Are chemical rockets or solar sails better to return resources from asteroids?

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Artist's depiction of an asteroid field. Credit: NASA / JPL / Caltech

If and when we ever get an asteroid mining industry off the ground, one of the most important decisions to be made in the structure of any asteroid mining mission would be how to get the resources back to where all of our other infrastructure is—somewhere around the Earth.

That decision typically will focus on one of two propulsion

methodologies—chemical rockets, such as those we already use to get us into space in the first place, or solar sails, which, while slower and unable to get us into orbit, don't require any fuel. So which propulsion methodology is better for these future missions? A study by researchers at the University of Glasgow looked at those two scenarios and came out with a clear-cut answer—solar sails.

When answering these types of theoretical questions, it is essential to impose limits on the answers. For example, billions of asteroids exist in the solar system, so it's more realistic to only look at those known as near-Earth asteroids (NEAs). But even so, there are over 30,000 known NEAs. It would have been impossible for lead author Merel Vergaaij, then a Ph.D. student at the University, and her colleagues to calculate optimized trajectories for each of them.

So they broke the area around Earth down into generalized orbital parameters—semi-major axis distance, eccentricity, and inclination. With those three parameters, it is easier to get a handle on what a general transfer orbit would look like to a given asteroid in that region of space, some of which would be quite close to Earth on its orbital path.

Other constraints were also necessary—such as calculating only the cost and benefit of transferring material back from the asteroid, not the mining of the asteroid itself. Getting the mining equipment there and set up was considered beyond the scope of this paper. Moreover, there needed to be a wait time at the asteroid itself so the return mission could have time to stock up on the material it would be carrying.

That material, in this calculation, was volatiles. Volatiles, such as water, have been a focal point of asteroid mining discussions, as they form the basis of rocket fuel that would be needed to explore farther into the solar system and cost a lot of money to bring up from Earth itself. Moreover, chemical rockets can then use some of those volatiles as their own fuel

to make their way back to the Earth system.

A few more constraints fell into place, including sending the volatiles back to geostationary orbit (GEO), some assumptions about launch costs based on the projected costs of Starship, and determining that all-important metric of economic studies—the net present value (NPV).

NPV is the outcome that the solutions would be judged on and based on various calculated factors. These would include a variety of costs, such as launch cost, development cost, manufacturing cost, and operational cost. The revenue would be calculated based on the expected value of the volatiles delivered to orbit. When the revenue exceeds the cost of the mission, the NPV turns positive, which, in this case, indicates whether a mission to an asteroid in that area would be worth it.

To make that determination, the authors used a technique called a genetic algorithm to solve an optimization problem. Essentially, they gave the algorithm a bunch of parameters, such as the orbital mechanics, masses of the spacecraft, and the amount of volatiles returned and told the algorithm to optimize the all-important NPV value. The algorithm's outcome was very clear—solar sails have positive NPVs for a wider variety of areas located in near-Earth space.

Primarily this was due to some weaknesses in chemical rockets. They had to use some of their delivered material to get back to GEO. And, while the time for their transfer orbit was shorter, another factor of the NPV, the discount rate, which lowers the amount of expected value of a resource the farther in the future it is sold, doesn't take enough out of the value of that which the solar sail can bring back that would make it on par with the chemical rocket.

There were still some areas of near-Earth space that even solar sails were not profitable in, so the authors suggest that future asteroid miners look

at asteroids in the specific regions they call out as potentially profitable if they are looking for their first major mining site. In addition, the researchers made some modifications to their original baseline missions structure, such as stopping at a Lunar Gateway, adding a second trip, and running a series of variable simulations, known as Monte Carlo simulations, that would test the extent to which these different schemes were profitable.

Both adding a second trip and stopping off at the Lunar Gateway rather than GEO added significant value to each type of mission architecture. The Monte Carlo simulations also showed that their profitability was consistent with slight input costs and output revenue variations. Overall, while there are potentially profitable targets for each type of propulsion system, it seems that solar sails are clearly the winner between the two. Now it's up to those who hope to build the first asteroid mining empire to listen.

The study is published in the journal *Advances in Space Research*.

More information: Merel Vergaaij et al, Economic assessment of high-thrust and solar-sail propulsion for near-earth asteroid mining, *Advances in Space Research* (2020). DOI: 10.1016/j.asr.2020.06.012

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