Mascot/CAM

MASCOT

Phase E

MASCOT CAM On-Asteroid Activities Planning

MSC-PFPS-OPS-001_-_CAM_OnA_Activities_20220607_Schroeder

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2/a	September 25, 2017	10-18	Minor revisions according to feedback by Michael Maibaum
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3/a	March 5, 2018	13-18	Revised uprighting sequence, made plans for day 3, mini-move
3/b	March 9, 2018	13	Added night uprighting sequence
3/c	April 20, 2018	10-18	Dark image exposure times, priority Day1_Seq2 & Day2_Seq1, MiniMove compression ratio, waiting time for Night1_Seq1 & Night2_Seq1
3/d	June 7, 2022	1	Changed document title

List of Acronyms

CAM	Mascot Camera
CMOS	Complementary metal-oxide-semiconductor
FM	Flight Model
GID	Ground ID
HDR	High Dynamic Range
IBR	
KB	Kilobyte
LED	Light-Emitting Diode
MAG	MASCOT magnetometer
MAM	MASCOT Autonomy Manager
OBC	On Board Computer
SDL	Separation, Descent, and Landing
TBD	To Be Defined

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1 Documents

1.1 Applicable Documents

AD…	Title	Identifier	Issue/Rev., Date
1	Document Naming and Enu-meration	MSC-RYOR-PL-001	0/2, 14 OCT 2011
2			

1.2 Reference Documents

RD…	Title	Identifier	Issue/Rev., Date
1	MASCOT On Asteroid Baseline	MSC-RB-MSC-PR-0001	0/draft, Jun 2017
2			

2 Introduction

2.1 General

This document provides a description of the imaging plans for CAM after MASCOT separation from Hayabusa 2. We distinguish several sequences of images, with sequence names displayed in *italic* type. Generally, CAM sequences are guided by input from the MASCOT autonomy manager (MAM). The MAM is a state machine designed for autonomous on-asteroid operations [RD1]. Relevant states for CAM are DESCENT, UPRIGHT, SURFACE, and RELOCATE. The DESCENT state follows separation from Hayabusa 2 and includes touchdown and subsequent bouncing on the surface. The moment of touchdown ("CP1") is at local noon [RD1]. The DESCENT state is terminated ("SP1") once MAM has detected MASCOT to be at rest on the surface, but may also be triggered by a time-out. The UPRIGHT state follows the DESCENT state. In this state MAM determines the attitude of MASCOT and, if necessary, attempts uprighting using the on-board flywheel. The UPRIGHT state is terminated ("MP1") once MAM has established that MASCOT is in the upright position or a maximum number of uprighting attempts has been reached. The SURFACE state follows the UPRIGHT state. In this state MAM may detect a day/night transition. The SURFACE state is terminated by a time-out. The RELOCATE state follows the SURFACE state. In this state MASCOT relocates to another site on the surface. It has not been decided yet when and under what conditions relocation will take place. In this report we assume that MASCOT will relocate 1 hour after sunrise on day 2 the latest. Relocation is followed by the UPRIGHT and SURFACE states. In the baseline mission scenario [RD1], the duration of asteroid day and night are 4 hours and 56 minutes and 2 hours and 39 minutes, respectively. On the first day, there are 1 hour and 24 minutes between the start of the SURFACE state and sunset (Fig. 5.1 in [RD1]). This is the time in which CAM can image and MASCOT can transmit data. The total amount of day time at the first landing site is therefore 2.5 hours[1].

Illumination during imaging can be provided by the onboard LED array in any of the following colors: red (R), green (G), blue (B), and infrared (IR). LED illumination will be used during both the asteroid day and night. Exposure time is defined in steps of 0.2138 msec. An image acquired with the shortest possible exposure time (1 step or 0.2138 msec) is referred to as a "bias image". The exposure time of some images will be determined by the on-board ("fast") auto-exposure algorithm. In tests, the algorithm typically converged within 4 iterations. The maximum number of iterations for the on-asteroid mission phase will be set to 6. After the completion of an exposure, the CAM CMOS detector will be read-out for a duration of 2 seconds.

[1] Following the suggestion by Jean-Pierre Bibring in his presentation at the MASCOT SWT on Wednesday 15 November 2017 at the TU Braunschweig.

A priority value is associated with each image acquisition that determines the order in which images are uploaded by MASCOT to Hayabusa 2. CAM images can be routed to either mass memory store ID 2 or 3. We will refer to these images are having either priority 2 or 3. Priority 1 is not available to CAM. Priority 3 images are uploaded only after all priority 2 images have been uploaded, so priority 2 is higher than priority 3. The images are uploaded according to the first-in-first-out (FIFO) principle. The priority 2 data buffer is shared with the µOmega instrument.

