Origins Spectral Interpretation Resource Identification Security-Regolith Explorer (OSIRIS-REx) Project

DETECTION OF A NATURAL SATELLITE CONTINGENCY PLAN

Associated with the Design Reference Mission and Mission Plan (DRM)

OSIRIS-REx-PLAN-0056

Revision -

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Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

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In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will," and descriptive material by "is."

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Item No.	Location	Summary	Ind./Org.	Due Date

1.0 Introduction

1.1 Overview

The presence of a natural satellite in orbit about Bennu is considered a low probability situation, and yet it could create unsafe conditions for continuing proximity operations as originally planned. The baseline mission calls for a comprehensive search for satellites larger than 10 cm during the Approach phase, while smaller satellites may only be found serendipitously as the mission progresses. Mission requirements call for any discovered satellites to be the subject of orbital and physical characterization efforts. Additionally, the Design Reference Mission (DRM) will presumably require some modification in order to assure mission success.

1.2 Relevant Requirements

This document satisfies the requirement for a natural satellite contingency plan:

MRD-600	The Ground System shall develop a contingency plan to characterize and operate in the presence of detected natural satellites.

The following requirements drive the natural satellite search and characterization:

MRD-144	OSIRIS-REx shall detect with > 95% confidence natural satellites > 10cm diameter with albedo > 0.02 within 31km of RQ36.
MRD-146	OSIRIS-REx shall produce four light curves of detected satellites by measuring the time variation in their irradiance in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters.
MRD-147	OSIRIS-REx shall measure the integrated spectral properties of detected satellites and compare them to those of 1999 RQ36.
MRD-148	OSIRIS-REx shall, for detected satellites, determine their average ECAS b-v color index, v-x color index, and the depth of the 0.7-micron absorption feature, relative to one or more recognized ECAS standard stars.
MRD-196	OSIRIS-REx shall determine the orbital properties and stability of detected satellites.

1.3 Satellite Search

To meet MRD-144 three separate searches for satellites of Bennu will be conducted during the Approach phase.

- The first search will be a visual inspection of OpNav and Science images obtained of Bennu at thousands of km range. Satellites detected during this search will be on the order of 5-m or larger.
- The second search will consist of 4 separate MapCam pointings repeated 5 times over the course of 4 hours. This search is planned at a range of 1000 km on approach (~27-Oct-

2018) and should detect satellites larger than 1-m in diameter within the Hill Sphere of Bennu (within 31-km of Bennu).
- The third search will consist of 16 separate MapCam pointings repeated 5 times over the course of 4 hours. This search is planned at a range of 150 km on approach (~04-Nov-2018) and should detect satellites larger than 10-cm in diameter within 20-km of Bennu.

1.4 Contingency Scenario Description

A satellite is found to be orbiting in the vicinity of Bennu during the natural satellite search on approach. This will trigger a pre-planned halt in the asteroid approach and operations profile that allows the team to characterize the satellite and re-plan the DRM as necessary in order to assure a safe and successful sample collection.

Though it is not the guiding assumption for this contingency plan, there is the possibility that a satellite could be discovered later than the planned natural satellite search, although this would imply a size smaller than the detection threshold for the search, i.e. <10 cm. Such a serendipitous discovery could happen in any mission phase, but is perhaps most likely to occur between the end of the planned satellite searches and the beginning of Orbit A. Such a late discovery is fully addressed by this contingency plan, with the key difference being that having a pre-planned maneuver to be executed on command is inapplicable.

1.5 Scope

This plan describes the activities that the Operations Teams will undertake to characterize the orbital and physical characteristics of any satellites and re-plan activities as necessary to safely continue the mission in the presence of known satellites. This is not a comprehensive step-by-step plan since the applicability of the actions/activities can vary widely depending on the nature and orbit of the detected satellite.

This document does not address the contingency where the planned satellite searches are not successfully completed as scheduled, e.g., due to a safe mode entry or temporary surge in cosmic ray events that significantly degrades the images. In such cases the mission team will respond appropriately in light of MRD-144.

