Inferring Small-Scale Surface Variability on Near-Earth Asteroids from Itokawa's Shape Data

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Renewed interest in visiting near-Earth asteroids (NEAs), spearheaded by the selection of OSIRIS-REx as the third New Frontiers mission [1], has generated many detailed questions concerning the small-scale surface variability of asteroids. Success of a lander mission will depend on knowledge of, and the ability to deal with, surface roughness that can make landing more difficult. Surface operations of a robotic or human explorer will require detailed mapping of total surface accelerations and slopes (the amount of acceleration tangent to the surface). These issues are intrinsically dependent on the variability of the asteroid surface. Furthermore, predictions of the dynamical evolution of an asteroid based on the Yarkovsky and YORP effects depend not only on the material properties, but also on the shape of the surface that interacts with the solar radiation.

NEA shape models are often initially generated through radar observations, and are sometimes improved by other measurements such as optical or thermal imaging. However, these Earth-based (or Earth orbit based) measurements have limited observability for determining an asteroid shape. The resolution of a generated shape model is based on many aspects, not the least of which are viewing geometry and measurement accuracy, given that the NEAs are typically on the order of only 1-10 km in diameter.

Previous missions which have orbited NEAs, specifically Hayabusa and NEAR, have produced high resolution shape models of the NEAs Itokawa and Eros, respectively. In this work, we compare the higher resolution shape models of Itokawa with a baseline model which is of similar resolution as Earth-based observation derived shape models. We statistically quantify variations in the surface geometry between different resolution models. These statistics are then used to explore the possible variations in physical parameters over the surface of less well-modeled NEAs such as 1999 KW4.

Baseline Shape Models The best available shape models for KW4 [3] and Itokawa [2] are used as a basis for this study. The physical characteristics of these baseline models are shown in Table 1. The shape models of KW4 and Itokawa are shown in Fig. 1. It appears that the KW4 model has a higher resolution, but this is simply due to the fact that KW4 is larger than Itokawa; in fact, it can be seen in the table that the mean facet area of the KW4 model is actually larger than the Itokawa model.

Table 1: Baseline model information for the three models considered. The variables listed are the maximum radius of the asteroid, R_M, the number of facets (F) and vertices (V) in the shape model, the mean facet area $\bar{A}$, and the standard deviation of the facet areas, σ_A.

Body	KW4 [3]	Itokawa [2]	Ito. High [2]
R_M [m]	750	270	270
F [#]	9168	768	3145728
V [#]	4586	422	1575770
$\bar{A}$ [m^2]	626.3	501.8	0.13
σ_A [m^2]	110.5	205.7	0.05

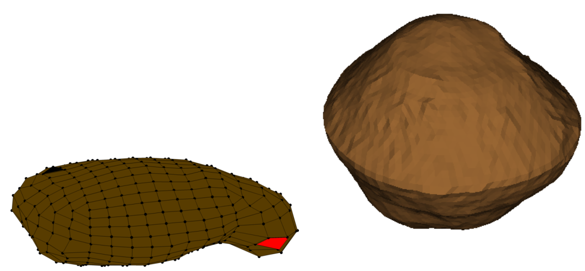

Figure 1: Baseline Itokawa shape model (left), from [2]. In this view, the red facet is on the "head" and the black facet is on the "tail." The baseline KW4 model is shown on the right [3]. Note the asteroids are not to scale with respect to each other.

Variation in Itokawa There are a number of higher resolution models available for Itokawa, the highest of which is shown in Table 1. This model is used to look at how the surface varies compared to the baseline model as we increase the resolution of the shape model.

We consider the variation of the surface properties of the higher resolution models in comparison to the baseline models. Fig. 2 illustrates this for one facet from the baseline model, drawn as a grey plane, with an overlay of the high resolution surface in brown. It is clear that the higher resolution model shows considerable variability on length scales below those of the baseline model. In Fig. 2, the entire high-resolution surface is above the baseline facet, which follows for most facets.

In order to quantify this variability, we look at the variation in height with respect to the baseline facets, as

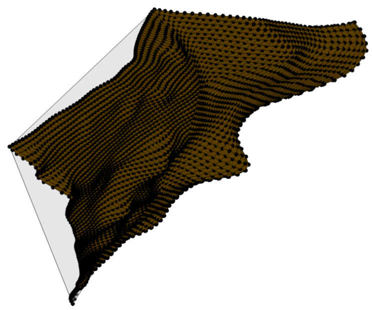

Figure 2: Illustration of the comparison of a facet from the baseline model (light grey) with the Ito6 data superimposed. This facet is shown in red in Fig. 1

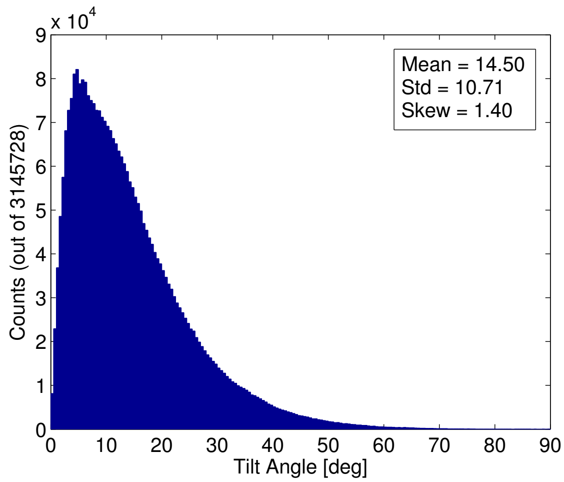

Figure 3: Histogram of the tilt angles, θ_i, for each facet of the high-resolution model compared to the larger baseline facets.

well as variation in the angle of the surface with respect to the baseline surface. This tilt angle, θ is determined for each high-resolution facet by

$$\theta_i = \arccos\left(\hat{\mathbf{n}}_b \cdot \hat{\mathbf{n}}_i\right) \tag{1}$$

where $\hat{\mathbf{n}}_b$ is the normal vector of the baseline facet, and $\hat{\mathbf{n}}_i$ is the normal vector of a high-resolution facet, denoted by i.

Comparison of the θ_i angles between the baseline Itokawa model and the highest resolution model, is shown in Fig. 3, and can be closely approximated by a Gamma distribution. From Fig 2, it appears that this distribution is due to the even coverage of high-resolution facets over hills and valleys. However, the individual facets appeared to be biased to be above the baseline facets. This is a general trend over the body, so that there is a skew of the height variation in the positive direction. The distribution in Fig. 3 is very similar to those found when comparing the baseline models with other Itokawa models between the two shown here, although the mean slope deviation increases as resolution decreases (in other words it is highest for the case shown).

This analysis can be explored in more detail by looking at the variation within each baseline facet. When comparing the two Itokawa models listed in Table. 1, there are 4096 high resolution facets per baseline facet. This analysis shows that most facets have a standard deviation of the high resolution tilt angles of near 10 degrees; therefore most baseline facets do contain a significant amount of roughness.

Note that Eros is a much larger body (34 km diameter maximum), and shape models of the resolution of the baseline models used in this study are not available. However, we will analyze the relative change in surface properties between different Eros shape models that are available, and compare these results to those found for Itokawa.

High-Resolution Models of KW4 The statistics derived from the Itokawa models can be used to create feasible high-resolution models of KW4. We will create these models to match the distributions of tilt angle and height variations seen on Itokawa, while keeping the surface smooth, as seen in Fig. 2. The theoretical high-resolution models will be analyzed and compared to the baseline models to understand how the variation in surface properties changes the body properties such as the surface roughness, gravitational slopes, and surface shadowing for the computation of the YORP effect.

References

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