A Novel Lifecycle Extension Plan for the Efficient Usage of On-Orbit Post-Consumer Assets

Jaclyn R. Wiley, Henry S. Neiberlien, Olivia R. Kirk, Andrew P. Bronshteyn

Abstract

Asteroid mining is a potential form of commercial space industry, and significant amounts of research have gone into the feasibility of that activity. Less research has been done on what happens to the asteroid post-mining; the two primary end-of-life scenarios for the remains of a mined asteroid are not ideal. The remains could be deorbited, which entails complex technical and legal challenges, or they could remain in orbit, which could lead to collisions and a general increase in space debris. This proposal outlines a solution for the post-consumer asteroid issue which avoids creating more space debris and the risky business of deorbiting. This solution is to use the post-consumer asteroid shell as a shelter for delicate equipment or as a “garbage can in space,” which would hold the remains of defunct satellites until the time they could be more safely deorbited. The shell of the asteroid would provide protection from space debris impacts and some radiation. This proposal also discusses some of the major technical and legal challenges that this solution would face, and how stakeholders could potentially address them. More research is required to gain a better understanding of the challenges and opportunities that this proposal faces, which can be conducted during the long-term development of commercial asteroid mining technologies.

Potential Design

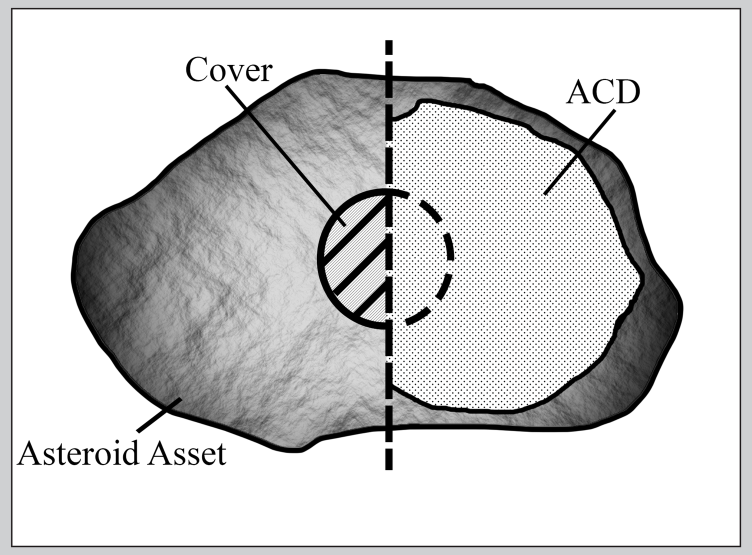

Fig. 1. A front view of an asteroid shell with a single, large sealed ACD

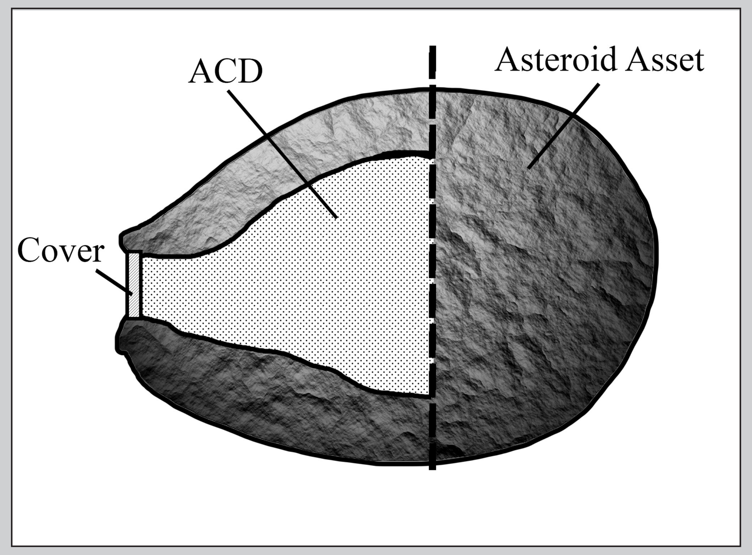

Fig. 2. Side view of an asteroid shell with a single, large, sealed ACD.

Introduction

The majority of space exploration has been motivated by political competition or scientific interest, rather than by economic interests. A potential boom for the space industry has been identified in resource extraction from asteroids. Space agencies and companies have developed technologically feasible plans to retrieve asteroids, some of which place the captured asteroid in in lunar orbit. Other studies have proved a Earth orbit would be technologically feasible. We assume that asteroid resource extraction ventures will be successful in the identification, capture, and retrieval of asteroid assets to Earth orbit.

