

**NEA HAZARD MITIGATION USING THE YARKOVSKY EFFECT.** J. N. Spitale, *Lunar and Planetary Laboratory, Tucson AZ 85719, USA, (spitale@lpl.arizona.edu).*

## 1 Introduction

A subtle radiation force known as the Yarkovsky effect may play an important role in delivering asteroids from the main belt to orbits that intersect that of the Earth [Bottke *et al.* (2001)]. Here, I show how that same effect might be harnessed to prevent collisions between such bodies and the Earth.

The Yarkovsky effect is caused by thermal radiation from a body whose surface temperatures are not distributed symmetrically. Thermal photons leaving the surface of the body carry with them momentum, producing a slight reaction force on the body whose direction is roughly normal to the surface and whose magnitude depends on the temperature of the surface at that point. Because there is a delay between the time that a point on the surface receives its maximum insolation and the time that it reaches its highest temperature, there is a Yarkovsky acceleration component along the orbit, causing work to be done and thus changing the semimajor axis. The other orbital elements are affected as well, but the semimajor-axis effect is the most important.

## 2 Hazard Detection

The first step in avoiding an impact is to identify the danger as early as possible. The more precisely we know the current orbit and how it will evolve under the influence of various gravitational and nongravitational perturbations, the further into the future we can predict an impact, and the easier it will be to avoid. The relevant gravitational perturbations are well understood and can be accounted for with high precision, but the nongravitational perturbations (of which the Yarkovsky effect is probably the most important for the bodies of interest here) are difficult to handle precisely because they may depend on an asteroid's shape, spin vector, composition, and details of its surface character. Therefore, our ability to predict future Earth impacts is limited by our ability to model nongravitational perturbations like the Yarkovsky effect.

## 3 Hazard Mitigation via the Yarkovsky effect

### 3.1 Theory

Given the ability to compute radiative orbital element perturbations with the precision necessary for accurate forecasting of terrestrial impacts perhaps centuries into the future, such effects may provide a means of modifying the orbit of the projectile enough to avoid the collision.

Because the Yarkovsky effect arises from the surface temperatures on a body, it can be sensitive to various surface characteristics such as albedo, thermal conductivity, etc. Therefore, the body's Yarkovsky mobility might be drastically changed by modifying only the upper few centimeters of the surface.

For example, based on results from the finite-difference heat flow calculation [Spitale *et al.* (2001)], a spherical body with properties and orbital elements similar to those of 1566 Icarus (~1-km diameter) might be moved 1400 km in 100 yr and nearly 14000 km in 300 yr by changing its surface thermal conductivity from that of bare rock to that of loose dirt. On the other hand, Yarkovsky mobility for a model of 1620 Geographos shows little dependence on the surface thermal conductivity so the Yarkovsky effect might be used to move that body by changing its albedo instead of its surface thermal conductivity.

### 3.2 Practice

For a bare-rock or bare-metal body, one might blanket the asteroid with a 1-cm layer of highly-insulating material, a depth comparable to the penetration depth of the diurnal thermal wave. To blanket the surface of a 1-km body with such a layer would require about 250000 tons of dirt, the mass of roughly 90 fully-loaded Saturn V's. The cost of launching that much of material would be high and it would be difficult to deposit uniformly in the complex gravitational field of a small asteroid.

Blanketing would also be one way to modify a body's albedo. Such a change could be achieved using much less material (say 1/10 as much) than required to change the conductivity to the depth of the diurnal thermal wave. Still, it would be difficult to deposit the material uniformly.

Perhaps instead, at least for a stony body, one might shatter the surface to a depth of a few centimeters by saturating the surface with conventional explosives, producing a porous regolith. However, such a small body is likely to lose much of that regolith. If, on the other hand, the hazardous body already possesses such a thin surface veneer (this would be more likely for a metallic body than for a stony body), it may be removed using explosives, thereby exposing a bare surface with considerably different thermal properties than the original. One ton of TNT could remove a 1-cm layer of loose material from the surface of a 1-km body if properly delivered.

Obviously, the solution must take account of the details of the body in question and should not be undertaken without the ability to accurately predict the consequences of such modifications.

## 4 Conclusions

Using simple thermal calculations, it is easy to demonstrate that the Yarkovsky effect might be useful for diverting some hazardous near-Earth asteroids. However, even if the Yarkovsky effect is never harnessed to alter the orbit of an asteroid, precise calculations of its consequences are important for providing the earliest possible warning. Such calculations do not currently exist, but the finite-difference approach [Spitale *et al.* (2001)] should soon approach the required level of sophistication.

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## References

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