PROJECT ORION: ORBITAL DEBRIS REMOVAL USING GROUND-BASED SENSORS AND LASERS

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A study was completed by NASA last year, co-sponsored by the US Air Force (USAF) Space Command, to determine the feasibility of removing the bulk of the threatening orbital debris in low-Earth orbit (LEO) by irradiating it with a ground-based laser. The laser energy ablates a thin surface layer from a debris particle, causing plasma blowoff. The dynamic reaction from one or more laser hits lowers the perigee of the orbit and hastens reentry,

The study was undertaken as an initiative of the Advanced Concepts Office at NASA Headquarters (HQ), and managed by the NASA Marshall Space flight Center (MSFC). The study team included USAF Phillips Laboratory, MIT Lincoln Laboratories, NASA MSFC, Northeast Science and Technology, Photonic Associates, and the Sirius Group.

A wide range of objects in orbit are characterized as orbital debris. The size range of greatest interest is 1 to 10 cm. While objects smaller than 1 cm are extremely numerous and difficult to defect, shielding against them is straightforward, although somewhat expensive. Objects larger than about 10 cm are routinely tracked, and their numbers are small enough that operational spacecraft can maneuver to avoid them. There remain about 150,000 objects between 1 and 10 cm in size. They problematic to track, too numerous to avoid, and shielding against them is very difficult or expensive.

NASA believes that the debris population likely to exist during the life of the International Space Station (ISS) is high enough that limited protection measures are being incorporated into the ISS program. These will protect it against objects up to about 2 cm in diameter.

Various strategies for irradiating the debris objects were analyzed, including those that engage objects in several passes over the laser, and those in which immediate reentry is caused by irradiation during a single pass. The laser is operationally the simplest: fire at any debris object the sensors show to be approaching in favorable circumstances, without regard to whether it has been previously irradiated or not. The former requires a plan such as our "steady rain" approach to guarantee that the risk to space assets does not temporarily increase at any orbital altitude.

The statistical characteristics of the debris population are reasonably well known. Five different representative debris objects were defined as reference targets to deorbit. The orbital distribution of the debris particles was addressed, and the velocity changed needed was determined to be a few hundred meters per second-sufficient to cause the perigee to drop to 200 km. Achieving a 200-km perigee reduces a particle's expected lifetime in orbit to a few days.

The interaction of laser beams with these debris objects was characterized, and the range of coupling coefficients of the resulting plasma blowoff determined from both experiment and theory. The required incident beam intensity and duration at the objects was then determined in order to cause the velocity change necessary for reentry within a few orbits. It was determined that the laser has to place many very short pulses on the objects to avoid self-shielding of the generated plasma at the object. The intensity of the irradiation was also determined.

Once the requirements at the debris objects were understood, the required ground laser characteristics were then defined, considering the effects of the atmosphere on the beam. Effects included in the calculations were turbulence, absorption, stimulated Raman scattering (SRS), stimulated thermal Rayleigh scattering (STRS), whole-beam thermal blooming, and nonlinear refractive index. A graphical technique was developed that enables selection of the optimum laser for this system.

A number of options for detection, acquisition, tracking and handoff of debris targets to the laser were investigated. These included radar, passive optical active optical using the laser itself, and combinations of these. In addition, a novel detection technique was analyzed that uses the many communications spacecraft that are or will soon be in orbit as “free” illuminators to form a bistatic surveillance system.

A spectrum of system concepts was developed, each of which meets some or all the system goals. These concepts span a range of costs and technology challenges. In addition, a demonstration of the capability on actual debris could be mounted using mostly existing assets for less than about $20 million.

The nearest term operational system would consist of a Nd:glass laser operating at 1.06 mm with a pulse width of 5 ns operating at a rate of 1 to 5 Hz. It would have 3.5-m diameter optics, operate with a sodium guide star, and produce 5-kj pulses. It would use an optical sensor. This system would cost about $60 million, and would cause the reentry of essentially all debris in the desired size range in 3 years of operation, up to an altitude of 800 km. This system would be sufficient to protect the ISS as well as all other satellites in LEO below 800 km, including the planned Iridium and Teledesic systems.

More ambitious technology systems were defined that have the ability to remove all such debris objects up to an altitude of 1,500 km. This would extend protection to higher altitude spacecraft as well as other civilian and defense assets. This more advanced system would require an additional $80 million and an additional year of operation.

It was noted that protection of the ISS and other assets below 400 km alone could be done with a system only capable of 500 km altitude, for less money.

A cursory analysis indicated that systems of this type are not inherently antisatellite weapons, being much too weak for such use. ORION would have to illuminate a typical spacecraft continuously for years to destroy its structure, or months to make major changes in its orbit, though some damage to some sensors and other subsystems would be possible. Such damage would be prevented by avoiding illumination of known spacecraft, and by warning space systems to avoid looking at the laser site.

Due to the inherently national character of such a system, if serious interest develops to pursue the capability, it is likely that the Department of Defense (DOD) would be the preferred agency to develop and operate it for the benefit of all spacecraft, be they commercial, civil, or defense. It was also noted that a system of this type is inherently international, protecting all spacecraft regardless of nationality, and thus represents an ideal opportunity for an international program undertaking.

The study concluded that the capability to remove essentially all dangerous orbital debris in the targeted size range is not only feasible in the near team, but its costs are modest relative to the likely costs to shield, repair, or replace high-value spacecraft that could otherwise be lost due to debris impacts for debris particles greater than about 1 cm in size. Due to the difficulty in detecting debris smaller than about 1 cm, and their great numbers, the presence of an ORION system would not obviate the need to shield high-value, large, long-lived spacecraft to resist impacts of debris particles that are about 1 cm, in size and smaller.

The study concluded that a demonstration system should be undertaken to demonstrate, at low cost, the ability to detect, track, illuminate, and perturb the orbit of an existing particle of debris.