Subject : The Yarkovsky effect and interpreting it as a heat engine

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Yarkovsky effect is the effect caused by anisotropic emission of rotating body heated by a star like the Sun. This effect was discovered by Ivan Osipovich Yarkovsky,who was the Rusiian civil engineear.

If a body doesn't have homogeneous temperature, there will be different radiation force, since different temperatures have different radiation forces. And this leads to non-zero net radiation force on the body caused by heating. There are two kinds of Yarkovsky effect, diurnal effect and seasonal effect.

Diurnal effect : It is caused by rotation of body. If a body is heated by sun, a day-side is warmer than night-side, that is day-side has more heat than night-side. Therefore there would be net radiation pressure to lower temperature side.

Seasonal effect: Principle is same as diurnal effect, but seasonal effect is caused by orbiting of body.

[ref. "E. J. Öpik, Collision probabilities with the planets and the distribution of interplanetary matter, Proceedings of the Royal Irish Academy, 54A, pp. 165–199 (1951)"

through "Wikipedia", our textbook "Imke de Pater and Jack J.Lissauer, Planetary Sciences"]

Since resulting radiation force is not so huge, it would have significant effect on orbit of small bodies(especially 1-10 km object, that is, meteoroids and small asteroids.) in long-term period. Therefore it is important in solar system dynamics. Recently, there are some examples of detection of Yarkovsky effect. [ref. "David Nesvorný, William F. Bottke, 2004, Detection of the Yarkovsky effect for main-belt asteroids, Icarus 170, 324-342", and etc.]

[From main paper "Ralph D. Lorenz and Joseph N. Spitale, 2004, The Yarkovsky effect as a heat engine, Icarus 170, 229-233"]

Yarkovsky effeck is usually calculated from a dynamic perspective. That is, temprature distribution is calculated, and then radiative force on each surface is calcualted using it. And this method explicitly requires momentum and direction of photon on each surface, therefore it could be complicated.

Therefore we wanted to find new perspective view, and it is found that thermodynamics perspective is also available. Since rotating body is single object, the available heat must be converted to work, that is, rotation by thermodynamic principle.

To show thermodynamics perspective is possible, we used simple example. For example, we only consider the diurnal Yarkovsky effect and assume a body to by cylindrical and rotation axis of body is normal to the orbital plane. In the classical thermodynamics, system is in equilibrium state, but non-equilibrium thermodynamics is applied in most of real situations. And it means that net local thermal balance must be non-zero. The object must absorb energy in a day time and re-radiate it in a night time. And it really applied to real situation. For local thermal balance to be non-zero, surface of the object must have a non-zero heat capacity or thermal inertia.

For example, temperature and energy balance on rotating cylindrical black body at 1AU with various

heat capacity values is calculated. And using them, am-pm heat flux is calculated. And after considering carnot efficiency, available work and yarkovsky force is calculated.

And results show that tendency of result is consistent with real situation since heat capacity could be thought as rotating rate. That is Yarkovsky effect shows maximum effect at intermediate rotating rate.

Therefore example calculation shows the how Yarkovsky effect could be calculated in thermodynamic perspective. It is not compared with real data explicitly yet, but tendency is consistent with real situation. Therefore if we can consider more effect to get more exact calculation, thermodynamic perspective will be very useful in calculation of Yarkovsky effect. And it also shows the possibility of thermodynamical perspective in other astrodynamic studies involving radiative forces.