The file size of the original (uncompressed) images is 2048 KB or 16.777 Mbit[2]. To reduce the file size CAM can compress images using a wavelet-based algorithm, with a user-defined compression rate (IBR). There are two fundamentally different options. An IBR of 1 will compress the image losslessly[3]. The data volume of the losslessly compressed image depends on the image content. The IBR can also be set to a number between 16 and 63 to achieve lossy compression. In this case, the image quality of the decompressed product depends on the image content. The IBR value can be interpreted as image quality of the decompressed product, with 16 leading to the lowest quality image (highest compression), and 63 leading to the highest quality image (lowest compression). The data volume of the lossy compressed product in KB can be calculated as 8 × IBR (Table 1). Whether the IBR 16 rate is available for use by CAM depends on the adoption OBC flight software version 4.0.1. For planning purposes we adopt a maximum compression rate of IBR 16[4].

The total time required to transmit an image from MASCOT to Hayabusa 2 is the time CAM spends compressing the image plus the data transmission time. The compression time depends on the IBR, as specified in Table 1. The transmission time is equal to the size of the image divided by the data rate. It is defined in terms of packets, one of which contains 1002 bytes (0.008016 Mbit) of image data. The data rate to be used during the MASCOT mission has not been firmly established yet. The best-case scenario has a transmission rate of 4 packets per second, or 0.03206 Mbit/sec. The worst-case scenario has a rate of 2 packets, or 0.01603 Mbit/sec. We assume an intermediate transmission rate of 3 packets per second[5], or 0.02405 Mbit/sec. The last column in Table 1 shows that the total image transmission time is dominated by the time it takes to transmit the data rather than the compression time.

[2] We use the following definitions: 1 KB = 1 KiB = 1024 bytes = 8192 bits and 1,000,000 bits = 1 Mbit.
[3] This option is not available to CAM following a decision by Tra-Mi Ho at the MASCOT SWT on Monday 13 November 2017 at the TU Braunschweig.
[4] Requires OBC version 4.0.1; use confirmed by Michael Maibaum in an email on December 15, 2017
[5] As suggested by Jean-Pierre Bibring in his presentation at the MASCOT SWT on Wednesday 15 November 2017 at the TU Braunschweig. However, in a telecon on Wednesday 18 April 2018, the instrument teams agreed to plan for a transmission rate of 4 packets per second. Note that calculations presented in this report are still based on 3 packets per second.

Table 1. Compressed file sizes. IBR 1 is lossless, others are lossy. t_{comp} is the time it takes CAM to compress one image. t_{trans} is the time it takes MASCOT to transmit one image to Hayabusa 2, assuming a rate of 3 packets per second (0.02405 Mbit/sec).

IBR	Volume (KB)	Volume (Mbit)	# packets	t_{comp} (sec)	t_{trans} (mm:ss)	$t_{comp} + t_{trans}$
1	<2048	<16.777	<2093	13.1	<11:38	<11:51
16	128	1.049	131	15.0[a]	00:44	00:59
32	256	2.097	262	15.0	01:27	01:42
48	348	2.851	356	15.4	01:59	02:14
63	502	4.112	514	16.6	02:51	03:08

[a] Estimate.

The on-asteroid CAM data budget is determined by the duration and rate of data transmission from MASCOT to Hayabusa 2. Data will be transmitted continuously only during day time. For the first day we adopt a duration of data transmission (and imaging) of 1 hour and 24 minutes. For the second day we adopt a duration of 1 hour and 6 minutes before the start of relocation. This corresponds to a total day time at site 1 of 2 hours and 30 minutes. For calculating the CAM data volumes we adopt a transmission rate of 1.5 packets per second, or 0.01202 Mbit/sec, which is consistent with a 50% share for CAM of the total MASCOT data volume[6]. The data volumes available for CAM imaging for day 1 and 2 (before relocation) are therefore 60.6 and 47.6 Mbit, respectively.

2.2 Purpose

The purpose of the document is to provide rationale and background for developing observation sequences for MASCOT CAM. The actual sequences to be uploaded to CAM shall be developed exactly as described in this report.

2.3 Scope

This document applies to operations planning.

[6] As confirmed by Jean-Pierre Bibring in his presentation at the MASCOT SWT on Wednesday 15 November 2017 at the TU Braunschweig. He subsequently departed from the agreement by quietly doubling the µOmega data budget, for which reason some of the numbers quoted in this report are no longer valid.

