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

LOSS OF POLYCAM OR MAPCAM CONTINGENCY PLAN

Associated with the Design Reference Mission (DRM)

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DOCUMENT CHANGE RECORD

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REV/ VERSION LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
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LIST OF TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1			Name/ Code	MM/YY

1.0 INTRODUCTION

1.1 Overview

This document provides contingency plans in the event of the loss of one of either PolyCam or MapCam before we arrive at Bennu. We examine each scenario individually. In the first scenario, we lose PolyCam, but retain MapCam. In the second scenario, we lose MapCam, but retain PolyCam. Both examples assume no loss of OLA. We summarize the major impacts of the loss of each camera and how we will attempt to recover from each contingency.

Data provided by PolyCam are used for the mission-critical functions of shape model development, navigation and sample-site selection. PolyCam serves as the primary navigation instrument during the Approach phase at distances > 195km from Bennu. At closer ranges during Approach and Preliminary Survey, PolyCam (along with MapCam) collects images that will be used to produce the early shape model of Bennu for navigation and global science mapping. In the Detailed Survey, Orbital B, and Recon phases, PolyCam provides the primary data sets used to identify safe and sampleable target sites and eventually to select the prime site.

Data provided by MapCam are used for the mission-critical functions of shape model development, navigation and environmental safety hazard assessments (natural satellites and dust plumes). MapCam serves as the primary instrument during the late Approach phase for conducting surveys for natural satellites and for navigation at distances <195km. At closer ranges during Approach and Preliminary Survey, MapCam (along with PolyCam) collects images that will be used to produce the early shape model of Bennu to be used for navigation and global science mapping.

Because PolyCam and MapCam provide these mission-critical data, and the mission must be single-fault tolerant to achieving the threshold mission, this contingency plan is developed for utilizing the functional redundancy provided by the cameras in the OCAMS suite and by other instruments that are part of the OSIRIS-REx payload.

1.2 Summary Of Major Impacts From Loss Of Polycam

All of the requirements associated with PolyCam needed for the threshold mission can be satisfied with the loss of PolyCam. In all cases but two, the requirements can be satisfied with no change in the DRM planned trajectories. In the Approach Phase the approach velocity will have to be reduced and the images will be replaced by MapCam images taken closer to Bennu. The braking burn planned as a contingency for the detection of natural satellites can be used for this purpose. If satellites are found, they can be tracked in combination with imaging Bennu during a slower final approach. The shape model imaging requirements will finally be satisfied with MapCam images during Preliminary Survey. The loss of PolyCam for the Reconnaissance Phase may require taking more time during the TAG Rehearsal Phase than currently planned or we may be able to validate an extrapolation of the particle size-frequency distribution to smaller sizes based on a limited number of MapCam images taken during the Matchpoint rehearsal. In all other cases, the requirements can be satisfied with other instruments using the currently planned trajectories.

1.3 Summary of Major Impacts from Loss of MapCam

All of the threshold requirements addressed by MapCam will be satisfied with no changes to the currently planned trajectories. The only loss in science that is not recovered is that due to the color imaging provided by MapCam. In most cases that loss can be made up with data from OVIRS, which has much better spectral resolution than the four color filters of MapCam but not nearly as good spatial resolution.

1.4 Applicable Documents

Document Number	Title
PLA-OSIRIS-REx-RQMT-0001	OSIRIS-REx Mission Requirements Document
PLA-OSIRIS-REx-OPS-0001	Design Reference Mission
OSIRIS-REx-PLAN -0079	Mission Plan
PLA-OSIRIS-REx-PLAN-0066	Navigation Plan
	Sampleability Data Product Description
PLA-OSIRIS-REx-PLAN-0056	Detection of a Natural Satellite Contingency Plan

2.0 LOSS OF POLYCAM

2.1 Scenario Description

PolyCam has stopped functioning prior to arrival at Bennu.

2.2 Affected Mission Objectives and Science Requirements

The loss of PolyCam would affect the following threshold mission requirements.

