Laser propulsion : preliminary definition of a demonstrator

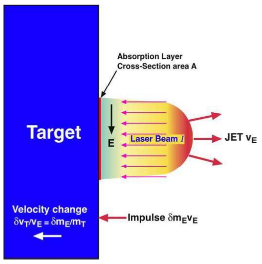
Context and stakes

Propulsion is a crucial issue for the development, deployment and operation of spacecraft. Actual technologies are based on onboard energy storage, which increases the overall cost of the mission. However, in a changing context, the development of **remote energy deposit** may be a solution to lower cost and increase flexibility. **The Laser ablation propulsion** (LAP) studied in this project could be a solution for addressing several issues :

- Today, **cost of launching is high**, around 10 k$/kg for GEO and 5 k$/kg for LEO
- Evolution of the payload : **More compact satellites** are in development, they require **smaller launcher**
- The increasing number of **space debris**, and the **difficulty to maneuver it** with "classical" propulsion
- Development of more and more powerful lasers and the demonstration of laser propulsion (Myrabo et al. 2001)

▶ This work aims at investing the critical points in designing a laser ablation propelled vehicle. This project relies on both **numerical** and **experimental** approach.

Principle of laser ablation Propulsion



▶ Ablation mechanism

- Laser impulsion at **high intensity** (> 1GW/cm²), **short duration irradiation** (from nano to femtosecond)
- Heating and **vaporization of a thin layer** of matter
- **Ejection of particles** at high velocities and plasma formation

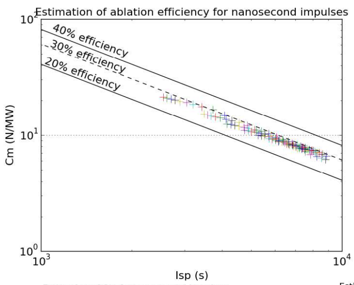
▶ Relevant parameters:

- **Coupling Coefficient :** $C_m = \frac{Total\ impulse}{laser\ energy} = \frac{Thrust}{Laser\ power}$
- **Specific impulse :** $I_{sp} = \frac{Total\ impulse}{Ejected\ Masse * g_0} = \frac{Exhaust\ Velocity}{g_0}$
- **Ablation efficiency :** $\eta_{ab} = \frac{Kinetic\ Energy\ of\ exhaust}{Energy\ of\ the\ laser\ pulse} = \frac{C_m I_{sp} g_0}{2}$

▶ At constant ablation efficiency, **High Cm implies low Isp** and reciprocally

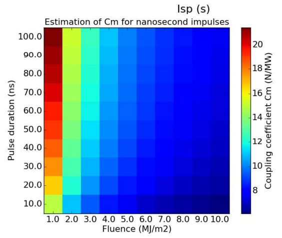
Simulation of the propulsion

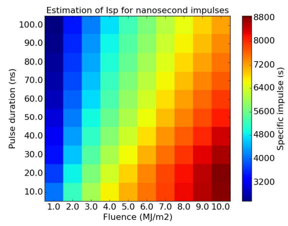
- Laser-Matter interaction with ESTHER (CEA Code)
- Simulation of thermodynamics, mechanics, and plasma behavior
- Simulation for a range of fluence and pulse duration
- Estimation of impulse and mass ejection : **estimation of Cm, Isp and efficiency**



Example of a laser ablation simulation for aluminium with nanosecond range impulses, from 1 to 10 MJ/m² in fluence, with a duration from 10 to 100 ns

Here, the ablation efficiency is around 30%

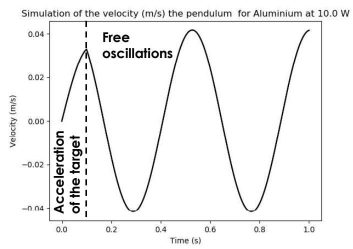




Experimental Approach Campaign in Nov. 2019

▶ Aim :

- Test material to find the best propellant (Al, POM, Hybrid)
- For a given material, estimate the best laser configuration in terms of wavelength, pulse duration and fluence
- Understand the mechanical and the thermal behavior of the material



▶ Experimental device :

- Pendulum acceleration with velocity diagnostic, and measurement of the angle of deflection with a laser : estimation of the **impulse** and then the **Cm**
- Mass measurement : estimation of the **Isp**
- Post-mortem observation : study of the multiple

Conclusion and perspectives

- Simulation
  - Simulation for now show trends in accordance with literature [Phipps et al. 2010] and previous experimental campaign (LULI 2017)
  - Give order of magnitude for the next campaign
- Experimental campaign
  - Preparation of a Hilase campaign in Prague in November 2019 (European collaboration), design using simulation results (ESTHER, RK4 simulation, Finite elements analysis)
  - Opportunity to study influence of repetitive pulses on the Cm, Isp and efficiency.

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AUTHORS

Gilles TAHAN
Séverine BOYER
Claude PHIPPS
Laurent VIDEAU
Michel BOUSTIE
Stéphane ORIOL
Christophe BONNAL

MAIN EVENTS TO COME

Experimental campaign at Hilase Facility in Czech Republic : Acces to a 10 W mean power laser with repetitive pulses (1 kHz), picosecond pulses. This is an opportunity to validate result of LULI 2017 and LULI 2018 campaign, and also to investigate the effect of repetitive pulses on the Cm, Isp and the efficiency for a picosecond regime.

CONTACT

gilles.tahan@mines-paristech.fr

REFERENCES

[Phipps et al., 2010] Phipps, C., Birkan, M., Bohn, W., Eckel, H.-A., Horisawa, H., Lippert, T., Michaelis, M., Rezunkov, Y., Sasoh, A., Schall,W., Scharring, S., and Sinko, J. (2010). Review: Laser-Ablation Propulsion. Journal of Propulsion and Power, 26(4):609–637.

[Myrabo, 2001] Myrabo, L. (2001). World record flights of beam-riding rocket lightcraft – Demonstration of "disruptive" propulsion technology. In 37th Joint Propulsion Conference and Exhibit, Salt Lake City,UT,U.S.A. American Institute of Aeronautics and Astronautics.

[Phipps et al., 2017] Phipps, C. R., Boustie, M., Chevalier, J.-M., Baton, S., Brambrink, E., Berthe, L., Schneider, M., Videau, L., Boyer, S. A. E., and Scharring, S. (2017). Laser impulse coupling measurements at 400 fs and 80 ps using the LULI facility at 1057 nm wavelength. Journal of Applied Physics, 122(19):193103.

[Bardy et al. 2017] S. Bardy, B. Aubert, L. Berthe, P. Combis, D. Hébert, E. Lescoute, J.-L. Rullier and L. Videau, "Numerical study of laser ablation on aluminium for shock-wave applications: development of a suitable model by comparison with recent experiments," Optical Engineering, vol. 56, p. 011014, 8 2016.