

De-Spinning Asteroids: Using Laser Ablation to Manipulate Asteroid Motion

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The Earth is continuously under threat from asteroids. We in the DE-STAR (Directed Energy System for Targeting of Asteroids and exploRation) Lab are working on technology to defend Earth from this threat. To do this, we use focused kilowatt-class lasers to vaporize a point on the asteroid's surface, and create a plume of ejected asteroid material that acts as propellant that changes the asteroid's trajectory and rotational motion. However, our technique has the potential not only to deflect, but also to de-spin large asteroids for mining, repurposing, or for more effective deflection. This project examined the plausibility of de-spinning an asteroid using laser ablation. We've found that this method is sufficiently effective.

Keywords: laser ablation, de-spin, DE-STAR, meteorite, asteroid, rotational motion

I. INTRODUCTION

About 116 meteorites strike Earth every year [1]. Most don't cause noticeable damage; however almost annually one will cause death, injury, or environmental damage [2]. These events usually involve relatively small particles; but if an asteroid on a kilometer scale were to enter the atmosphere and strike the Earth, the damage could be catastrophic.

This possibility has concerned scientists for years, and as a result they have developed means of predicting asteroid courses [3]. In the DE-STAR lab we are developing technology that, once an asteroid is found to be on a collision course with Earth, would effectively deflect it and avoid impact.

There are many other proposed methods to mitigate asteroid threats. For example, impactors are a common consideration, which either collide with [4] or collide and explode upon the target [5]. They are capable of delivering megatons of force in a short period of time; however that force often goes into splintering the asteroid [5] and not effectively deflecting it. DE-STAR is not only reliable, but also capable of delivering equivalent amounts of force over longer periods of time.

While others have focused on our method of directed-energy ablation as a means of avoiding collisions, there is additional potential not only to achieve more efficient deflection but also to manipulate and utilize non-threatening asteroids for multiple beneficial purposes.

Asteroids contain a wealth of materials useful for construction, obtainable without ravaging our planet and destroying its ecosystems. M-type asteroids contain very large quantities of refinery-grade nickel and iron [6], perfect for use on Earth or even for in-space construction.

There is potential to use asteroids to build large vehicles directly in space, or even to hollow out and use an asteroid itself [7]. Manipulation of near Earth asteroids is a key component of the NASA roadmap for space technology development [8].

DE-STAR was created as a defense against incoming asteroid threats. However it has the capability not only to deflect, but also to precisely guide asteroids. DE-STAR can manipulate asteroids to be convenient for landing, or safely bring them near Earth to be mined, studied, even built upon. However, this process would be extremely difficult if the asteroid were spinning at high speed, so it is beneficial to first arrest its rotational motion.

This project examined the plausibility of de-spinning an asteroid using laser ablation.

II. METHODS

In order to get valid results, lab conditions needed to be as similar to those in space as possible. We developed a setup involving extremely low friction, realistic rotation, and a low-pressure environment (6 millitorr). Jewel bearings ensured minimal kinetic friction in our setup; but to properly simulate an asteroid rotating in two dimensions, static friction had to be overcome so that the asteroid would be in motion before ablation. To do this, we made an attachment to the spindle containing rare Earth magnets offset from the center of rotation, and a large secondary magnet that was dragged across the front of the chamber, forcing the attachment to move.

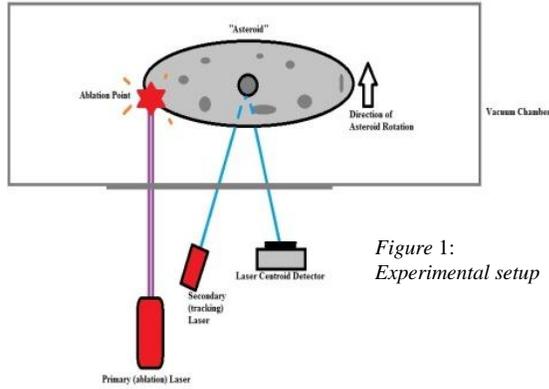


Figure 1:
Experimental setup

To measure the speed of rotation we used a method involving laser tracking. As the asteroid assembly rotated in the vacuum, a secondary laser reflected off of two mirrors mounted on either side of the spindle. The reflected laser beam swept across a laser centroid detector, which then measured the rotation rate (as shown in Figure 1).

The experiment yielded raw data for initial speed, frictional torque, and measured torque. To determine accurately the time from initial laser contact to zero rotation, we utilized Equation 1

where:

- α - rotational acceleration
- τ - torque
- ω - rotational speed
- I - moment of inertia
- m - mass
- r - radius
- l - lever arm
- w - rectangle width
- h - rectangle height
- t - time
- F - force
- P - power

$$\tau_{measured} = I\alpha$$

$$I_{disk} = \frac{mr^2}{2}$$

$$I_{rectangle} = \frac{1}{12}m(h^2 + w^2)$$

when spinning up:

$$\tau_{ablation} = \tau_{friction} + \tau_{measured}$$

then apply for de-spin:

$$\tau_{ablation} + \tau_{friction} = -I\alpha_{measured}$$

$$\alpha = -\frac{\tau_{ablation} + \tau_{friction}}{I}$$

so given an initial rotational rate ω_i and a final rate of 0:

$$\omega_f = \omega_i + \alpha t$$

$$0 = \omega_i + \alpha t$$

$$t = -\frac{\omega_i}{\alpha}$$

$$t = \frac{I\omega_i}{\tau_{ablation} + \tau_{friction}}$$

Equation 1: to convert experimental data to time

This method was used with multiple shapes of asteroid, and analyzed using the measured values of initial speed, fraction of received laser power, and lever arm, in conjunction with their different moments of inertia, to confirm the derived (equation 2) representation of deceleration under laser ablation.