Once these assets are returned to the Earth and completely mined, they can be deorbited, abandoned on orbit, or used for a further mission. The primary objective of this study is to identify a useful secondary mission to prolong the profitable lifetime of an asset in Earth orbit. A further objective of this study is to reduce the risk to human life and property that could arise from deorbiting asteroid assets.

A mined asset combines two useful characteristics - an on-orbit source of mass and an object with artificial caverns and depressions (ACDs). The ACDs in the surface are a result of the extraction efforts. Depending on the asteroid’s composition, the ACDs will vary in size and depth, potentially ranging in volume from a few cubic centimeters to tens of cubic meters. The ACDs will be surrounded by massive amounts of material, which could be used as passive shielding. We propose that the ACDs in the asteroid be used to store space debris and delicate payloads (“objects”). This solution would make use of the existing characteristics of the asset and would help to combat space debris, as well as providing a further revenue stream for the asset’s owner beyond the finite resources the asset holds.

Theory

Asteroid assets post resource mining operation can be utilized for further scientific research and storage after their useful life for resource extraction has been exhausted. The Artificial Caverns or Depressions (ACD) created by mining operations can then be used for storage or as a protective vessel for future missions.

The ACD’s can be inexpensive prefabricated capsules that would act as a natural shield against space debris and offer shielding against radiation due to the material composition of the asteroid. The thickness of the material surrounding the ACDs would determine the passive shielding potential of the ACD.

A space object can be struck at any point on its surface by space debris and micrometeoroids. Collisions between objects in space take place at high velocities, and are often quite destructive and costly. Placing an object within an ACD would reduce the risk of an impact with a space object. Being able to have access to a low cost protective shell provided by a previous space mission and with no overhead launch cost could become very advantageous in the crowded space environment in the future.

Space objects interact with multiple types of radiation while orbiting the Earth. Passive radiation shielding is advantageous because it is simpler than active shielding and can block high-energy radiation if thick enough. Asteroid material used as passive shielding could be used to protect objects from potentially harmful radiation.

ACD’s created as a result of future mining operations have enormous potential for future utilization in the space environment for a wide variety of missions due to the unique advantages they provide.

Calculations

Billingham et al. found that a column density value of 550 g/cm2 of passive shielding material is required to simulate radiation levels of 0.5 rem/year, and the radiation exposure from a solar flare is attenuated to below 20 rem [17]. In order to calculate the thickness of the walls needed to simulate radiation levels on Earth, the density of the asteroid asset is needed. Carry calculated the average bulk density of Bus-Demeo taxonomic classes of asteroids in 2012 [19].

To calculate the Te, the constant for column density was divided by the ρa of common types of asteroids.

$$T_e = C/\rho_a \quad (1)$$

The uncertainty of the ρa was accounted for by converting the uncertainty into a percentage, and then multiplying the Te by that percentage to find the uncertainty of the Te value.

$$\sigma_{T,e} = (\mu\rho_a)(T_e) \quad (2)$$

The absolute value of Te,s was added to the Te to find the minimum safe thickness.

$$T_{e,m} = T_e + |\sigma_{T,e}| \quad (3).$$

To achieve a 300% safety factor, the Te,m was multiplied by 3.

$$T_s = (T_{e,m})(3) \quad (4).$$

Results

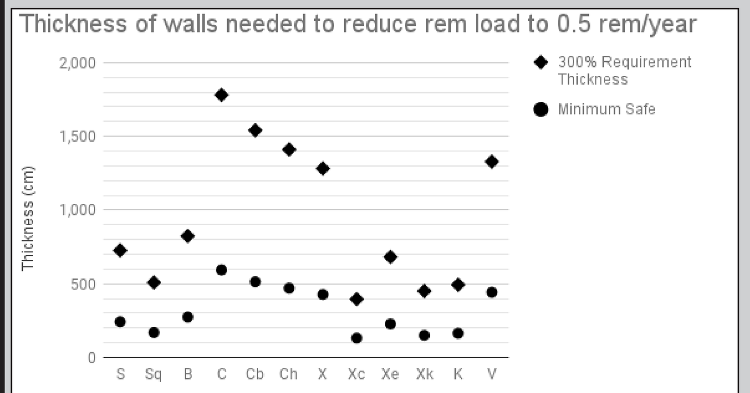

Fig. 4. The thickness of the walls required to simulate Earth rem/year levels, using the 20% accuracy restriction calculations.