Phase	MRD #	Requirement
Approach	**123**	**Bennu Shape Model** OSIRIS-REx shall produce a > 1 million vector shape model.
Prelim Survey	**678**	**Global 75cm DTM Ground Sample Distance** The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.75 m in ground sample distance (sample resolution).
Detailed Survey	**121**	**Global Imaging of Bennu** OSIRIS-REx shall image > 80% of the surface of Bennu with < 21cm spatial resolution (4-pixel criterion) to produce a global mosaic, stereo images, mosaics of hazards and regions of interest, and image sequences of the asteroid surface.
Detailed Survey	**137**	**Boulder Distribution** OSIRIS-REx shall identify and map the distribution of all boulders on > 80% of the surface of Bennu > 21cm in shortest dimension.
Detailed Survey	**687**	**Global 35cm DTM Ground Sample Distance** The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.35 m in ground sample distance (sample resolution).

Orbital-B	**115**	**Sample Site Topographic Maps** OSIRIS-REx shall, for a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a topographic map at < 5cm spatial resolution and < 5cm (1-sigma) vertical precision.
Orbital-B	**576**	**Candidate Sample Site Stereo Imaging** OSIRIS-REx shall collect OCAMS panchromatic data with < 5cm spatial resolution over 100% of a 3σ TAG error ellipse around each of up to 12 candidate sampling sites from the 1km-radius Safe Home Orbit at ranges between 600m and 1000m.
Recon	**116**	**Sample Site Particle Size-Frequency Distribution** OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around at least 2 candidate sampling sites map the areal distribution and determine the particle size-frequency distribution of regolith grains < 2-cm in longest dimension.
Recon	**578**	**Recon Site < 2cm Resolution Image Data Collection** OSIRIS-REx shall collect PolyCam data over > 80% of a 2σ TAG error ellipse around at least the prime and backup sampling sites from a nominal range of 225m.

2.3 Discussion of Affected Mission Objectives and Recovery Plans

The net effect of losing PolyCam data, which are the highest spatial resolution data at any given time at Bennu, is the likely delay in achieving some of the proximity operations milestones because data products of the required resolution to support key decisions will not be available until later in the timeline. This section describes alternate strategies for obtaining the data needed to produce shape and topographic data products with MapCam and OLA (Table 1) that support navigation and TAG site selection. In this scenario, final TAG site selection will be made without the benefit of 80% coverage of the prime and backup sites with <2cm resolution, but due to the other products that provide indicators of TAGSAM ingestibility, there is only a moderate increase in risk to sampling success. Table 1 provides a summary of the relationship between the images collected by PolyCam and MapCam. Fields of the same color show where MapCam data taken later can be compared to PolyCam data taken earlier. None of the options discussed below require flying different trajectories than those already planned. The approach will be to take MapCam data at different times in the mission than currently planned in the DRM.

Table 1: Summary of Options

Mission Phase	Objectives	Range to Surface (km)	PolyCam Pixel size (cm)	MapCam Pixel size (cm)	Comments
Approach	Navigation	6,000	8,000	40,000	Bennu = 1 pixel in both
Approach	Shape Model	140	200	1000	
Approach	Shape Model	38	50	250	
Prelim. Survey	Shape Model	10	13		
Prelim. Survey	Shape Model	7		47	~ 1 week after Approach
Orbital-A	Shape Model	1.3		9	~ 1 month after P.S.
Detailed Survey	21-cm boulders	3.5	4.7		
Orbital-B	21-cm boulders	0.8		5.4	~ 3 months after D.S.
Orbital-B	5-cm rocks	0.8	1.1		
Recon	5-cm rocks	0.225		1.5	
Recon	2-cm psfd	0.225	0.3		
Matchpoint	2-cm psfd	0.03		0.2	FOV only 2 meters

