Mission Design for Global Mapping Orbits at Primitive Bodies

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Short Abstract:

Global mapping campaigns are part of most primitive body exploration missions. However, designing a mapping orbit without station keeping maneuvers is challenging due to the highly perturbed environment near small bodies. In this paper, we present a new design methodology to support mapping campaigns using 'quasi-terminator' orbits, a class of quasi-periodic orbits that exist in the vicinity of the well-known terminator orbits. The inherent stability of quasi-terminator trajectories and their wide variety of viewing geometries make them a very compelling option for mapping campaigns. A high-fidelity test case solution is also presented to prove the existence of these mapping orbits in full ephemeris.

Extended Abstract:

A lot of missions aimed at the characterization of small primitive bodies are currently in flight and under development. Prominent examples are ESA's Rosetta, JAXA's Hayabusa-2, and NASA's OSIRIS-REX. These primitive body missions must typically include some sort of global mapping campaign where visible spectrum imaging is used to build up a global image database and a global shape model. Other scientific objectives can also involve inferring the internal structure and composition of the body through global radar measurements. For all these applications, it is necessary to collect data from directions that encompass the whole body. In particular, for good imaging we need entire visibility of the lit side of the object from a variety of angles and orientations.

The standard technique to perform mapping is to rely on station keeping, such as controlled polar orbits or vertical hovering (where the spacecraft stays along the line joining the Sun and the body through instantaneous maneuvers). However, these strategies require spending delta v's, which increases the mission cost. It is therefore crucial to look for stable solutions that would provide extensive coverage without the need of controlling the spacecraft. Finding such desirable stable orbits is a challenge because the dynamical environment near small bodies is highly perturbed by solar pressure and gravitational forces. Even the well-known stable retrograde equatorial orbits cannot exist in this environment [Scheeres 2009].

Recently, a new class of stable, quasi-periodic orbits has been discovered in the solar pressure perturbed Hill model around a primitive body [Broschart 2013]. These trajectories are called 'quasi-terminator' orbits because they are part of quasi-periodic tori around the well-known periodic terminator orbits that exist in that environment. These tori arise from the center manifolds of the stable terminator orbits, as predicted by KAM theory. Contrary to the terminator orbits, the quasi-terminator orbits make significant

departure from the terminator plane, and therefore provide much better viewing geometry: a significant portion of the period is spent over the Sun or Dark sides with a variety of solar phase angles. On any orbital orientation, station keeping is not in theory required since these orbits are also robust to solar pressure perturbation.

Figure 1 depicts a representative quasi-terminator orbit. Figure 2 demonstrates that a variety of Sun-relative orientation can be achieved in this type of orbit.

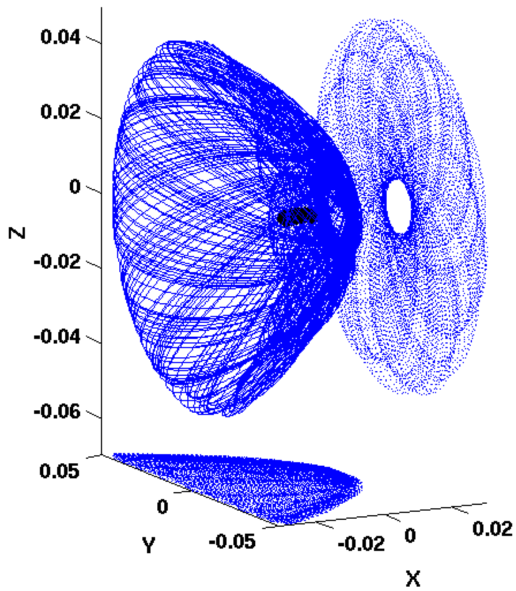

Fig 1 – Example of Quasi-terminator orbit (with projections). Coordinates are in normalized units with a normalized version of Itokawa shown.

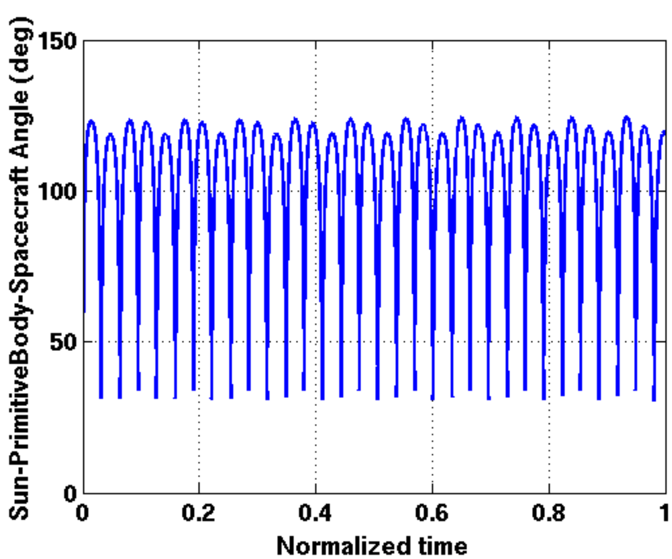

Fig 2 – Solar phase angle for the quasi-Terminator orbit shown above.