1.6 Applicable Documents

Document Number	Title
PLA-OSIRIS-REx-RQMT-0001	OSIRIS-REx Mission Requirements Document
PLA-OSIRIS-REx-OPS-0001	Design Reference Mission & Mission Plan
PLA-OSIRIS-REx-PLAN-0066	Navigation Plan
OSIRIS-REx-SOPS-PLAN-0131	Science Operation Plan
Science Wiki Pages	Satellite images and proof of existence (MRD-144)
	Satellite light curves (MRD-146)
	b-v index, v-x index, and 0.7-µm color ratios of satellites (MRD-148)
	Satellite Mineralogy and Chemistry (MRD-147)
	Satellite ephemerides (MRD-196)

2.0 Actions

2.1 Overview

In the event that a satellite is detected during the planned search, the exit criteria for Approach will not be satisfied and the spacecraft will execute a pre-planned maneuver to initiate station keeping at a safe position on the sun line approximately 40 km from Bennu. If a satellite is discovered after the exit of the Approach phase then a new maneuver will be planned and executed as soon as practicable after detection in order to put the spacecraft on a trajectory to a safe, low phase angle station-keeping position at an appropriate distance. If the satellite detection occurs after the planned search, the safe station-keeping distance will depend on the detection circumstances.

While station keeping, three separate activities will take place concurrently.

- Satellite orbit characterization. Optical tracking will be used to define the satellite orbit. This is an operational and scientific objective.
- Satellite physical characterization. The spectral and photometric properties will be monitored as a part of the OSIRIS-REx science investigation.
- The subsequent mission activities will be re-planned as necessary to maintain spacecraft safety and assure collection of asteroid material and safe return to Earth.

2.2 Cruise Activities

In the period between EGA and AAM-1 the operations and science teams will conduct a thread-test to exercise and test all of the interfaces involved in satellite ephemeris development. This should be scheduled to take place in early to mid-2018.

2.3 Satellite Search and Detection

The AAWG is responsible for conducting the satellite search and for identifying any natural satellites seen in the search images. During the planned natural satellite search effort (Sec. 1.3, above), source extraction software will be used during the second and third searches to identify all point sources with a S/N > 2 in each of the fields. Astrometry and photometry will be determined for each source. Moving objects that conform to the expected motion of a satellite of Bennu will be identified. Candidate satellites will then be visually inspected to ensure their reality. Astrometry, along with image identifier and pixel coordinates, of any confirmed satellites will be communicated to FDS, FDS-STI and RSWG within two days of image downlink for orbit and ephemeris determination and verification. (See the Satellite images and proof of existence [MRD-144] DPD on the Science Team Wiki under Astrometry and Photometry.)

In the event that a satellite is identified, the Mission Operations Manager (MOM) will direct initiation of the Satellite Contingency Plan.

2.4 Perform Contingency Maneuver

Post-launch, the Operations team will develop the contingency maneuver commands. These products will be built using the nominal command build process, approved by the MOM, and loaded on the spacecraft after AAM3.

The MSA will have on-board a maneuver to halt the Bennu approach at a pre-determined time. If no satellites are detected then the MSA, after approval from the PI and DPM, will send a command to cancel the maneuver. The advantage of this approach is that the maneuver will be performed without reliance on DSN coverage. The worst case is the maneuver does not need to be executed, DSN not available to send stop command, and the start of Preliminary Survey will be delayed a few days. This fail-safe scenario ensures the safety of the spacecraft in the event that satellites are found and the ground is unable to command the spacecraft in time for the contingency maneuver.

Rev C of the DRM calls for the satellite contingency maneuver to be executed on 16-Nov-2018 at approximately 44 km range to Bennu. However, a significant under-burn for AAM-3 on 29-Oct-2014 could have the spacecraft closing inside 40 km a few days earlier and so the contingency maneuver may have to be scheduled for earlier than 16-Nov-2018. The AAM-3 clean-up maneuver scheduled for 6-Nov-2014 should be designed so that there is at least six days between the final satellite search and passing within 40 km range of Bennu. Note that it is not generally necessary to execute the contingency maneuver as soon as practical after a satellite is discovered, but rather at a pre-determined time and position.

2.5 Obtain DSN Tracking

An important parallel task to the contingency maneuver execution is for the MSA to review the upcoming DSN schedule to ensure the future tracking coverage provides enough support for characterization of the satellite and the station-keeping maneuvers.

