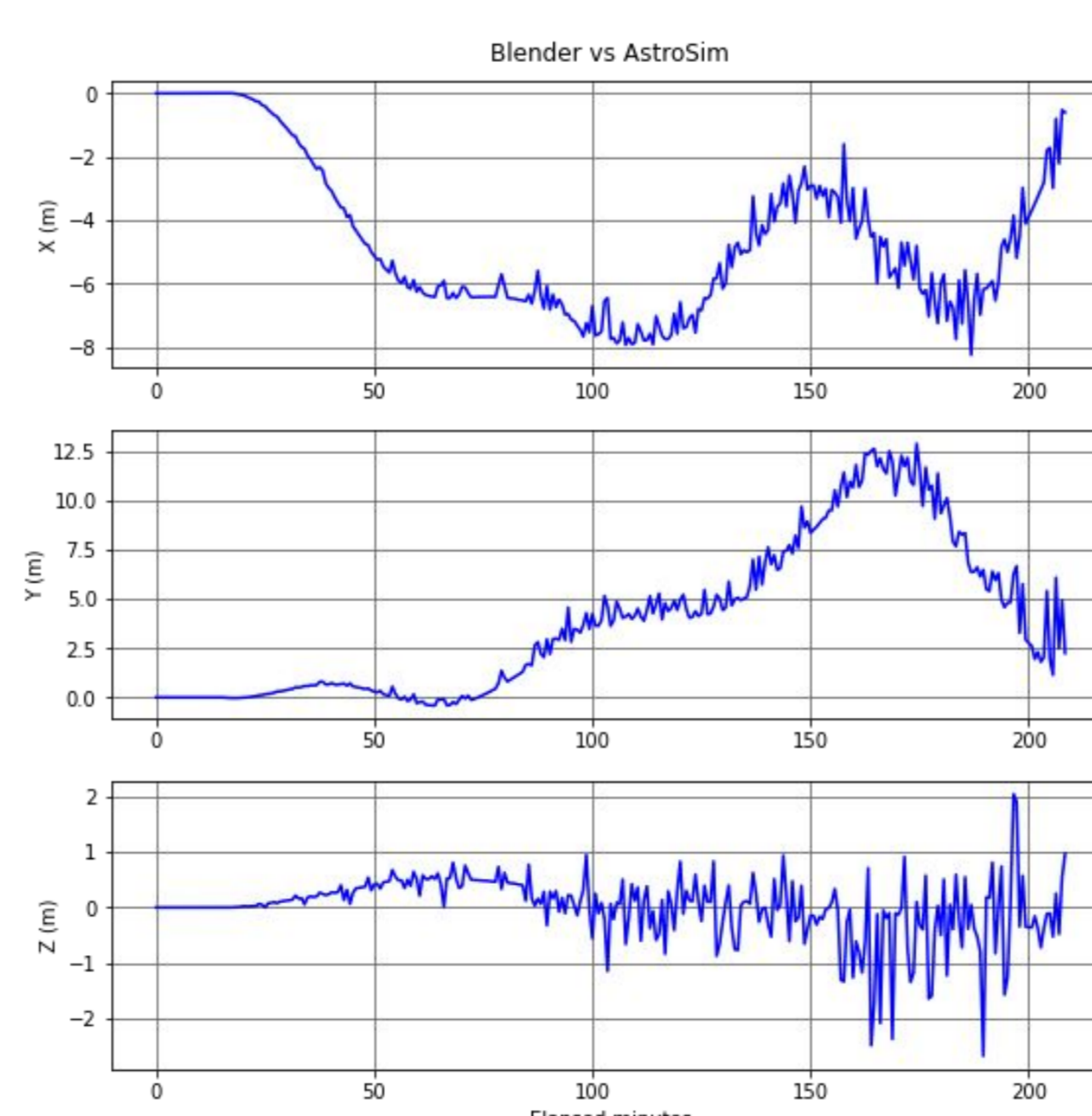


Figure 4: Trajectory propagation errors between Blender and AstroSim.

Results

For the preliminary analyses in this work and to test the methodology developed, the CubeSat starts the simulation from a static position and is accelerated towards the body by its gravity only, creating an effect referred to as "CubeSat rain". 3600 cases are simulated, starting from a gate at an altitude of 10 m, uniformly distributed. The attitude of the CubeSat is the same for each trajectory: payload pointing towards nadir and solar panels aligned with the Z-axis of the asteroid fixed frame.

