MRD 196

Requirements Overview

Level-2 Science Requirement	MRD-#	Description & Rationale
2.12.6	196	Determine the orbital properties and stability of any detected satellites

This report outlines the approach to be taken for characterizing the orbit and stability of any satellites detected by the OSIRIS-REx spacecraft on approach to the asteroid, or detected at some later time during the mission duration. As the nominal expectation is that a co-orbital will not exist, this plan is part of the baseline, but not threshold, science activities. Note that the stability analysis has been expanded to include evaluation of whether a TAGSAM sampling attempt might also create temporary satellites, and what their lifetime and orbital properties may be.

The approach taken in the current report is to first outline the process by which the initial and refined orbit determination of any detected satellites will be carried out. Then we provide a discussion of how the stability and longer-term dynamics of these satellites will be evaluated. Significant components of these processes have yet to be developed, so a plan for their completion is outlined. A benefit of studying and determining the stability properties of putative satellites around 1999 RQ36 is that these results will help shape and direct the observing strategy on approach. That component of the study may also help identify potential concerns about the stability of regolith perturbed during one of the sampling attempts, and could help develop guidelines on how long of a waiting period between surface sampling attempts would be prudent to avoid impact with any transient satellites created during an earlier sampling attempt.

Process Overview

Data products to be produced:

Estimated orbit elements / epoch state for any satellite detected, along with associated uncertainties in the state estimate. Associated with these estimates will be an ephemeris file providing locations of the satellites as a function of time.

The ephemeris files of any satellites will be in NAVIO and SPK formats. These are the same format as the target asteroid ephemeris files, which are part of the baseline SPOC archive.

Estimates of the long-term dynamical stability of the estimated orbit, sampled across the entire uncertainty distribution.

Evaluation of the post-TAGSAM sampling environment about the asteroid, performed for each tentative sampling site.

The orbit estimation and ephemeris development process uses standard format optical navigation files (Picture Sequence Files) produced by FDS, as well as the FDS-delivered s/c ephemeris. The software for this task will

be the JPL Solar System Dynamics natural satellite software suite, which will need some modest revisions in Phase C/D to function with an asteroid as primary body. JPL Solar System Dynamics personnel will deliver the orbit and ephemeris data products to the SPOC.

RSWG personnel will conduct satellite stability analyses. Such analyses may be crucial to distinguish alternate orbital solutions during the days after discovery, when there are insufficient observations to make a robust orbit determination.

These products will be based on astrometric measurements of the detected satellites to be produced by the FDS. The necessary data needed will be the inertial direction from the spacecraft imager to the detected satellite at each observation epoch. This information can be combined with the current estimate of the asteroid relative spacecraft location to define asteroid-relative locations of the satellite, nominally defined as an intermediate 1-dimensional line with associated uncertainty. When at least three such measurements exist it becomes possible to develop and test hypotheses on which orbits the satellite could reside on, given constraints on estimates of the total asteroid mass. As more observations are accumulated the confidence in particular orbit solutions will increase and become statistically more relevant. Then, based on these estimates the longer-term motion and stability of the measured orbit can be determined. This process can be used to exclude certain solutions – if for example the orbit is seen to immediately escape– and can be used to start developing confidence on how the satellite can be avoided during nominal operations.

Instrument Capabilities

The satellite search plan on for the Arrival Phase is being designed by the AAWG based on the arrival circumstances and planned instrument specifications. PolyCam is the intended instrument for this effort and the associated images will be searched by AAWG for potential satellite targets. If a satellite is found the RSWG will become involved to perform orbit determination and ephemeris development for any satellites. In that scenario, RSWG will be consulted on the appropriate cadence of additional observations.

For the orbit determination process, the desire is to obtain observations of the satellites in two distinct observing cadences.

First, the capture of measurements with relatively short time spans between observation epochs can help develop estimates of the angular rate at which the satellite may be moving. The specific cadence of observations will depend on the expected rates of motion of objects at different distances from the asteroid, and will be studied in the future.

Second, the capture of measurements with longer time spans between observations allowing for larger changes in position, which will break ambiguities in orbit solutions and enhance the accuracy of the orbit estimates. The specific timing of these cadences must be developed in the future.