3 Mission Phases

3.1 Separation / Descent / Landing (SDL) and Uprighting

After ejection from Hayabusa 2 (separation), MAM will enter the DESCENT state, in which MASCOT descends to the asteroid surface. The descent time can be predicted [RD1] and is expected to be 10±2 minutes, depending on the asteroid gravity[7]. The CAM sequences critically depend on the availability of an accurate estimate of this time. After an unknown amount of time of bouncing on the surface (estimated to be 50 minutes in the baseline scenario of [RD1]), MASCOT will settle on the surface. As MASCOT may still be moving at this stage, a certain amount of time will be allowed to pass (14 minutes and 20 seconds in the baseline scenario) before MAM moves into the UPRIGHT stage. CAM will be imaging in the DESCENT phase. Data will be transmitted by MASCOT to Hayabusa 2 continuously during the descent. All descent images shall be acquired with (low) priority 3 and compressed at the maximum rate of IBR 16.

Immediately after separation, CAM will start imaging according to the *Descent* sequence in Table 2. The sequence is planned to continue past touchdown (CP1) and end 3 minutes later. Imaging during the 10 minute descent consists of two phases: (1) 6 minutes of low cadence imaging in which images will be transmitted in real time, and (2) 4 minutes of high cadence imaging in which images are not transmitted in real time. Phase (1) is unique, as, apart from MAG, CAM will be the only instrument generating data and essentially all 3 packets per second are therefore available for uploading the data in real time. The time it takes to transmit a single image at IBR 16 (including compression time) is 59 seconds (Table 1). We choose the cadence of phase (1) imaging as 60 seconds. Only 4 of the images acquired in phase (2) can be transmitted before landing. The remaining 4 descent images plus the 6 post-landing images (total 10 images, or 10.5 Mbit) will be transmitted after landing. The transmission time for these images is 14 minutes and 33 seconds, calculated on the basis of 1.5 packets per second and assuming they were compressed at an earlier stage. The exposure time of the images in Table 2 will be pre-set and identical for all images, the value depending on the phase angle of observation at the time of MASCOT ejection. After a landing site has been selected, the CAM team will be provided with a best estimate of the phase angle at separation with an associated uncertainty interval[8]. From this range we will calculate a number of possible exposure times, to be stored on-board. One of these values will be selected for use shortly before the start of the mission.

[7] Information provided by Laurence Lorda. More extreme values for the gravity lead to descent times as short as 5 minutes and as long as 14 minutes.
[8] The provider is Laurence Lorda (CNES).

Table 2. The *Descent* sequence (MUOR A). Δ*t* is the time between images and t_{exp} the exposure time, where "stored" means that a pre-set value will be used. "Vol" is the compressed data volume of the image series. The total data volume is 21.0 Mbit.

# images	Δ*t* (sec)	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
6	60	none	stored	3	16	6.29	100-105
14	30	none	stored	3	16	14.69	106-119

In the UPRIGHT state (SP1), MASCOT will attempt to upright itself by using its flywheel up to 8 times. Just before each uprighting action, CAM will acquire a single image according to the *Upright1* sequence in Table 3. The exposure time of the images in Table 3 will be pre-set and identical for all images, but may differ from those in Table 2. If the lander is already upright at the end of the DESCENT state, no image will be acquired. Otherwise, up to 8 images may be acquired, to a maximum data volume of 8.4 Mbit. If, for any reason, uprighting takes place during the asteroid night, the *Upright_Night* sequence in Table 4 will be executed instead of *Upright1*.

Table 3. The *Upright1* sequence (MUOR B). t_{exp} is the exposure time, where "stored" means that a pre-set value will be used. "Vol" is the compressed data volume of the image.

image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	stored	3	16	1.05	150

Table 4. The *Upright_Night* sequence (MUOR W). t_{exp} is the exposure time, where "stored" means that a pre-set value will be used. "Vol" is the compressed data volume of the image.

image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	G	stored	3	16	1.05	160

3.2 Day 1, site 1

The start of the SURFACE state (MP1) initiates the CAM surface science phase, which includes both day and night imaging. MASCOT is expected to land on the day side of the asteroid, at local noon. Image data will be uploaded by MASCOT to Hayabusa 2 continuously during day time. The first set of images acquired on the first day will have priority 2 and will therefore be uploaded immediately. The image sequence planned for the first day on the asteroid is the following. First, CAM acquires the images in the *Day1_Seq1* sequence in Table 4. The first of these is acquired without LED illumination and compressed lossy with the highest quality setting (IBR 63). The exposure time of this image is determined by the on-board (fast) auto-exposure algorithm. Next are two images that form the high dynamic range (HDR) sequence, and are compressed more strongly (IBR 48). The next image is a bias image, acquired with the shortest available exposure time. The last four images are taken with LED illumination, each with a different color, and compressed lossy with the highest quality setting. The time between image acquisitions is the CMOS read-out time of 2 seconds. The full set is 29.1 Mbit in size, and can be transmitted in 40 minutes and 21 seconds.

