Rapid Communications

Proposal and Demonstration of Laser-Driven Micro-Airplane

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As an important near-future application, we here propose a propulsion concept applied to a micro-airplane that can be used for observation of climate and volcanic eruptions. The micro-airplane can fly by means of a wing and need not be launched vertically, and thus it can be made lighter sufficient for loading observation and communication devices if no engine and controlling devices are necessary. In order to demonstrate the concept, we have performed fundamental experiments using a 590 mJ / 5 ns YAG laser and successfully flew a paper-craft micro-airplane.

Keywords: laser propulsion, micro airplane, aircraft, experiment, simulation

As an alternative to chemical propulsion for space vehicles, the use of ablation induced by laser irradiation was proposed by Kantrowitz in 1972[1]. As metal reacts to this ablation, it gains momentum in the manner of a conventional rocket. Since the driving laser can be placed on the ground, no extra device is required for a flying object. The recent developments in high power lasers will allow the realization of this concept[2-4]. In fact, the vertical launch of the rocket of approximately 100 g has already been demonstrated[3].

As an important near-future application, we here propose and demonstrate a propulsion concept to drive a micro-airplane that can be used for the observation of climate and volcanic eruptions. A paper-craft airplane of 38 mm× 30 mm× 5 mm size and 0.1 g-weight is placed on the platform with a guiding groove and is irradiated by one pulse of a YAG laser. A 0.1 mm-thick thin aluminum film is pasted onto the rear edge of the airplane and coated with a 0.6 mm-thick acryl layer. The area of aluminum and acryl patch is 3.5 mm× 3.5 mm.

Figure 1 shows the most frequently observed example, in which the airplane makes a circular flight and turns back. We measured the velocity of the airplane for the case where the flight path is normal to the camera and found it was initially 1.4 m/sec. In the figure, the large bright spot on the left shows the instance of laser irradiation.

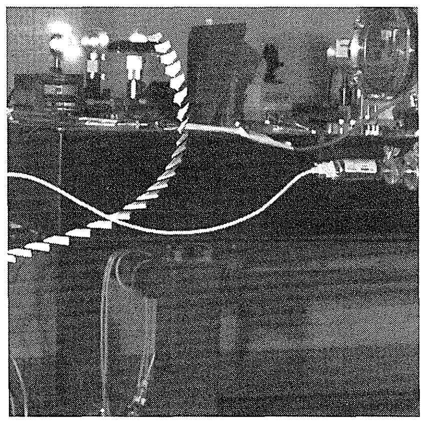

Fig.1 The flying trajectories of a paper-craft micro-airplane of 38 mm× 30 mm in size. One typical examples is shown. In the figure, the large bright spot shows the instance of laser irradiation.

The employment of the layered target, which we call "exotic target (ET)", in the rear edge of the airplane relies on the enhanced coupling efficiency

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of the ET that consists of a metal layer over-coated with transparent material. This increase of efficiency is attributed to the Cannon-ball effect suggested independently by Winterberg[5], Azechi[6], Anderholm[7], and Yabe[8]. The former two[5, 6] use a closed configuration such as a real cannon-ball and the latter two[7,8] employ transparent tamper which was introduced to laser propulsion by Fabbro[9] and Phipps[10]. In order to investigate this coupling, we have performed systematic surveys with experiments and simulations. The numerical simulation code PARCIPHAL used here is based on the CIP-CUP method[11]. Figure 2 shows the experimental results achieved by the LHMEL Nd:glass laser of 70 J /25-100 ns at Wright-Patterson AFB, Ohio[10] with the aluminum target over-coated with glass as a transparent material. As the simulation results suggest, the momentum coupling is greatly enhanced by this "exotic target". Here, the momentum coupling efficiency $C_m = m\Delta u / W$ is given by the momentum $m\Delta u$ of the target obtained after irradiation with laser energy W.