This paper will therefore describe the orbit design method to support mapping campaigns for various representative small bodies. The paper will develop the background necessary to explain what a quasi-terminator orbit is and how it works. Practical plots will be provided to enable mission analysts to quickly select an appropriate quasi-terminator orbit that would meet the mapping campaign needs of a specific mission. This design process will address the range of small body masses and spacecraft mass-to-area ratios that can be encountered in primitive body missions. Figure 3 gives the values of the normalized solar pressure strength (the only parameter in the solar pressure perturbed Hill dynamics) as a function of these quantities. For context, a number of historical and current primitive body mission configurations are marked.

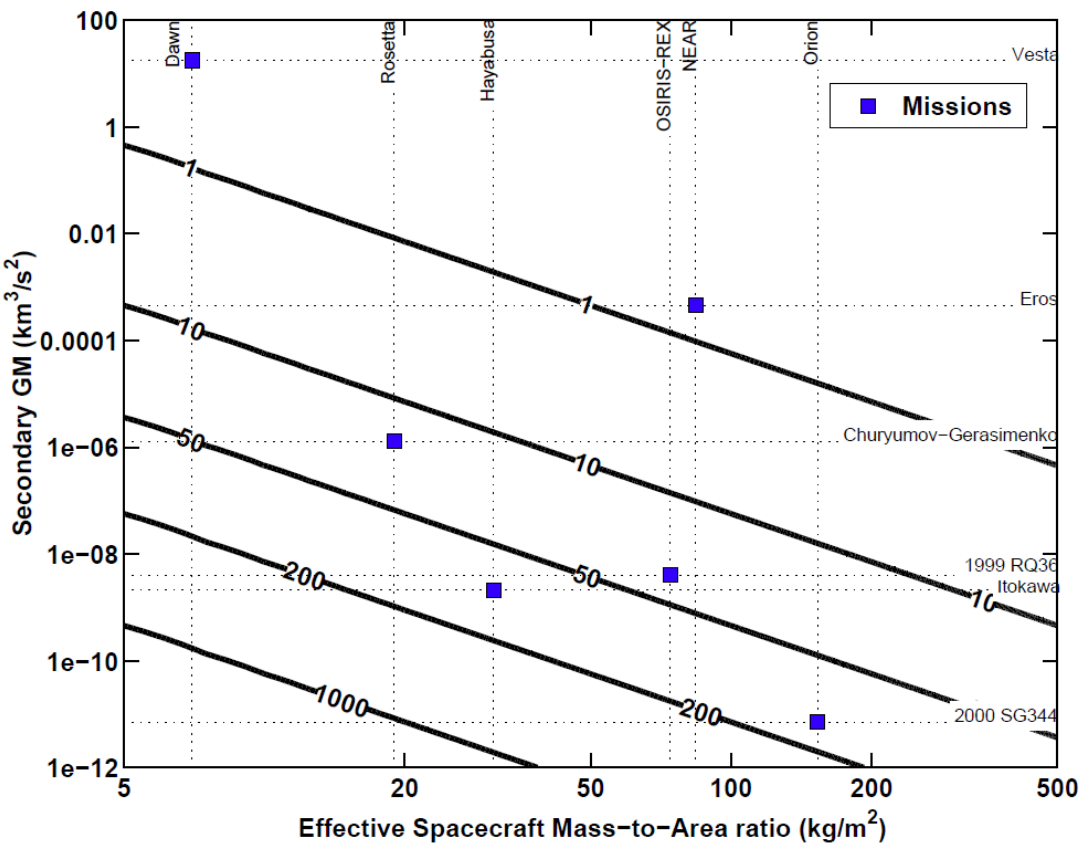

Fig. 3 - Normalized solar pressure strength as a function of effective spacecraft mass-to-area ratio and small body gravitational constant. Approximate spacecraft and secondary properties are given for a number of historical and current primitive body missions.

Finally, a multiple shooting differential correction algorithm will be used to transition the quasi-terminator orbit selected by our method to a full ephemeris dynamics model.

References:

[Scheeres 2009] D.J. Scheeres, Orbit mechanics about small asteroids. Presented at the 2009 AAS/AIAA Spaceflight Mechanics Meeting, February 2009, Savannah, GA. AAS 09-220

[Broschart 2013] S.B. Broschart, D. J. Grebow, G. Lantoine, "Characteristics of Quasi-terminator Orbits near Primitive Bodies", AAS Paper, 2013 AAS/AIAA Spaceflight Mechanics Meeting, February 2013 (abstract submitted).