2.6 Station-keeping

The station-keeping trajectory maintenance relies on maneuvers every 14 days (Figure 1), which allows for a reduced navigation level of effort while FDS is heavily engaged with re-planning the DRM. To maintain spacecraft safety and facilitate satellite characterization, the selected station-keeping trajectory should maintain the spacecraft between roughly 40-60 km range with Bennu phase angle less than 30°.

Once it is judged safe to continue, either to a lower station-keeping range or to Preliminary survey, one of the station-keeping maneuvers will be redesigned to achieve the new desired trajectory. This allows for exit points every 14 days. However, if appropriate, station keeping could be interrupted at points other than the normal 14-day station-keeping maneuvers, e.g., in order to expedite the descent to a lower station-keeping position.

2.7 Satellite Ephemeris Development

After a satellite is discovered, and possibly even before the execution of the satellite contingency maneuver, the mission team will begin a satellite observation campaign to obtain tracking data for ephemeris development and to more intensively search the area for possible additional satellites. The design of tracking observations will depend on the nature of the satellite and its orbit, but the plan will generally require optical observations of the satellite with stars visible in the background and if practical should include some optical observations that include both Bennu and the satellite.

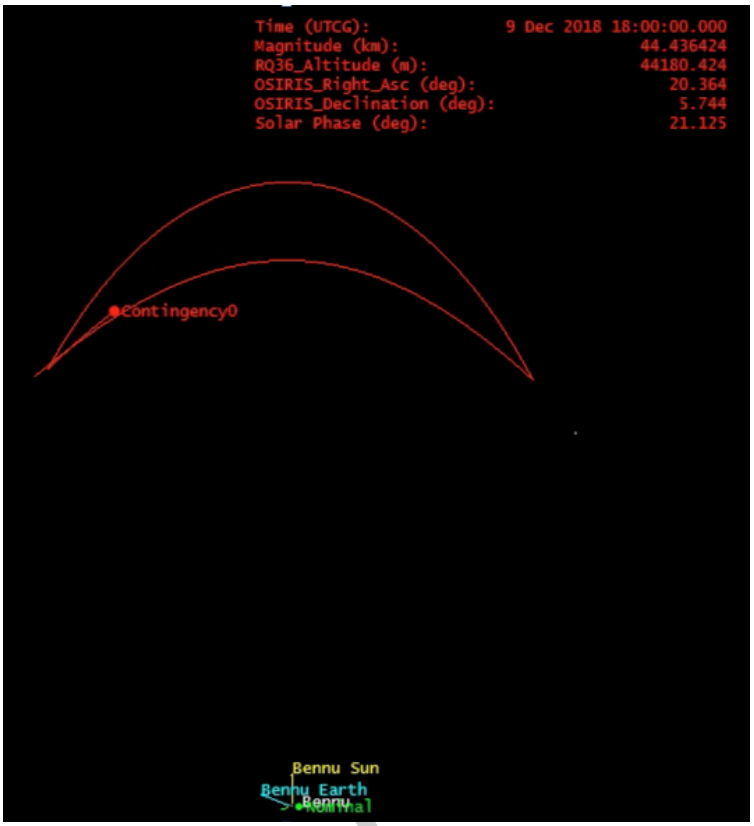

Figure 1. Station-keeping trajectory example.

It will be important to obtain tracking information as quickly as possible after the satellite detection, and yet it will take time to develop an ephemeris accurate enough for pointing. Before reliable satellite ephemeris predictions are available the mission team should continue to search the applicable region with an appropriate cadence and downlink the images for analysis. To be prepared for this contingency, the AAWG shall lead development of a Contingency Satellite Search plan to be executed from approximately 50 km range that would search for satellites within an appropriate distance (~10-20 km) from Bennu. Post-launch, the Operations Team shall prepare the associated sequencing commands to implement this contingency search plan. This sequence could be re-executed as frequently as practicable to ensure early coverage of the satellite orbit. This will allow continuing measurements of the satellite position as well as afford a more rigorous search for additional companions. After satellite pointing predictions become available more focused observations of the satellite can be recorded. The observations should be designed to capture a few to several satellite detections per satellite orbital period for a period of approximately two weeks.

