Solar Sail Acceleration by Thermal Desorption and Temperature Restriction on Heliocentric Orbits

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For extrasolar space exploration it might be very convenient to take advantage of space environmental effects such as solar radiation heating to accelerate a solar sail coated by materials that undergo thermal desorption at a particular temperature. In this study we considered a solar sail coated with materials that undergo thermal desorption at a specific temperature, as a result of heating by solar radiation at a particular heliocentric distance. Thermal desorption here comes as an additional source of solar sail acceleration that provides additional thrust as heating liberates atoms, embedded on the surface of a solar sail.

The gradual acceleration of a solar sail can be mitigated with the thermal desorption of various lightweight volatile coatings at several key mission phases achievable by ground based microwaves at low Earth orbit (LEO), and adjusting trajectories for optimal utilization of solar energy at perihelion. Higher activation energy coatings can be applied via absorption while lower activation energy coating are applied afterwards by adsorption to completely saturate the sail with propellant, however, having lower activation energy coatings trapped under a higher activation energy coating could increase kinetic energy upon desorption. Integrating nanotube technology offers benefits to increased thermal desorption capabilities as well as possible significant directed thermal desorption acceleration rather than at random angles which naturally occurs. The surface coating could reach activation energy at perihelion in LEO to increase escape velocity with the easy aid of ground based microwaves. For near-Sun trajectory, when the spacecraft close approaches flyby with complete solar sail exposure, would be best for the second thermal desorption coating to enhance the escape velocity, provided the solar sail retains structural integrity under higher temperatures and stronger gravitational forces. Thus the trajectory must keep the sail at an optimal distance for safety and efficiency.

For near-Sun missions, the spacecraft approaches very close to the Sun. Strong restrictions on how much close it can get derive from the maximum temperature that the used materials can stand, in order not to compromise the spacecraft's activity and functionalities. In other words, the minimum perihelion distance of a given mission can be determined based on the materials' temperature restrictions. The temperature of an object in space depends on its optical properties: reflectivity, absorptivity, transmissivity, and emissivity. Usually, it is considered as an approximation that the optical properties of materials are constant. However, emissivity depends on temperature. The consideration of the temperature dependence of emissivity and conductivity of materials used in the aerospace industry leads to the conclusion that the temperature dependence on the heliocentric distance is different from the case of constant optical properties. Particularly, taking into account that emissivity is directly proportional to the temperature, the temperature of an object increases as $r^{2/5}$ when the heliocentric distance r decreases. This means that the same temperature will actually be reached at a different distance and, eventually, the spacecraft will be allowed to approach closer to the Sun without compromising its activities. We focused on metals used for aerospace structures, however our analysis can be extended to all kinds of composite materials, once their optical properties - in particular emissivity - are defined.

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