Navigation For Low-Cost Missions to Small Solar-System Bodies

D.J. Scheeres, B.G. Williams, W.E. Bollman, R.P. Davis, C.E. Helfrich, J.K. Miller, S.P. Synnott, D.K. Yeomans
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

A variety of planned low cost space missions (e.g. NEAR, MASTER, ROSETTA, CA, CNP) will involve rendezvous with, and orbits about, small solar-system bodies such as asteroids and comets. Rendezvous missions of this nature have not been performed previously, with all previous encounters having been flybys. Thus there are a number of issues and challenges for navigation which have not been previously considered. This paper will identify the different mission phases for small body encounters and the navigation requirements, objectives and goals involved with each phase. Also, certain practical limitations with respect to mission design will be identified and discussed. The basic phases and issues to be addressed are as follows.

Pre-encounter characterization. Prior to the actual encounter with the small body the knowledge base pertaining to the body must be expanded. This includes an improvement to the ephemeris of the body as well as estimates of the body size, shape, density, rotation rate and rotation pole.

Encounter and Rendezvous phase. This phase extends from target acquisition to delivery of the probe at some nominal distance (thousands of kilometers) from the target. During this phase the target must be acquired and a sequence of maneuvers must be executed which target the probe to the small body, essentially a point in space.

Initial Characterization phase. During this phase the probe flies towards the target at a reduced speed and begins to build up an optical information base about the target. A model of the target must be constructed which includes the body's size and shape, attitude and attitude dynamics, and preliminary estimates on the body's mass and gravitational harmonics. If the target body is a comet, then preliminary estimates of the outgassing field must be made as well as locations of the major jets on the comet surface.

Initial Orbit phase. When the probe enters into an initial orbit about the body, the gravitational harmonics and mass of the body are estimated, relying on Doppler data. If the body is a comet, then the outgassing field is also estimated. This period is crucial as a checkout, period where the assumed mission plans and control algorithms are compared with the actual environment at the small body.

Mission phase. Pending satisfactory results from the previous phases, the mission phase consists of an extended period of orbits about the body, but may also consist of preparing a probe delivery to the surface of the body. Due to the small size and mass of these bodies and their irregular size, the probe will be subject to large perturbations from solar pressure, gravitational harmonics and non-gravitational effects which are not encountered in classical planetary missions. Estimates on the sizes of these perturbations and their effects on orbits in various geometries are given. We also address the control, reconstruction and prediction of orbits about these small bodies and the amount and type of data necessary to fulfill these goals. For certain types of missions it may be feasible to introduce some level of autonomous navigation and control during this phase, allowing for a reduction in operations cost.

Navigation of spacecraft to and about small solar-system bodies is challenging and raises many issues of fundamental importance which should be understood by mission designers and sponsors. This paper will identify the most important issues and discuss ways in which they must be dealt with. It also provides a methodology with which to approach navigation for small body missions.