JPL Solar System Dynamics (SSD) will be responsible for satellite ephemeris development. The required inputs to the ephemeris development include

- Relevant satellite imagery with UTC time tags (FITS format)
- Spacecraft attitude history to determine image pointing (PCK format)
- Spacecraft ephemeris (NIO and SPK formats)

- Bennu gravity model (SPOC format)
- Bennu rotation model (SPOC format)

Early in the contingency scenario SSD will also require the satellite detection information derived from the satellite search effort, e.g., the location of the target in search images. This information is contained in the Satellite Ephemerides (MRD-196) Data Product Description on the Science Wiki.

The SSD ephemeris delivery will include trajectory information in NIO and SPK formats. NIO files will be uploaded to the SSD FTP site for use by FDS/KinetX. SPK files will be uploaded to the SPOC. Ancillary information will be included in associated memoranda describing the input measurements and discussing the uncertainties in the associated ephemeris predictions. The first ephemeris delivery will take place as soon as feasible, with a goal of four days after sufficient data becomes available. To ensure that planners always have suitable ephemeris predictions, ephemeris updates will continue for the duration of proximity operations on an ad hoc basis driven by the satellite-tracking cadence.

2.8 Satellite Physical Characterization

While in the station-keeping phase, and sooner if practicable, the mission team will conduct satellite characterization observations on a best efforts basis. Disk-integrated spectroscopy and light curve, ECAS color and phase function photometry will be conducted throughout the remainder of the Encounter. The exact timing of the characterization observations will depend on when the satellite is bright enough for study.

It is probable that the spacecraft will have to move in closer to get adequate signal for the spectrometers, a step that will require 2-4 weeks of tracking to secure the satellite ephemeris. A notional plan could be to drop to a 30-km station keeping after 2-3 weeks at the preliminary station-keeping position. After another 2-3 weeks it may be possible to close to 10 km (assuming satellite is at 1-2 km orbit radius, as is likely).

Additional detail on satellite characterization can be found in the following DPDs on the Science Wiki: Satellite light curves (MRD-146), b-v index, v-x index, and 0.7-μm color ratios of satellites (MRD-148) under Astrometry and Photometry and Satellite mineralogy and chemistry (MRD-147) under Spectral Analysis.

2.9 Re-planning the DRM for Satellite Avoidance

The re-planning effort will commence as soon as the first satellite ephemeris delivery becomes available, which could be 5-10 days after the discovery. The process is assumed to take at least 4-6 weeks, assuming that the satellite orbit presents significant challenges to operations.

It is impractical to describe the re-planning process for this contingency, but the key objective is to develop a safe strategy for achieving the mission objectives, with special attention to the threshold objective of returning a sample to Earth.

2.10 Notional Timeline of Events

The following notional timeline of events is one of the ways that the satellite contingency

scenario could unfold. Clearly there are countless variations, and yet the notional timeline gives an idea of the cadence and sequence of key contingency events.

Event	2018 Date	Remark
Satellite Search #1	Oct. 1-26	5m from ~2000-20000 km
Satellite Search #2	Oct. 27	1m from 1000 km
Satellite Search #3	Nov. 4	0.1m from 150 km
Satellite Discovered	Nov. 6	Two days after downlink of Search #3
Contingency Satellite Search	Nov. 8	Starts ASAP and continues daily UFN
Contingency Maneuver #1	Nov. 16	Pre-planned maneuver
Preliminary Satellite Ephemeris Delivery	Nov. 16	10 days after discovery
Begin DRM Re-planning	Nov. 16	Based on prelim. ephemeris
Contingency Maneuver #2	Nov. 30	Station-keeping
Robust Satellite Ephemeris Delivery	Nov. 26	20 days after discovery
Precise Satellite Ephemeris Delivery	Dec. 6	30 days after discovery
Contingency Maneuver #3	Dec. 14	Descend to lower station-keeping alt.
Conclude DRM Re-planning	Dec. 14	4 weeks from 1st ephemeris
Contingency Maneuver #4	Dec. 22	Target to enter Prelim. Survey
Enter Preliminary Survey	Jan. 5	On re-planned DRM

2.11 Routine Satellite Orbit Maintenance

The mission team will maintain the satellite orbit with regular tracking observations throughout the proximity operations period. After the initial orbit characterization period of approximately 20 days, routine monitoring can be accomplished with weekly tracking observations (5-10 images with both Bennu and the satellite in the field of view) for the first few months. Such observations can likely be gathered with little or no extra effort, for example during Preliminary and Detailed Surveys the spacecraft is already in excellent position for recurring observations. Monitoring during the Orbit A & B phases may require special-purpose imaging, depending on the satellite orbit, but it is also likely that the Orbit A & B phases will need significant modification in order to avoid putting the spacecraft at risk.

