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EXPERIMENTAL CHARACTERISATION OF THE THRUST INDUCED BY LASER ABLATION ONTO AN ASTEROID

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LASER ABLATON

Analysis gained from a series of experiments has demonstrated the effectiveness and sensitivities of laser ablation as a potential method for the contactless deflection of Near Earth Asteroids. In vacuum, a 90 W continuous wave laser beam has been used to re-create the asteroid-to-laser ablation event. Assessed parameters included the mass flow rate, temperature and velocity of the ejecta plume and the height, density and absorptivity of the deposited ejecta.

Laser ablation resulted in the initial, volatile and hemisphere ejection of small, yet solid particles of ejecta. This was combined with the gaseous ejection of material that is similar to the rocket exhaust in standard methods of rocket propulsion. The ejection of solid material represents an explosive and volumetric removal of mass. It is caused by intense heating from the underling surface. This will affect the direction of the resultant thrust vector. The contamination caused by the deposited ejecta – density and absorptivity – was also found to be significantly lower, and loosely bound to the underling substrate. It could be easily removed by applying a small vibration or increase in the temperature. These results have enabled specific advancements within the ablation model to be considered. Critical factors includes the energy absorption within the target material, the formation of the Knudsen layer and the incongruent ablation of the target material.

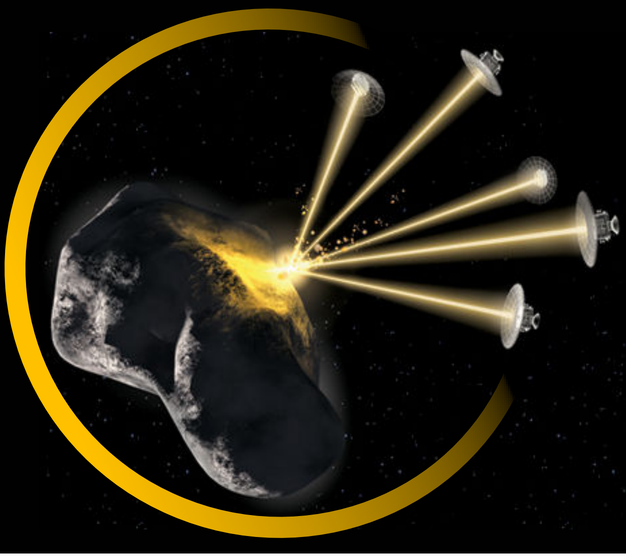
UPDATED ABLATON MODEL

The revised ablation model, improved from the experimental analysis, can be used to derive the mass flow rate per unit are of the sublimation material μ. This is achieved by considering the one-dimensional energy balance at the surface spot location. It combines the absorbed laser beam per unit area P_I, the latent heat of complete sublimation E_V, the velocity of the gaseous ejecta v, specific heat at constant volume Cv, heat capacity of the gas at constant pressure Cp, the sublimation temperature T_{SUB}, the temperature of the material prior to sublimation T_0, and the energy losses through radiation Q_{RAD} and conduction Q_{COND} respectively.

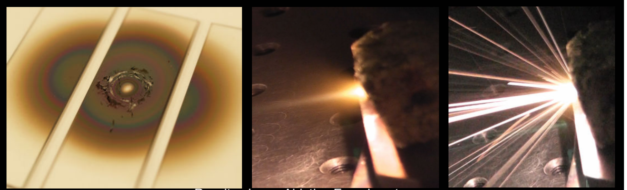
$$\dot{\mu}\left[E_V + \frac{1}{2}\bar{v}^2 + C_P\left(T_{SUB} - T_0\right) + C_V\left(T_{SUB} - T_0\right)\right] = P_I - Q_{RAD} - Q_{COND}$$

$$k_A = k_{A0}\left(\frac{298}{T_{SUB}}\right)^{0.5} \qquad \ln\frac{p_s}{p_{ref}} = \frac{E_V}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_{SUB}}\right) \qquad \dot{\mu} = (1-k)\,p_s\left(\frac{1}{2\pi R_S T_{SUB}}\right)^{\frac{1}{2}}$$

The model also accounts for energy that is absorbed by the vapor in the Knudsen layer, the dependence on the local pressure and temperature and the recondensation of the ablated material. It is currently expected that the ejecta plume will absorb 10-15 % of the incoming laser beam. The laser beam also resulted in a self-cleaning action. Local heating thermally re-evaporates & re-excites the previously deposited particles of ejecta. This would assist in increasing the lifetime of the ablation system, but would also contribute to the ongoing heating of the ejecta plume.



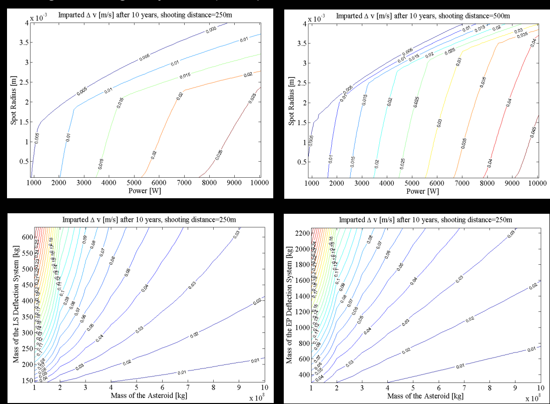
Design - Laser Ablation Experiments



Results - Laser Ablation Experiments

REVISED PERFORMANCE

The updated model has been used to evaluate the performance of the laser ablation system. Achievable Δv was assessed for different input powers to the laser, the surface spot size and the distances between the spot and the laser. The mass efficiency of the laser system was also compared to electrical propulsion systems (i.e. ion beaming and the gravity tractor) that provided the same Δ*v*.



Results - Achievable *Δv* and Mass Efficiency

For the same Δv (at the same installed power) the laser system is more advantageous. For any ion beaming technique a higher Δv can only be achieved by increasing the onboard propellant mass and mission complexity. This is not an issue for laser ablation. The propellant to sustain the defection action is provided for free by the direct ablation of the asteroid.

MISSION POTENTIAL

Ablation is advantageous as it provides a high level of controllable deflection, with a relatively short warning time and low mass into space. It also avoids the unwanted fragmentation of the asteroid and eliminates the need to physically interact with the asteroid. This removes the need for any complex landing and surface operations, It will reduce the overall complexity and risk of any ablation-based mission.

An ablation-based mission could be achieved through the utilisation of a moderately sized, yet high efficient laser. Depending on the size and composition of the asteroid, and the warning time before impact, deflection could be achieved with the successful rendezvous of a number of identical spacecraft. Their overlapping laser beams would be used to increase the surface power density, initiating the ablation process.

This will increase the redundancy, endurance, flexibility and scalability of the mission design. Multiple spacecraft also permits the delivery of a much more powerful system. reduces the risk of any single point failure from occurring.