Figure 5 shows the horizontal displacement for each trajectory, i.e., the horizontal delta in position from the start of the trajectory (at the gate) to the final settling point (on the surface). Trajectories that started above a highly-sloped point of the surface exhibit the greatest displacement, which is direct consequence of the slide/rebounds they suffer until they stop.

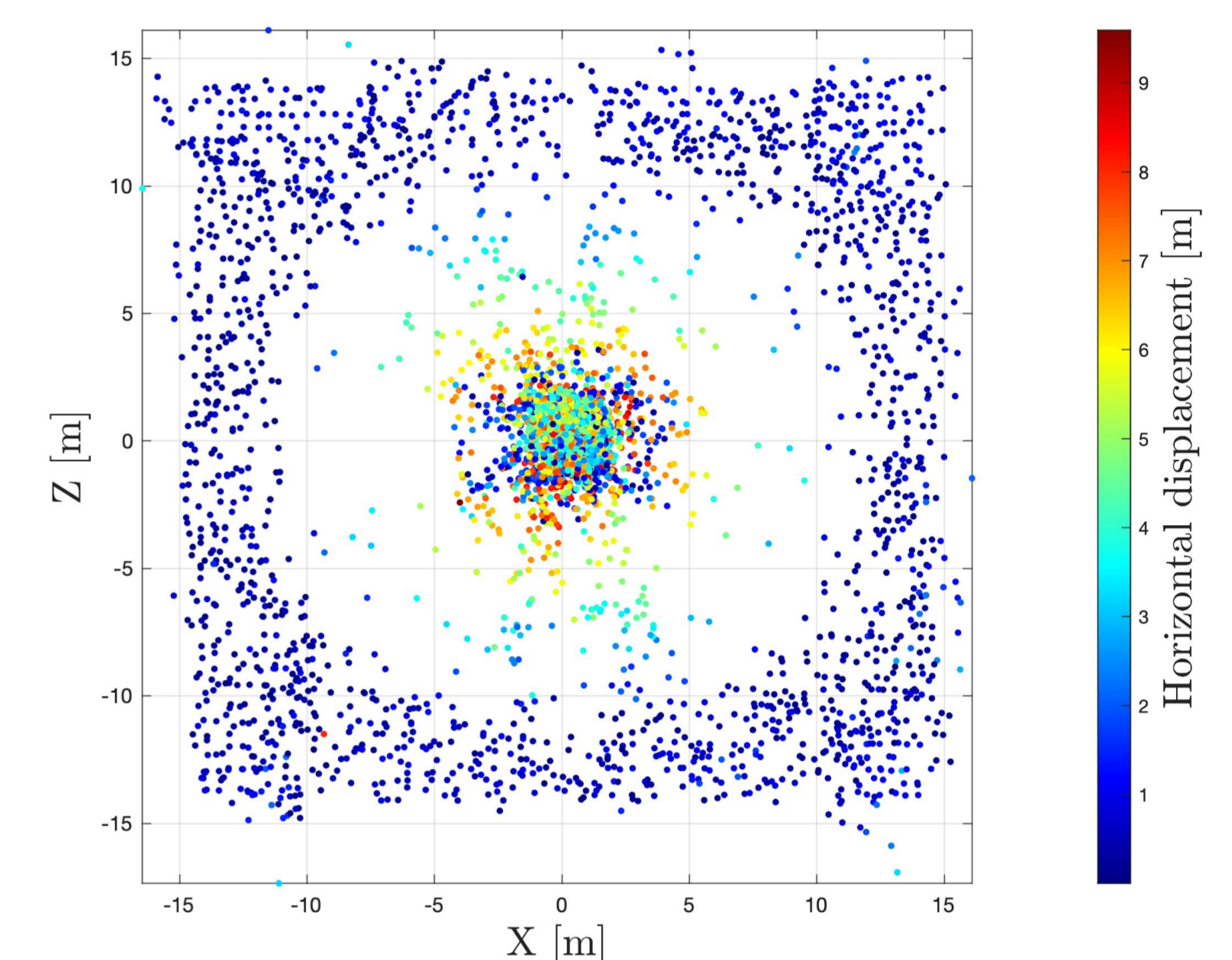


Figure 5: Settling positions for the simulated scenario.

