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ANALYSIS OF BIDIRECTIONAL REFLECTION DISTRIBUTION FUNCTION ON A SOLAR CELL WITH A MICROSTRUCTURE

Abstract

This paper describes a modelling technique of the solar radiation pressure (SRP) exerted on spacecraft which can incorporate general surface with anisotropic reflectance property. The SRP torque is a major disturbance for the attitude of spacecraft especially in deep space missions. It depends not only on the shape and attitude of spacecraft, but on their surface optical reflectance property. Many past missions successfully modeled and suppressed the SRP effect. Some missions even attempted to exploit the SRP to stabilize and reorient spacecraft attitude rather than compensating it.

Two such typical missions are the JAXA's solar sail technology demonstration spacecraft IKAROS and the asteroid explorer Hayabusa2. They modelled very precise SRP torque exerted on the spacecraft bodies (GSDM: Generalized Solar-sail Dynamics Model) and successfully extracted a useful behavior to control the spacecraft attitude. The application of the GSDM to actual missions contributes to reduce the fuel consumption for their attitude maintenance while increasing reliability due to its good stability nature. On the other hand, owing to precise SRP modeling used in the operation of IKAROS and Hayabusa2, at least 5% of directional inconsistency has found between the SRP torque estimated from the conventional SRP model used in the GSDM and the actual flight data. Our detailed sensitivity analysis implies the error should be due to unmodelled anisotropic optical reflectance of a large area on the spacecraft, such as solar array panels (SAPs).

Therefore, the aim of this paper is to create a precise reflectance distribution model by measurement of a bidirectional reflection distribution functions (BRDF). A BRDF, a technique originally developed in the field of Computer Graphics, describes a reflectance map between arbitrary incident and emitted rays in a general mathematical form. Hence, accurate optical characteristics of spacecraft can be obtained by assigning appropriate BRDF properties over the whole spacecraft surface.

The BRDF measurement was performed for test cells of the Hayabusa2 SAPs. As a result, a distinctive anisotropic reflectance property was found which hadn't been modelled in the conventional model. It was also suggested this reflection should be due to the microscopic structure of the solar cell. Then a compact mathematical model of the reflection which reproduces the anisotropic property observed in the BRDF measurement has been developed. This model successfully describes the inconsistency between the SRP torque estimated from the conventional model and the flight data to be less than 0.6%, and relates material's microstructure to the optical property.