NEW TRAJECTORY ESTIMATES OF THE HAYABUSA SPACECRAFT FROM LIDAR. O.S. Barnouin, E.G. Kahn, and C.M. Ernst. The Johns Hopkins University Applied Physics Laboratory (Johns Hopkins Road, Laurel, MD 20723; Olivier.Barnouin@jhuapl.edu; Eliezer.Kahn@jhuapl.edu; Carolyn.Ernst@jhuapl.edu)

Abstract: We present new trajectory results obtained from data collected by the laser altimetry or lidar on board the Hayabusa spacecraft that hovered and subsequently sampled 25143 Itokawa. [1]. These new trajectories are the result of two new corrections made on top of the efforts described in Barnouin-Jha et al. [2] and used in Abe et al. [3] for estimating Itokawa's mass *M*. The first correction makes use of a very high-resolution Itokawa shape model derived from a combination of imaging and lidar data [4]. The trajectories are shifted such that the differences between the lidar surface points and Itokawa's shape are minimized. The second correction makes use of the physical equations of motion to further refine the trajectories. This correction provides new constraints on the mass and density of Itokawa that can be compared to earlier results [3].

Original Data Reduction Process: The Hayabusa laser altimetry dataset has been challenging to reduce. The Hayabusa laser altimetry team had to refine and improve estimates of the position of the Hayabusa spacecraft relative to Itokawa throughout the mission. These improvements were initially achieved through least-squares fitting of data obtained from the wide-angle imager, spacecraft attitude information obtained from the star trackers, an a priori Itokawa shape model, and the ranges measured by the Hayabusa laser altimeter. This crude fitting approach yielded significant improvements to the laser altimetry dataset, but was limited to data where Itokawa's limb was within the wide-angle camera's field of view. The data derived by this technique have been delivered to the Small Body Node of the Planetary Data System and are accurate to within 10m of the shape model. The spacecraft trajectory derived by this approach has helped to geo-reference many of the images from the AMICA camera to the Itokawa shape model.

Additonal Data Reduction: While these data are useful for re-aligning most images obtained by the mission, they still allow for significant errors in estimates of Itokawa's mass, especially without the use of Doppler ranges, which are not available to the public. In addition, many of the close-up images of Itokawa still remain poorly registered. To further improve the trajectories of the spacecraft, we have adapted an additional algorithm. We note that in general the laser altimetry data collected by the spacecraft curve and wind around the asteroid in complicated ways, but that a simple translation is sufficient to shift short tracks so that their difference are minimized relative to the surface of the asteroid.

Our algorithm begins by first dividing up the location of laser altimetry points derived by [2] into small tracks of several hundred points each, such that the resulting tracks do not wind too far around the asteroid and a simple translation is sufficient to minimize differences between the measured altimetry and the shape model of Itokawa. We assume the original pointing information derived from the spacecraft is correct so that only the position of the spacecraft needs to be improved, as was found previously to be sufficiently accurate [2].

Next, for each small lidar track the following procedure was performed: 1) Denote the set of lidar points in the track as *S* (the source points); 2) For each *S*, compute a nearby point on the asteroid by intersecting with the highest-resolution shape model of the asteroid [4] using a ray originating from the spacecraft position (using results in [2]) in the direction of the lidar point. These intersection points now form a second set denoted as *T* (the target points). 3) Use a point-matching scheme to shift the spacecraft trajectory to find the optimal translation that best matches the source points *S* to the target points *T*. A new set of *T* values was obtained after each trajectory translation until the sum of squared difference between and the new *S* and *T* points was at minimum.

Results: The topography-matching scheme has significantly improved the calculated trajectory of the Hayabusa spacecraft from an RMS error of 7m to 3.5m. These new trajectory solutions will be further refined by using a least-squares fit of the equations of motion to our improved trajectories. Solar pressures and degassing effects are detangled from Itokawa's gravity field by first looking at solutions for the trajectory of Hayabusa far from the asteroid, at ranges >10km. The solutions for *M* were then obtained from ranges much closer to the asteroid. Iterations were undertaken using the The new trajectory solutions derived from the equations of motion with the *S* and *T* procedure detailed above, until the errors differences between the values of *S* and *T* values no longer changed. The results from these solutions will be presented and should lead to a validation of the mass and density of Itokawa.

References: [1] Akira et al. (2011), Science 333, 1125-1127. [2] Barnouin-Jha et al. (2008), *Icarus 198*, 108-124. [3] Abe et al. (2006), Science 312,1344-1347. Clark et al., Icarus, 216, 462-475. [4] Gaskell et al. (2008), MAPS 43, 1049-1061.