The most obvious result is that the trajectories whose first bounce happens within the crater diameter tend to end up lying on the centre of the concavity. A very interesting consequence of the selected attitude is a denser group of points along the Z-axis. This is explained by the orientation of the solar panels, which are parallel to this axis, and prevent the CubeSat from rolling towards the centre. Because the CubeSat will slide over the crater's interior instead of roll, the settling point for a considerable number of trajectories ends up further away from the crater's center. This results demonstrate how easily the attitude can affect the bouncing of the CubeSat on the surface of the asteroid.

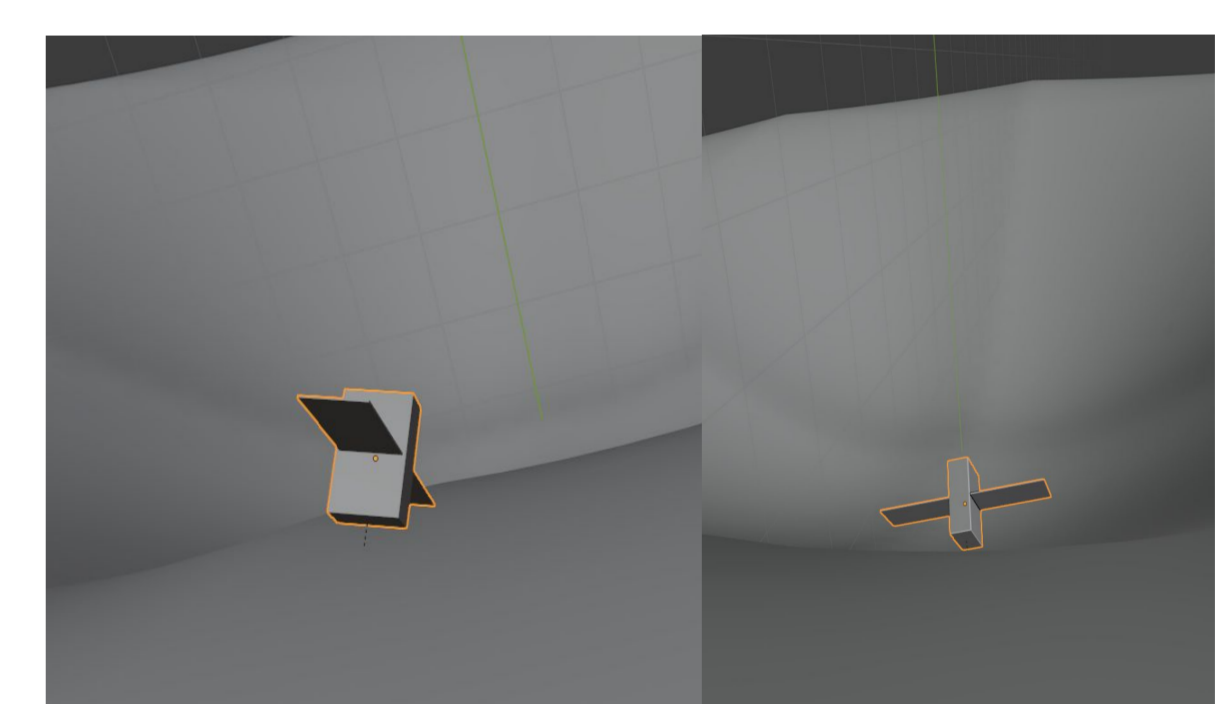


Figure 6: Examples of landings where the panels generate a "breaking effect" (left) and where they don't (right).

Conclusions and Future Steps

In this work Blender has been adopted as an experimental tool to simulate contact dynamics for Cubesat landing simulations within the crater region of Dimorphos. The system dynamics have been replaced by a spherical grid interpolator and the trajectories have been propagated using Blender's own numerical methods. Validation tests have shown that Blender is a valid tool to simulate landing and bouncing on the surface of an asteroid.

Future steps will be directed towards mapping landing surfaces of different crater models, and how to make use of these maps for navigation purposes, correlating them with on-board images.

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