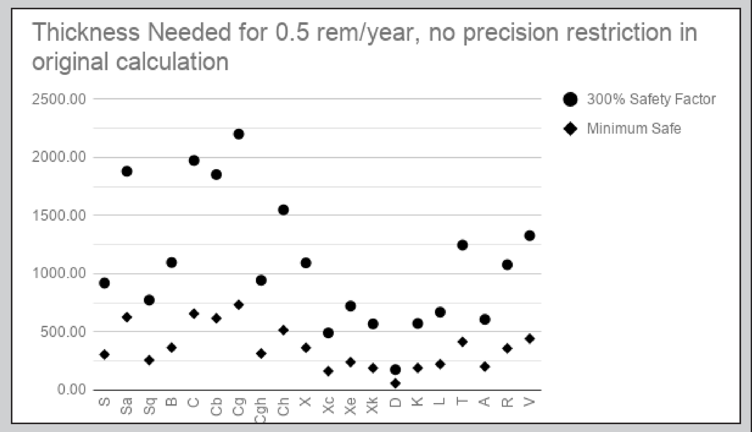

Fig. 5. The thickness of the walls required to simulate Earth rem/year levels, with no restriction on measurement precisions.

Discussion

While ACD’s provide many advantages they have several issues and disadvantages that that present themselves when attempting to utilize the asteroid assets for space debris disposal. First obstacle is capture, rendezvous and insertion. Multiple designs for spacecraft have been proposed to actively remediate space debris, called “catcher” spacecraft. These “Catchers” would retrieve the debris for storage in the ACD’s inside the asteroid asset. Catcher spacecraft must rendezvous with thea steroid asset. This rendezvous could be done with human assistance or autonomously. The concept of autonomous rendezvous has been proven by the Defense Advanced Research Projects Agency (DARPA) Demonstration of Autonomous Rendezvous Technology (DART) mission. Though the concept has been proven, the technology is still being improved and developed. Powering the payload inside the ACD is also an issue that needs to be addressed. A sealed ACD would not be compatible with solar cell technology, since the solar cells would be sequestered from solar energy, and therefore useless. Solar cells would have to be mounted to the outside of the asteroid in order to capture sunlight. Another source of power to payloads within the asteroid asset is a radioisotope thermoelectric generator (RTG). RTGs do not require sunlight or other outside factors to create power, and can operate continuously for decades. Another issue with the ACD is the creation of space debris. A space debris removal mission is a failure if the mission creates more space debris than it removes from the space environment. One of the mission designs in this proposal is an active space debris removal plan. Multiple portions of the mission design could result in the creation of space debris.

Using post-mining asteroid assets also presents some advantages. A benefit to utilizing an asteroid asset as passive shielding is that the shielding material is already on orbit, and therefore, does not need to be launched. Utilizing massive assets that are already on orbit as passive shielding could be a way to reduce launch costs and encourage more business in space. Beyond shielding delicate or heat-sensitive payloads, the asteroid could be used to store space debris, potentially creating a positive impact on the space debris environment around Earth. There are multiple potential applications of the ACD storage concept, for both biotic and abiotic missions.

Conclusions and Recommendations

Conclusions

1. Comprehensive study of asteroid assets considered for the implementation of this proposal is required.
2. The placement of space debris into the asteroid asset will be technically challenging, though they might become less so as related technologies develop.
3. Asteroid material could provide adequate passive shielding material against radiation if utilized on orbit.

Recommendations

The authors recommend multiple areas of further study, which are concentrated into two main areas: Pre-Mission and Mission-Specific.

The Pre-Mission recommendations are:

*To conduct comprehensive study of asteroid assets returned to Earth orbit
*To experiment to determine the effectiveness of the mission design with a coherent non-ccoherent asteroids.
*To research atmospheric effects on the asteroid asset

The Mission-Specific recommendations are:

*To research different designs for ACD covers
*To research the potential implementation of inflatable habitats within assets
*To determine the space debris impact of such a mission
*To compare the space debris creation vs. mitigation potential of the mission

Finally, the authors of this paper recommend a full-scale feasibility study for this concept. If it is found to be feasible in some or all conditions, then it should be pursued further.