DYNAMICS AND GRANULAR MECHANICS OF ZERO GRAVITY EXCAVATION OF C-TYPE RUBBLE PILE ASTEROIDS. C. Purrington[1] and D. Crull[1], [1]Karman+, c.purrington@karmanplus.com, d.crull@karmanplus.com (Karmanplus Inc., 2301 Blake St Suite 100, Denver, CO 80205)

Introduction: The path to a successful asteroid mining operation is not trivial. However, with multiple national asteroid sample missions successfully interacting with small bodies, collecting material and returning samples back to Earth there is sufficient data that warrants re-visiting surface excavation of C-Type asteroids. Karman+ is currently building the first commercial asteroid mining mission to a C-Type asteroid.

C-Type Surface Conditions: The evidence of low grain cohesion, unconsolidated surfaces and relatively weak strength of material observed on Ryugu and Bennu, is informative for the development of asteroid surface excavation technology. In the mission to Bennu, the OSIRIS-Rex spacecraft during descent penetrated ~48.8cm into the surface of Bennu, with only a small reactive force of 10-15N [1]. This led to the conclusion that the surface is an unconsolidated surface of loosely held together material. Even under this light load the surface material was observed to fracture and disaggregate, indicating that some material on Bennu has relatively weak material strength. Finally, during the operation of the OSIRIS-Rex Touch-and-Go Sample Acquisition Mechanism, an estimated 6000 kg of material was mobilized while an estimated 2 kg or less of material was captured [1]. The asteroid material in this low cohesive and low gravity environment was easily mobilized under relatively light forces. Ryugu and Bennu have low density relative to their volume, supporting the conclusion that both bodies have high porosity; for example, 40% of Ryugu's volume is estimated to be empty space [2]. This is further evidence for a body that is loosely held together.

Surface Excavation: The surface properties in both Ryugu and Bennu indicate that excavation on the surface is an attractive path for collecting mass. This is in contrast to capturing the entire asteroid to perform excavation. With relatively small forces applied mechanically to the surface, asteroid grains of various dimensions can be mobilized and redirected to an onboard storage system. This can be accomplished in a number of methods; however, it is prudent to choose excavation equipment that will impose predictable and controllable forces upon the host spacecraft. A mechanical arm would impose a lateral reaction force on the host spacecraft pulling it across the surface, for example, or cause the spacecraft to spin about its center of gravity. An uncontrolled movement like this could put the spacecraft into an unrecoverable scenario. The primary excavation equipment proposed in this study is an auger system. Pulling material up into the spacecraft causes a reaction force normal to the surface. A direction that can be controlled with an RCS system. Additionally, with a slowly rotating auger, the moment forces are relatively small when moving material at scale of a few kilograms compared to the mass of the host spacecraft. If the surface contact time can be constrained to less than 10 seconds, it is anticipated that the primary force will be concentrated in the direction normal to the surface.

Technical Pathforward: Simply observing the granular mechanics of Ryugu and Bennu is not sufficient to ensure a successful mining operation. Karman+ is first using a Granular DEM software, EDEM, to show that a pilot mission can successfully recover 2-5 kg of material in approximately 10 seconds. This is possible because the technology leverages the properties observed during the Hayabusa2 and OSIRIS-Rex operations in a near-zero gravity environment. This excavation equipment will then be flown on multiple zero-gravity flights to increase the technology readiness level. Successful tests must be performed in zero-gravity before graduating to flight hardware. Humans in general have very limited experience with moving granular material in a near zero-gravity environment and creating initial design experiments in simulations prior to moving on to zero-gravity flights increases the probability of successfully optimizing testing parameters and efficiency, setting up the best possible scenario for when Karman+ arrives at our first C-Type asteroid in the next few years.

References:

[1] D. S. Lauretta et al., (2022) Spacecraft sample collection and subsurface excavation of asteroid (101955) Bennu Science, 377 (6603), pp. 285-291 https://www.science.org/doi/abs/10.1126/science.abm1018

[2] A. Tsuchiyma et al., (2011) Three-Dimensional Structure of Hayabusa Samples: Origin and Evolution of Itokawa Regolith, Science, v. 333(6046), p. 1125-1128, doi: 10.1126/science.1207807

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