An appropriate orbit maintenance plan depends heavily on the satellite orbit and it is impractical to detail this effort as a part of the natural satellite contingency plan. JPL SSD will, as a part of its initial ephemeris delivery, develop an ongoing tracking plan and deliver it to SPOC/MSA/FDS so that these observations can be included in the revised baseline mission plan.

2.12 List of preparatory contingency plan activities

The following tabulated activities will be implemented in preparation for this contingency scenario

Activity	Date or time frame	Responsible party
Satellite ephemeris development thread test	NLT Jun 2018	MSA/Chesley
Baseline satellite search sequence design	NLT Jan 2018	MSA/Hergenrother
Contingency satellite search sequence design	NLT Jan 2018	MSA/Hergenrother
Phase Transition table top for Approach to Prelim Survey	NLT Aug 2018	Cheuvront
Final satellite contingency maneuver design	After AAM3	FDS/Sutter

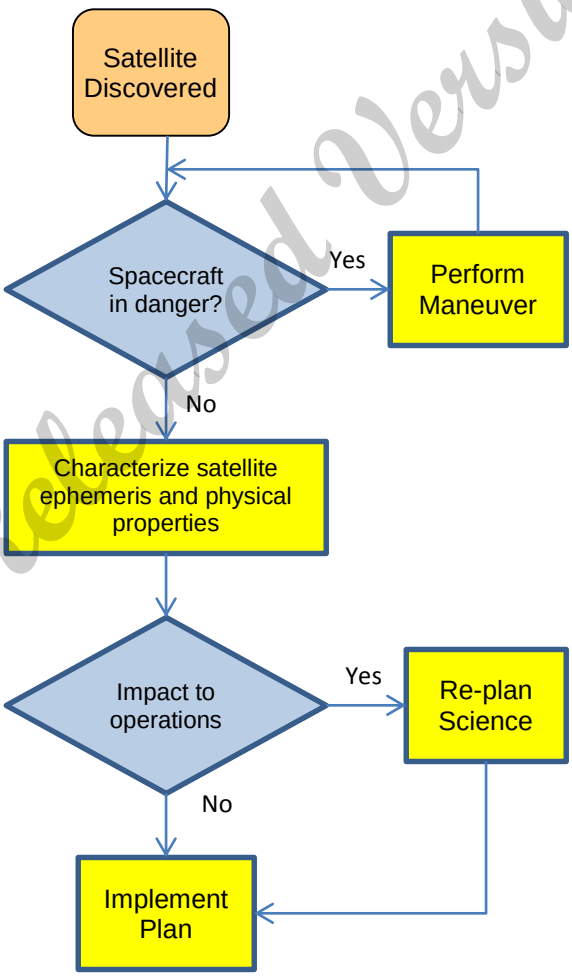

Figure 2 Decision Flow Diagram

APPENDIX A: ACRONYMS

AAWG – Asteroid Astronomy Working Group

AAM – Asteroid Approach Maneuver

DPD – Data Product Description

DPM – Deputy Project Manager

DRM - Design Reference Mission

DSN – Deep Space Network

ECAS – Eight Color Asteroid Survey

EGA – Earth Gravity Assist

FDS – Flight Dynamics System

FDS-STI – Flight Dynamics System – Science Team Interface

FITS – Flexible Image Transport System

FTP – File Transfer Protocol

GSFC – Goddard Space Flight Center

JPL – Jet Propulsion Laboratory

MOM – Mission Operations Manager

MRD – Mission Requirements Document

MSA – Mission Support Area

NIO – Navigation Input/Output

NLT – No Later Than

PCK – Planetary Constants Kernal

PI – Principal Investigator

RSWG – Radio Science Working Group

S/N – Signal-to-Noise

SPK – SPICE Kernal

SPICE – Spacecraft Planet Instrument C-matrix Events

SPOC – Science Processing and Operations Center

SSD – Solar Systems Dynamics

UFN – Until Further Notice

UTC – Coordinated Universal Time