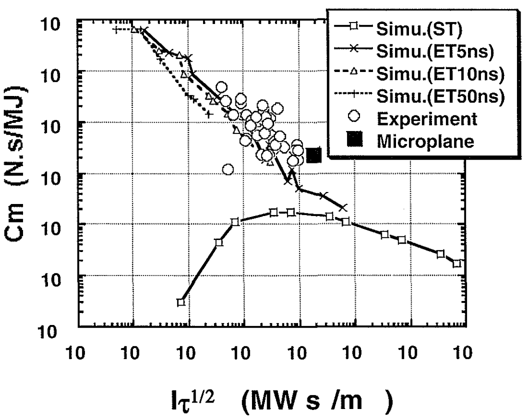

Fig.2 Dependence of C_m on $I\tau^{1/2}$. ST indicates the standard target which is the single layered target, while ET indicates the exotic target which consists of a metal layer over-coated with transparent material. The open circles show the experimental result achieved by LHMEL laser, and the closed square represents the result of the micro-airplane. In the simulation, the pulse width of the laser was varied from 5 ns to 50 ns.

In the simulation of the standard target (ST) involving the single layered target, C_m has the maximum of 17 N.sec/MJ at 7×10^3 MW.sec$^{1/2}$/m^2 as shown in Fig.2. In contrast to ST, C_m increases even with decreasing intensity I because the space between the two layers is filled with evaporated gas, and a significant amount of energy can be used to drive the metal target [10], while the reduced C_m at strong laser intensity is the same as in the case of ST, which is due to the laser cut off by generated plasmas.

Even in the experiment regarding the micro-airplane, this increase has been clearly demonstrated and the airplane without overlay failed to gain a speed sufficient for flight. The measured flying speed shown in Fig.1 gives C_m = 237 N.sec/MJ. This approximately agrees with the scaling law shown in Fig.2 for $I\tau^{1/2} \approx 1.8 \times 10^4$ MW.sec$^{1/2}$/m^2 which is calculated by the measured focal spot diameter of 760 μm. Following this scaling law, we have already experimentally achieved 5,000 N.sec/MJ using a larger laser and an ET target, and simulation results indicate that much better efficiency can be expected. Therefore the use of the exotic target concept for a propulsion system is attractive for practical applications. In order to use this concept in an actual system, we need to develop a mechanism to rotate the irradiation surface because the over-coated layer will be removed by one shot of laser irradiation. For this purpose, we have also placed a water droplet instead of a layer of acryl on the aluminum's surface and obtained a similar rate of acceleration.

Lastly we should notice that the airplane can also be controlled by direct ablation of the wing material or by heating the smart structure on the wing. Although it is too early to restrict the area of application, the most immediate application will be for the observation of climate and volcanic events. The medium size radio-frequency-controlled airplane has already been used but it is frequently lost and does not return owing to radiation noise, and the reciprocal engine can not be used at high altitudes.

[1] A. Kantrowitz, Astronaut. Aeronaut. **10**, 74 (1972).
[2] C.R. Phipps,Jr., T..P. Turner and R.F. Harrison, J. Appl. Phys. **64**(3), 1083 (1988).
[3] L.N. Myrabo and F.B. Mead, Jr., **AIAA98-1001**, *Aerospace Sciences Meeting & Exhibit, 36th,* Jan. 12-15, 1998
[4] C.R. Phipps and M.M. Michaelis, Laser Part. Beams **12**, 23 (1994).

[5] F. Winterberg, Lettere al Nuovo Cimento **16**, 216 (1976).
[6] H. Azechi, N. Miyanaga, S. Sakabe, T. Yamanaka and C. Yamanaka, Jpn. J. Appl. Phys. **20**, L477 (1981).
[7] N.C. Anderholm, Appl. Phys. Lett. **16**, 113(1970).
[8] T. Yabe and K. Niu, J. Phys. Soc. Japan **40** , 863 (1976).
[9] F.J. Fabbro, P. Ballard, D. Devaux and J. Virmont , J. Appl. Phys. **68**, 775 (1990).
[10] C.R. Phipps, D.B. Seibert II, R. Royse, G. King and J.W. Campbell, *III International Symbosium on High Power Laser Ablation*, Santa Fe, 2000, SPIE Vol.4065.
[11] *see for review of the method* T. Yabe, F. Xiao and T. Utsumi, J. Comput. Phys. **169**, 556 (2001).