For orbit determination purposes, we also need to specify the desired accuracy of measurements. To preclude the levying of overly strenuous requirements, additional interactions between the AAWG, IPWG, FDS and RSWG must occur to align the expected precision of measurement and the possible precision of measurement.

Expected Data Return by Mission Phase

Estimated orbit elements will be returned after the detection of satellites in orbit about the asteroid. Initial estimates are expected to have large uncertainties, although these will decrease with additional observations taken over longer time periods. Updated orbit estimates will be produced upon the acquisition of additional observations or when significant improvement in the estimate occurs.

In conjunction with the orbit estimates will be immediate analysis of the stability of the found orbit, based on previous studies. This immediate stability analysis will be augmented by longer-term orbit integrations that will probe the expected stability of the estimated orbit and the associated uncertainty.

If, based on future analysis, we identify the possibility of transient satellites to be created during sampling attempts, we shall outline the necessary observation cadence to be inserted into the DRM to scan for this possibility. This would insert another possible period of data return associated with the close proximity phase of the mission.

Ground System Observation Planning Capabilities and Resources

The Project will be developing a satellite contingency plan for the OSIRIS-REx mission. The RSWG should be closely involved as this contingency plan is developed.

The ground system requirements for carrying out these activities are:

1. Access to the observation data from the SPOC to ingest into RSWG computers and transmit to processing site (which may be remote at JPL).

2. RSWG computers will be used to perform the orbit determination, estimate epoch states for the satellites, and produce satellite ephemerides.

3. Predicted ephemerides of the satellites will be sent to the SPOC and can be used by the AAWG to design subsequent observation cadences.

Data Processing Products and Timeline

Predicted ephemeris: Observations of satellites

Stability characteristics: Observations of satellites and orbit determination output

On approach to the asteroid, during Phase 3. Closeout will occur on the order of 2 weeks following the last input data. Redelivery of ephemerides may occur throughout the mission and all subsequent phases. Note, detection of satellites will force a redesign of the initial phases of the DRM in order to acquire sufficient data for orbit determination. Orbit determination should be an important component of the contingency plan.

Upon receipt we will use observations in our orbit determination code for estimation of the orbits.

Given a full set of data, computation of a precise orbit and determination of stability will take less than two weeks. More precise processing time constraints will be available upon further study.

Verification occurs once the estimated orbit accurately predicts the future observations and all of the quality observation data can be fit consistently.

Software Development in Support of Near-Asteroid Environment Science

For the orbit determination and ephemeris development, existing software developed by JPL's Solar System Dynamics group will require very modest extensions to function with an asteroid as the central body, rather than a planet. The software already ingests the standard format optical navigation data type (PSF file) and the standard format spacecraft ephemeris file (NAVIO). The software modifications will be conducted during Phase C/D under the direction of Co-I Chesley. This software will not be hosted by the SPOC, but rather Operational interface Agreements (OIAs) or Interface Control Documents (ICDs) will be drafted to conform with SPOC requirements.

Software for stability analyses of satellites will be developed at CU, starting from legacy software developed by Co-I Scheeres. Current estimates are based on analytical theory and will require further development to provide an accurate assessment of the stable orbit environment about 1999 RQ36. This development will take place in Phase C/D.

Summary and Conclusions

If natural satellites are detected around 1999 RQ36, observations of these satellites must be processed to determine the orbits of these bodies and their predicted ephemerides. Characterization of the stability of motion is also needed to develop longer-term predictions to cover the entire mission.

Detection of such satellites is not expected, but would potentially be disruptive to the DRM if they are found. These considerations have not been dealt with in detail yet.

The software needed for many of these tasks is substantially ready. Orbit determination and ephemeris development will be conducted by JPL Solar System Dynamics Group personnel, who will deliver data products to the SPOC under an OIA/ICD. Modest changes are required to the software to support OSIRIS-REx.

The CU stability software will be developed during Phase C/D, and will be based on existing capabilities.

Discussions between AAWG, IPWG, FDS and RSWG for a contingency plan on how detection of a satellite will be handled must occur in Phase C/D.