During the early Approach Phase, PolyCam images Bennu primarily for navigation though some of the data will be useful for beginning the shape model determination. Though its pixel resolution is a factor of 5 larger than that of PolyCam, MapCam can still serve to locate Bennu in the sky for navigation. Later in Approach, PolyCam takes image mosaics, one for every 10° of Bennu rotation, on each of nine days for the purpose of generating the Bennu shape model. The images are taken on successive days as the spatial resolution improves allowing the processing via stereophotoclinometry (SPC) to proceed with only small scale variations between image sets. This imaging happens over the range from 140 km to 38 km providing a factor of 3.5 change in the image scale. If PolyCam were lost, comparable resolution imaging would be conducted by MapCam during the Preliminary Survey phase. Thus MapCam images taken toward the end of the Approach phase, when combined with the images already planned for the Preliminary Survey Phase, will satisfy the requirement to generate the shape model. The DRM has only PolyCam images taken during the Preliminary Survey equatorial flyby, so MapCam images would replace those images to provide the necessary close-range data for the shape model that was missed in Approach.

The DRM has no data collection with science instruments in the Orbital-A phase, but taking MapCam data in Orbital A could replace the PolyCam images lost in Preliminary Survey. These data may be necessary for the shape model to be determined well enough to be used for the transition to landmark navigation, which is required to exit the Orbital-A phase. In addition, OLA will collect altimetry data in Preliminary Survey and, though not currently in the DRM, it could be used to collect altimetry data in Orbital A to help generate the shape model to the necessary <1-meter resolution. If OLA data collection in Orbital A is needed for this contingency, OLA high-energy laser life will be carefully managed to ensure adequate margin for its operation in Detailed Survey.

During Detailed Survey, PolyCam is used to satisfy the requirement for 21-cm resolution over

four pixels. With the loss of PolyCam, nearly equivalent data can be collected via MapCam later in Orbital-B. As can be seen from Table 1, however, these data come nearly three months after they would normally be supplied in Detailed Survey. The long delay is due to seven weeks collecting data from the equatorial stations of Detailed Survey and to spending nine days collecting gravity data early in Orbital B. On the other hand, if we collect MapCam data in Orbital A, we get 9-cm pixels, but we get them about a month earlier than we would in Detailed Survey. These data could be very useful in providing an early elimination of candidate areas based on 30 or 40-cm rocks.

The spatial resolution achieved by PolyCam during the site-specific imaging currently planned in Orbital-B can be nearly achieved by MapCam during the 225m Recon passes. Imaging the prime and backup landing sites with PolyCam as planned in the DRM is challenging due to the possible large navigation errors and the small FOV of PolyCam. With MapCam, on the other hand, we have a much larger FOV, so it is possible to image the site at two or three different illumination and emission angles in a single pass. With the small FOV of PolyCam, the targeting of the Recon passes currently requires two weeks to plan and execute. It seems clear, however, that being able to examine twelve candidate sites, as currently required for Orbital B, is out of the question. We will need to narrow the selection of sites to a smaller number based on other criteria and plan on using MapCam in a Recon pass as a check on our ability to narrow the selection based on these other criteria.
The most difficult requirement to satisfy with the loss of PolyCam is the need to get images with < 2-cm spatial resolution, which is used to get the particle size-frequency distribution (psfd) down to 2-cm size to help assess sampleability. This requirement is currently met with PolyCam imaging at ranges < 300 meters during the Recon phase. We achieve better spatial resolution using MapCam at the Matchpoint during TAG Rehearsal, where a 0.2-cm pixel size is obtained.

Normally the 2-cm data would be used to help in site selection as it is one of the criteria for sample-ability by TAGSAM. The TAG Rehearsal Phase is not begun until a site is already selected, so in this case collecting the high-resolution data during rehearsal would be data to be used to force a reconsideration of the site selection if the high-resolution imaging suggested that the sample-ability of the material at the site might not be adequate. It should be noted that there are many factors that go into determining sample-ability, and it is quite reasonable to make the site selection without these data and to then confirm the site during rehearsal.

