Dust Impact Sensor and Counter (DISC) for comet exploration: Laser simulations of hypervelocity impacts.

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Introduction: The ESA Comet Interceptor mission, designed to explore a pristine comet, will host onboard the Dust Field and Plasma (DFP) package, equipped with the Dust Impact Sensor and Counter (DISC) [1]. DISC is expected to measure the dust mass distribution from particles having mass 10^{-15}–10^{-8} kg emitted from the nucleus of the comet, and characterize the impacts in terms of duration to retrieve information on particles density/structure. Since the spacecraft velocity will be in the range of 10–70 km/s, and the expected particle radius is 1–200 µm, the impacts will be characterized by a momentum release of the order of 10^{-11}–10^{-3} kg m/s. Because of the high values of spacecraft velocity, a calibration of the instrument by means of hypervelocity projectiles results pretty complicated, when not physically impossible. For such a reason, laser pulses will be employed to simulate the effect of impacting particles [2]. Here, a preliminary analysis of the appropriate laser parameters is reported.

DISC design: The instrument consists of a square aluminum diaphragm, with a thickness of 0.5 mm and a sensitive area of 100 mm x 100 mm, three lead zirconate titanate ceramic piezoelectrics (PZTs), placed at three corners of the aluminum diaphragm, and a fourth PZT used as internal calibrator. A dust particle impacting the aluminum diaphragm generates acoustic waves that propagate in the diaphragm till the PZTs, which begin to vibrate at the resonant frequency. The PZTs are capable of measuring the particles momentum up to a rate of 200 particles per second; their mass is derived knowing the spacecraft speed. The design of the sensing device will be similar to the GIADA Impact Sensor subsystem on-board Rosetta ESA mission [3].

Laser simulation of hypervelocity impacts: The hypervelocity impacts expected for DISC can be efficiently simulated in laboratory using a laser following the late stage equivalence: laser intensity, beam area, and pulse duration can be adjusted to match the particle parameters requested [2]. Since laser-simulated impacts have to match the impact pressure generated by the particles on the target surface, such quantity is evaluated considering an olivine particle impacting on an aluminium plate. Following [2], the densities behind the shock have been fitted from [4] in the velocity range of interest for the mission. Four particle types are considered, described by different density values: fluffy aggregates (1 kg/m^3 [5]), two porous aggregates (600 and 900 kg/m^3 [6]), and single olivine grains (representing the smaller particles) having zero porosity (3214 kg/m^3 [4]). From the properties of particle and target, the impact pressure p_I generated on the target' surface can be evaluated as [2]:

$$p_I = \frac{\rho_{p0} V_p^2}{1-\rho_{p0}/\rho_{ps}}\left[1+\frac{\rho_{p0}}{\rho_{t0}}\left(\frac{1-\rho_{t0}/\rho_{ts}}{1-\rho_{p0}/\rho_{ps}}\right)\right]^{-2}$$

where V_p is the projectile velocity, and ρ_{p0}/ρ_{ps} and ρ_{t0}/ρ_{ts} are the unshocked/shocked particle and target densities, respectively. The values of impact pressure as a function of particle velocity are reported in Fig. 1.

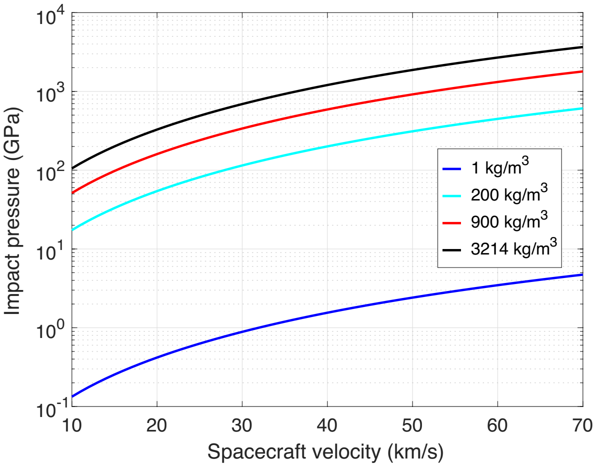

Fig. 1. Impact pressure as a function of spacecraft velocity for different particle densities.