The first CAM imaging sequence is followed by 20 minutes of activity by the µOmega instrument. Immediately following this, CAM will acquire the images in the *Day1_Seq2* sequence (Table 6). The first four images in this sequence use LED illumination, and the fifth is a bias image. The time between image acquisitions is the CMOS read-out time of 2 seconds. The total data volume is 10.5 Mbit, which can be transmitted in 14 minutes and 34 seconds.

Table 5. The *Day1_Seq1* sequence planned for the start of day 1 (MUOR C). t_{exp} is the exposure time, with "auto" indicating the use of the auto-exposure algorithm. t_1 is the actual exposure time of image 1. The total data volume is 29.1 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	auto (t_1)	2	63	4.11	200
2	none	t_1 / 2	2	48	2.85	201
3	none	$t_1 \times 2$	2	48	2.85	202
4	none	0.2138	2	48	2.85	203
5	R	auto	2	63	4.11	204
6	G	auto	2	63	4.11	205
7	B	auto	2	63	4.11	206
8	IR	auto	2	63	4.11	207

Table 6. The *Day1_Seq2* sequence planned for day 1 (MUOR D). t_{exp} is the exposure time, with "auto" indicating the use of the auto-exposure algorithm. The total data volume is 10.5 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	R	auto	2	32	2.10	250
2	G	auto	2	32	2.10	251
3	B	auto	2	32	2.10	252
4	IR	auto	2	32	2.10	253
5	none	0.2138	2	32	2.10	254

Immediately following *Day1_Seq2* is the *Phot* sequence in Table 7, which consist of a single image acquisition. This sequence shall be repeated every 8 minutes until MAM signals the end of day (beginning of night). To deal with the hypothetical scenario that MAM erroneously does not detect night if it is, in fact, night, *Phot* will be repeated 15 times, followed by *Night1_Seq2* (Table 9), and again followed by 15 times *Phot*. The sequence *Night1_Seq2* is part of the imaging plans for the first night on the asteroid, and will be detailed in the next section.

In the baseline mission scenario [RD1], the duration of CAM operation on day 1 will be 1 hour and 24 minutes. This means that there is time for CAM to acquire about 8 such images (16.8 Mbit), which can be transmitted in 23 minutes and 18 seconds.

Table 7. The *Phot* sequence (MUOR E). It consist of a single acquisition that is repeated, with Δ*t* the time between images. t_{exp} is the exposure time, with "auto" indicating the use of the auto-exposure algorithm.

Δ*t* (min)	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
8	none	auto	2	32	2.10	300

3.3 Night 1, site 1

The night lasts 2 hours and 39 minutes in the baseline mission scenario [RD1]. In this period we plan for CAM to acquire three sets of images. One set will have the highest quality compression rate of IBR 63, whereas the other two will have the lower quality rate of IBR 48. As the temperatures are expected to be highest at the beginning of the night[9], and the duration of the night is uncertain, the second set shall have the highest quality compression. In addition, CAM will wait 15 minutes after the start of the night before imaging. In the worst-case scenario (CAM facing the Sun in the afternoon), the CAM temperature should have dropped to 30°C by the time of the second set, i.e. 1.5 hours after sunset. The time between image acquisitions in all sets is the CMOS read-out time of 2 seconds.

Table 8. The *Night1_Seq1* sequence planned for the start of night 1 (MUOR F). t_{exp} is the exposure time, with "auto" indicating the use of the auto-exposure algorithm. The total data volume is 16.4 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	106.9000	2	48	2.85	350
2	R	auto	2	48	2.85	351
3	G	auto	2	48	2.85	352
4	B	auto	2	48	2.85	353
5	IR	auto	2	48	2.85	354
6	none	0.2138	2	32	2.10	355

The images acquired 30 minutes after the start of the night are part of the *Night1_Seq1* sequence in Table 8. The first image in the sequence is a dark image (without LED). The next

[9] Presentation "*LSSP Dry Run MASCOT Selection Meeting Thermal Control System*" by Barbara Cozzoni and Michael Maibaum in the LSSP meeting at DLR Köln on 20 July 2017.

four images use LED illumination in all four colors. The last image is a bias image. The exposure times of the LED images will be determined by the auto-exposure algorithm. The total data volume is 16.4 Mbit, which can be transmitted in 22 minutes and 44 seconds.