The FOV of MapCam at Matchpoint is only 2 meters, so only a small portion of the sampling ellipse would be imaged. If necessary, additional rehearsals could be flown to produce an adequate random sampling to confirm models in which we extrapolate a size-frequency distribution down from larger sizes. If the extrapolation is confirmed in the places with the high-resolution data, we can have reasonable confidence in the quality of the site.

3.0 Loss of MapCam

3.1 **Scenario Description**

MapCam has stopped functioning prior to arrival at Bennu.

3.2 Affected Mission Objectives and Science Requirements

The loss of MapCam would affect the following threshold mission requirements:

Phase	MRD #	Requirement
Approach	MRD-144	OSIRIS-REx shall detect with > 95% confidence natural satellites > 10cm diameter with albedo > 0.03 within 35km of Bennu.
Approach	MRD-196	OSIRIS-REx shall determine the orbital properties and stability of detected satellites.
Approach	MRD-397	OSIRIS-REx shall image 5 times with MapCam each of the natural satellite search fields.
Detailed Survey	MRD-561	OSIRIS-REx shall collect OCAMS panchromatic data with < 2m spatial resolution and >13.0 magnitude/arcsec^2 sensitivity off the limb of Bennu in < 15° (goal of 10°) increments over two rotation periods.
Detailed Survey	MRD-142	OSIRIS-REx shall search for dust and gas plumes originating from the asteroid surface, and characterize their source regions and column densities.
TAG Rehearsal	MRD-30	OSIRIS-REx shall image the surface of Bennu at ranges between 26m and 30m for at least 30s after the Matchpoint maneuver during the Matchpoint rehearsal. Range is measured from the TAGSAM contact surface to the surface of Bennu.

3.3 Discussion of Affected Mission Objectives and Recovery Plan

During the Approach Phase, MapCam takes multiple images of the sky around Bennu searching for natural satellites. This search is for both scientific interest and for safety of the spacecraft to avoid collisions. MapCam is used because the region of the sky that must be searched is large. For the 1-m satellite search, the current plan calls for five 2x2 arrays of 4-second-exposure MapCam images spaced an hour apart taken at a distance of about 1000 km from Bennu. Multiple image sets are taken to both confirm that a detection is real as well as to estimate the orbital parameters of any suspected satellites. Without MapCam, images will be taken by PolyCam from a distance of about 5,000 km. The PolyCam FOV is about 1/5 that of MapCam, so it will see the same amount of sky as the baseline plan. There will be less light at the greater distance, but PolyCam's aperture is about 5 times greater, so the exposure times will be similar. For the 10-cm satellite search, the current plan calls for five sets of 4x4 image arrays at a distance of about 200 km. Like for the 1-m satellite search, this search can be performed by PolyCam at a distance five times farther away, and again the number of images and the exposure times will be similar to that in the baseline plan.

During Detailed Survey, the two requirements dealing with dust and gas plumes would be satisfied with images taken by NavCam. This camera has a much larger FOV than that of MapCam, so only one image would need to be taken to capture the area needed, however the sensitivity of NavCam is not as good as that of MapCam so longer exposures will be needed. At

this point it is not clear how much longer the exposures will need to be, but because any plumes will be an extended source, blurring due to long exposure times is not a concern.

During the Matchpoint Rehearsal, MapCam collects images during descent from 30m to 26m that are used by FDS to verify the surface-relative lateral velocity of the spacecraft satisfies the requirement of <2cm/s. In case of the loss of MapCam, either SamCam or NavCam can be used to verify the lateral velocity prior to committing to the TAG.

APPENDIX A: ACRONYMS

DRM - Design Reference Mission

FDS – Flight Dynamics System

FOV – Field of View

OCAMS – OSIRIS-REx Camera Suite

OLA – OSIRIS REx Laser Altimeter

OVIRS – OSIRIS REx Visible and Infrared Spectrometer

PSFD – Particle Size-Frequency Distribution

SPC - Stereophotoclinometry

TAG – Touch-and-Go

TAGSAM – Touch and Go Sample Acquisition Mechanism