III. RESULTS

The laser ablation was capable not only of quickly stopping rotation, but even reversing the direction of rotation (shown in Figure 2).

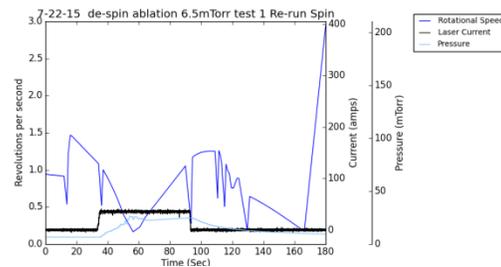


Figure 2: Rotational speed vs time plot. Data from ablation test.

Figure 2 depicts a plot (blue) of the speed of rotation of the asteroid and spindle. Also the current (black) is shown to denote at what point the laser is on. Pressure (cyan) is seen to increase during ablation.

The noise-free period in which the laser is on and ablating shows an increase in deceleration until the sample stops¹, and then a reverse in direction and an increasing speed until the laser turns off.

The laser spot is at a distance from the center of rotation smaller than the length of the rectangle but larger than its width; therefore the laser is not always contacting the sample. The rate of deceleration therefore increases as the object speed slows because at slower speeds the laser spends more time ablating the sample.

In the chamber the pressure increases as material is ablated and ejected from the sample. Nonetheless the pressure remains much lower than atmospheric pressure. The following two graphs (Figure 3 and Figure 4) show the deceleration of the same object in our setup under air and bearing friction. In Figure 4, pressure is extremely low and therefore air resistance is negligible. These graphs also show that our method of determining speed is very accurate.

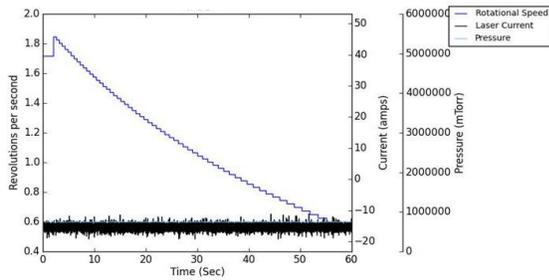


Figure 3: frictional deceleration at atmospheric pressure of 750 torr (ignore stepping)

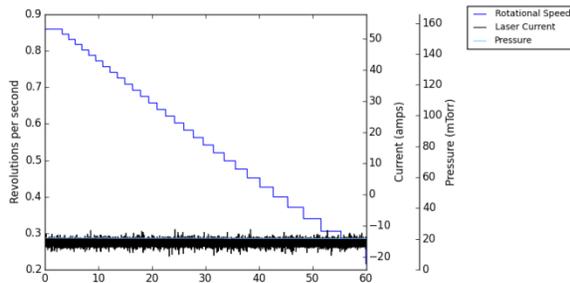


Figure 4: frictional deceleration at 6 mtorr (ignore stepping)

given initial ω_i and final speed 0:

$$\tau = I\alpha = -I \frac{\omega_i}{t}$$

$$t = -\frac{I\omega_i}{\tau}$$

τ being:

$$\tau = Fl = (\epsilon P \chi_{incident})l$$

$$F(\text{newtons}) = (\epsilon P(\text{watts}) \chi_{incident})l$$

$\chi_{incident}$ = incident fraction (fraction of total time laser is focused on target); dimensionless

ϵ = optical power coupling coefficient \Rightarrow 50 micronewtons/watt: ablation force per watt of optical power absorbed by target [9]

$$t = -\frac{I\omega_i}{(\epsilon P \chi_{incident})l}$$

Equation 2: De-Spin Formula

We derived the de-spin formula (Equation 2) using torque and rotational dynamics, and checked it against our experimental data. We found that the formula holds true. The principal sources of error arise from the estimates of the incident fraction (χ) and the optical power (P).

IV. CONCLUSIONS

The experimental data confirmed the validity of the assertion made by the de-spin formula. To ensure that this prediction method applied for different shapes of asteroid, we tested with multiple shapes and found that the different geometries did not affect the accuracy of our predictions compared to experimental results.

Applying the de-spin formula, we can estimate the amount of time it would take to de-spin larger asteroids. Using a simple 50 kW laser focused at the maximum radius, we could de-spin a hypothetical spherical asteroid having a 150 m diameter, a density of 2,000 kg/m³ and an initial spin rate of one rotation per hour, in about eleven days.

¹ Due to the rate at which the speed is sampled the plot does not show a point at zero speed

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APPENDIX

1. Video of the Setup in action



<https://www.youtube.com/watch?v=e6KMehUsK34>

2. Near Earth Asteroid Information

“There are currently over 8,000 known near-Earth asteroids (NEAs), and more are being discovered on a continual basis. More than 1,200 of these are classified as Potentially Hazardous Asteroids (PHAs) because their Minimum Orbit Intersection Distance (MOID) with Earth’s orbit is ≤ 0.05 AU and their estimated diameters are ≥ 150 m. To date, 178 Earth impact structures have been discovered, indicating that our planet has previously been struck with devastating force by NEAs and will be struck again. Such collisions are aperiodic events and can occur at any time.” [5]

3. Thermal Transpiration

In order to prove that thermal transpiration (Knudsen force) did not play a role in the force we were observing, we tested at varying pressures. The measured deceleration followed an exponential trend as the pressure changed, contrary to the dictations of the Knudsen force.

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