Acquisition of the *Night1_Seq2* sequence (Table 9) follows one hour later. The images in this sequence are the same as in *Night1_Seq1*, but are compressed at the highest quality lossy rate (except the bias image). The data volume of this set is 23.4 Mbit and the time it takes to transmit (assuming compression upon acquisition) is 32 minutes and 27 seconds. The combined (priority 2) data volume of *Night1_Seq1* and *Night1_Seq2* is 39.8 Mbit, which can be transmitted in 55 minutes and 11 seconds. The exposure times of the LED images will be determined by the auto-exposure algorithm. These times shall be stored (one time for each LED color) for use in the third sequence.

Table 9. The *Night1_Seq2* sequence planned for night 1 (MUOR G). t_{exp} is the exposure time. The total data volume is 23.4 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	962.1000	2	63	4.11	400
2	R	auto	2	63	4.11	401
3	G	auto	2	63	4.11	402
4	B	auto	2	63	4.11	403
5	IR	auto	2	63	4.11	404
6	none	0.2138	2	48	2.85	405

Table 10. The *Night1_Seq3* sequence planned for night 1 (MUOR H). t_{exp} is the exposure time, where "stored" means that the same value will be used as used in set 2 for that particular LED color. The total data volume is 16.4 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	962.1000	3	48	2.85	450
2	R	stored	3	48	2.85	451
3	G	stored	3	48	2.85	452
4	B	stored	3	48	2.85	453
5	IR	stored	3	48	2.85	454
6	none	0.2138	3	32	2.10	455

Again one hour later, the images in sequence *Night1_Seq3* are acquired (Table 10). This sequence is similar to *Night1_Seq1*, but has lower priority settings. The (priority 3) data volume is 16.4 Mbit, which can be transmitted in 22 minutes and 44 seconds. Just in case the night lasts longer than expected, *Night1_Seq3* will subsequently be repeated twice with a one hour interval, until MAM signals the start of day 2.

3.4 Day 2, site 1

The imaging sequence planned for the start of day 2 is *Day2_Seq1* (MUOR J, GID 500-504), which shall be identical to the *Day1_Seq2* sequence (Table 6). The temperatures in the morning are expected to be relatively low, meaning low dark current, and therefore the image quality should be high.

A small mobility manoeuver ("mini-move") is planned for the morning of day 2. Immediately before the mini-move CAM will execute *MiniMove_Seq1*, which plans for the acquisition of two images, one regular one and one with LED illumination. Immediately after the mini-move CAM will execute *MiniMove_Seq2* (MUOR T, GID 530-531), which is identical to *MiniMove_Seq1*. Subsequent relocation of MASCOT will take place after emptying the priority 2 buffer.

Table 11. The *MiniMove_Seq1* sequence planned for the morning of day 2 (MUOR S). t_{exp} is the exposure time. The total data volume is 6.2 Mbit.

Image #	LED	t_{exp} (msec)	Priority	IBR	Vol (Mbit)	GID
1	none	auto	2	63	4.11	520
2	G	auto	2	32	2.10	521

3.5 Day 2, site 2

After relocation, during the UPRIGHT state (SP2), CAM will acquire a single image just before each uprighting action according to the *Upright1* sequence (Table 3). The imaging sequence planned at the start of the SURFACE state (MP2) is *Day2_Seq2* (MUOR L, GID 600-607), which shall be identical to the *Day1_Seq1* sequence in Table 5.

3.6 Night 2, site 2

The CAM imaging plans for night 2 are identical to those for night 1, except that acquisition of the first image set shall start immediately after the start of the night. The sequences are named *Night2_Seq1* (MUOR M, GID 650-655), *Night2_Seq2* (MUOR N, GID 700-705), and *Night2_Seq3* (MUOR P, GID 750-755).

3.7 Day 3

In theory, it is possible for MAM to detect day and night incorrectly and in the process skip entire day or night observation plans. To prepare for such an eventuality, we plan the following CAM activities for Day 3: *Day3_Seq1* (MUOR Q, GID 800-807), which is identical to *Day1_Seq1*, and *Day3_Seq2* (MUOR R, GID 850-854), which is identical to *Day1_Seq2*.

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