Following [2], the incident laser intensity can be related to laser wavelength and impact pressure as:

$$I_0 = \left[\frac{p_I}{8.65\times 10^{-7} W^{-7/9} g \alpha^{1/9} M^{7/18} \nu^{2/9} R_p^{-1/9}}\right]^{9/7}$$

where W, g, and α are constants, M is the atomic weight of the plasma generated on the target, ν is the laser frequency and R_p is the laser beam radius, i.e., the particle radius. Results for I_0 are shown in Fig. 2 for particles having 1 µm and 200 µm radii, considering a 1064 nm laser.

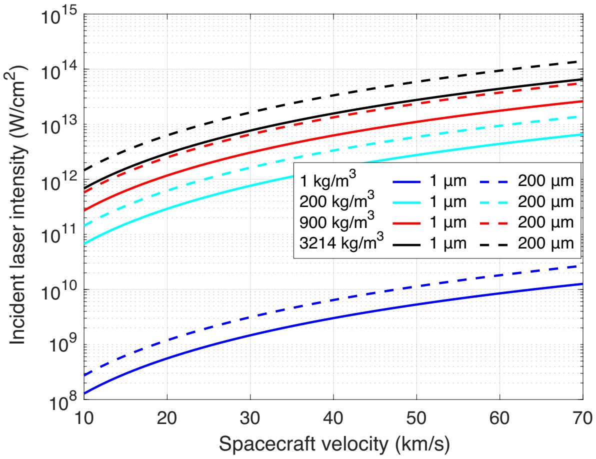

Fig. 2. Incident laser intensity as a function of spacecraft velocity for different particle densities and radii.

Finally, the laser energy E and the pulse duration τ are connected to both particle velocity and radius [2] via:

$$E = I_0 \pi R_p^2 \tau$$

and

$$\tau = \frac{R_p}{V_p}\left[1 + \sqrt{\frac{\rho_{p0}}{\rho_{t0}}}\right].$$

Following [2], the polygons reported in Fig. 3 for different density values represent the possible energy and pulse duration values related to the extreme values considered for velocity and particle radius. Any particle falling inside the velocity/radius range can be simulated by a laser having energy and pulse time comprised inside the polygon.

As noticeable from Fig. 3, the energy/pulse duration range is pretty vast. In particular, it will be impossible to reach the higher energies (up to 1 MJ). Nevertheless, some commercial laser such as Nd:YAG crystals have been successfully employed to simulate meteoroid impacts in similar energy/time ranges [7]. Thus, by means of some attenuators and pulse reducers, the central/left part of the parameters space (i.e., around mJ energy and ns pulse time) could be reasonably covered by using a similar laser.

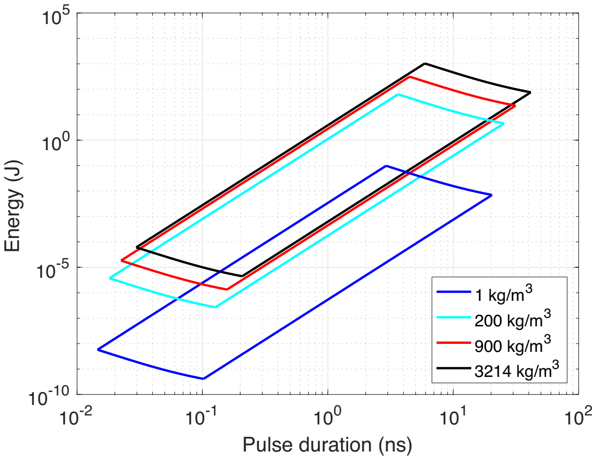

Fig. 3. Laser energy and pulse duration relationship for different particle densities.

Summary: A laser-based simulation of hypervelocity impacts can be successfully employed to calibrate the DISC instrument onboard Comet Interceptor mission. Our simulations allow us to identify the relevant parameters of interest for a 1064 nm laser, revealing the possibility to cover a significant range of the parameters space. Thus, by integrating experiments employing physical particle impacts (e.g., [8]) and laser-simulated impacts with smoothed-particle hydrodynamics numerical simulations (e.g., [9]) we will be able to accurately cover the relevant parameter space for DISC.

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