Solving the Tyranny of the Rocket Equation: A Theoretical and Experimental Study of Laser Propulsion

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The rocket equation dictates that the maximum payload a standard rocket can carry is only a few percent due to the extreme need for fuel. Even with modern technologies the energy and cost effectiveness of this kind of space travel seems unsustainable. We contributed to solving this tyranny by studying an alternative method of accelerating matter by laser propulsion. Interaction between laser light and a solid always results in gained momentum of the irradiated object – due to ablation (material recoil) and/or photonic pressure. The latter occurs inevitably as it is the result of the system's momentum conservation. If, however, the fluence threshold for material ablation is exceeded, the material is recoiled and the force impulse is increased by four orders of magnitude. Therefore, we focused our experiments only on ablative propulsion while theoretically studying both regimes. We used a ballistic pendulum consisting of cylindrical rods. The ablation effect was increased by adding a water/ethanol droplet into the front surface of the rod. This surface was irradiated by a short laser pulse. The movement was monitored by a high-speed camera with up to 40 000 fps. The rod position as a function of time was analyzed and further used to calculate the initial speed, momentum and kinetic energy of the rod, which are necessary to estimate the coupling coefficient and the energy-conversion efficiency. Both quantities are essential for comparison with other propulsion methods (standard rockets). During experiments, we varied the parameters of the liquid volume and laser pulse energy. The measured coupling coefficient, defined as the ratio between the momentum and the pulse energy was in the range 2–8 mN/W, while the energy-conversion efficiency was in the range of 1–11×10^-5.

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