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ASTEROID'S ORBIT AND ROTATIONAL CONTROL USING LASER ABLATION: ADVANCES IN PHYSICAL AND SIMULATION MODELLING

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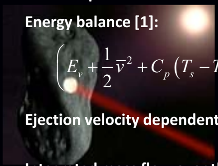
Introduction

We presents an analysis of the coupled orbit and attitude dynamics of a 50 m radius asteroid deviation mission through laser ablation. A laser beam is focused on the surface of an asteroid to induce sublimation. The resulting thrust induced by the jet of gas and debris from the asteroid, directed as the local normal to the surface, can be employed to contactless manipulate its orbit. The effect of an off-set of the thrust vector, induced by the laser, with respect to the centre of mass can produce a variation of the angular velocity. In turns this induces a variation of the sublimation that affects both the orbital and attitude motion. Thus, the control of the coupled orbit and rotational motion of the asteroid represents one of the key aspects contributing to the success of this deflection technique.

Methodology

- Laser performance:



Energy balance [1]:

$$\left(E_v+\frac{1}{2}\bar{v}^2+C_p\left(T_s-T_0\right)+C_v\left(T_s-T_0\right)\right)\dot{\mu}=P_I-Q_{RAD}-Q_{COND}$$

Ejection velocity dependent on temperature: $\bar{v}=\sqrt{\dfrac{8k_bT_s}{\pi M_a}}$

Integrated mass flow over the spot including rotation:

$$\dot{m}=2V_{rot}\int_0^{y_{max}}\int_{t_{in}}^{t_{out}}\frac{1}{E_v^*}\left(\left(P_I-Q_{rad}\right)-\left(\sqrt{\frac{c\kappa\rho}{\pi}}\left(T_{subl}-T_0\right)\right)\sqrt{\frac{1}{t}}\right)dt\,dy$$

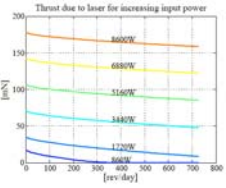
Thrust model includes a scattering factor λ:

$$F_{sub}=\lambda\bar{v}\dot{m}$$

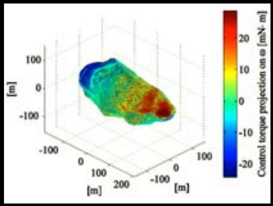
Input power dependent on system efficiency η_{System}:

$$P_I=\eta_{System}\frac{P_{1AU}A_{SA}}{A_{spot}R_{AU}^2}$$

The thrust generated depends essentially on the optical power (plume impingement), the distance to the target (defocusing) and its rotation speed (heating time).



- Control of asteroid angular velocity



The thrust is generated on points over the surface such that the resulting control torque results almost aligned with the instantaneous angular velocity (in the opposite direction) [2]:

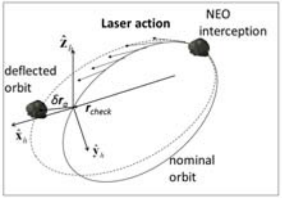
$$\min_{s}-\mathbf{M}_c\widehat{(s)}\cdot\boldsymbol{\omega}$$

- Deflection

Gauss equations [3]

$$\delta\mathbf{r}_a\left(t_{check}\right)=\mathbf{A}_{check}\delta\boldsymbol{\alpha}\left(t_{check}\right)$$

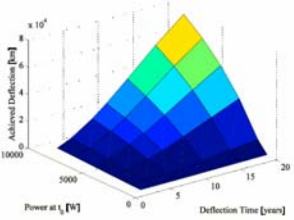
$$\delta\boldsymbol{\alpha}\left(t_{check}\right)=\left[\delta a\quad\delta e\quad\delta i\quad\delta\Omega\quad\delta\omega_a\quad\delta M_a\right]^T$$



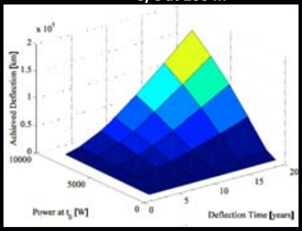
Preliminary results

- Spacecraft distance selection
  - Laser beam diameter = 3 mm.
  - Spherical 50 m radius asteroid and 175 rev/day.
  - Pure tangential thrust with no rotational control.

S/C at 100 m

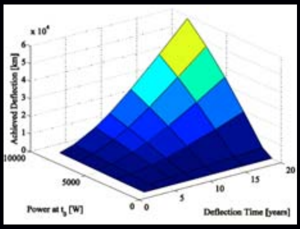


S/C at 200 m

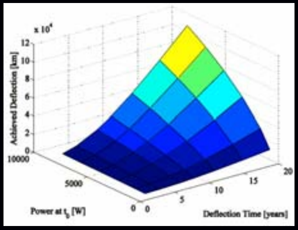


- Actual shape
  - S/C placed at 200 m
  - Nominal angular velocity vs. zero rotation

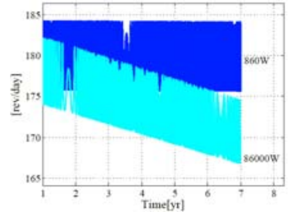
175 rev/day



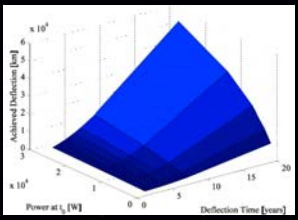
0 rev/day



Angular velocity control trend:
Negligible decrement with high power laser



200 m 2013 PDC15 – no roughness:
No safe deflection in 7 years



Conclusions

- Optimal distance affects the performance of deflection
- Rough surfaces reduces dramatically the achieved deflection (-60%)
- Rotational control is not possible unless MW lasers are employed
- Spacecraft turn-out to work at higher laser efficiency
- S/C formation for high power requirements or short warning times

References

[1] Vasile, M., Gibbings, A., Vetrisano, M. et al.: Light-Touch2: A Laser-Based Solution for the Deflection, Manipulation and Exploitation of Small Asteroids. Planetary Defense Conference 2013, Flagstaff, USA.
[2] Vetrisano, M., Colombo, C. , Vasile, M. : Asteroid Rotation and Orbit Control via Laser Ablation. Paper submitted to the Journal of Advances in Space Research, 2015.
[3] Vasile, M. and Colombo, C. : Optimal impact for asteroid deflection. Journal of guidance, control, and dynamics, 31(4), 858-872, 2008.

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