MASCOT

MASCOT Mobile Asteroid Surface Scout

MASCOT Landing

MSC-RBMSC-OPS-RP-0001

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Table of Contents

Distribution List

Name	Contact information	Quantity

Document Change Record

Issue/ Revision	Date	Affected pages or chapter	Description

List of Acronyms

AD	Applicable Document
AOS	Acquisition of Signal
APID	Application Process Identifier
AVM	Analogue Voltage Monitor
Acronym	Meaning
BOT	Beginning of Transmission (same as AOS)
CAM	MASCOT Camera
CCOM	Child Communication Unit
CCSDS	Consultative Committee for Space Data Systems
CNES	Centre National d'Etudes Spatiales
COM	Communication Unit
DHU	(HY2) Data Handling Unit
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EOT	End of Transmission (same as LOS)
ESA	European Space Agency
FDIR	Fault Detection Isolation and Recovery
FSW	Flight Software
GDS	Goldstone
GNC	Guidance, Navigation & Control
GRM	Ground Reference Model
GSE	Ground Segment Engineer
HGA	High Gain Antenna
HKTM	House Keeping Telemetry
HW	Hardware
HY2	Hayabusa-2
ICD	Interface Control Document
IOM	Input Output Module

JAXA	Japan Aerospace Exploration Agency
LOS	Loss of Signal
MAD	Madrid
MAG	Magnetometer
MAM	MASCOT Autonomy Manager
MARA	MASCOT Radiometer
MASCOT	Mobile Asteroid Surface Scout
MCC	MASCOT Control Center
MFOP	MASCOT Flight Operations Plan
MLG	Malargüe
MOR	MASCOT Operations Request
MUOR	MASCOT Unit Operations Request
N/A	Not Applicable
NEA	Non Explosive Actuator
OBC	On-Board Computer
OME	Onboard MINERVA Equipment
ONC	Optical Navigation Camera
OPS	Optical Proximity Sensor
OnA	On Asteroid
PCDU	Power Control and Distribution Unit
PEC	Photo Electric Cell
PI	Principal Investigator
PRM	Preload Release Mechanism
PS	Packet Store (Telemetry)
RD	Reference Document
SGM	Safe Guard Memory
SSA	Subsystem Authority
SSOC	Spacecraft Operations Center (JAXA)

SW	Software
SpW	SpaceWire
TC	Telecommand
TM	Telemetry
UDSC	Usuda Deep Space Center
µΩ	MicrOmega

List of Figures

List of Tables

1 Documents

1.1 Applicable Documents

AD…	Title	Identifier	Issue/Rev., Date

1.2 Reference documents

RD…	Title	Identifier	Issue/Rev., Date
1	Mascot Pre-Separation Operations	MSC-OPS-PL-1000	6/3
2	Mascot Post-Separation Operations	MSC-OPS-PL-2000	5/1
3	MSC_MAM_OnA_Report	MSC-RBMSC-MAM-RP-0001	1/1
4	MASCOT time scales	MCS-TN-1053_Time Scales	1/1
5	MASCOT MAG time conversion procedure	MASCOT-MAG-DR01-TimeConv-000	0/0
6	MASCOT OnAsteroid Operations TCS	MSC-TCS-RP-0002	2/0

2 Introduction

2.1 Purpose and scope

This document describes the MASCOT landing on the asteroid Ryugu from an operational point of view.

The scope is focused to the end phase of the mission, which starts with the separation of MASCOT from Hayabusa-2 (HY2) and ends with the last telemetry packet received from MASCOT. However, there is also a short summary of the preparation activities starting on the 26th of September.

2.2 Timing

The MASCOT Mission involves several clocks:

- Ground segment clocks
- Hayabusa 2 Clock
- MASCOT OBC Clock
- MAG Internal Clock

All of these clocks were started / calibrated at different points in time (also called epoch time) and have a different drift from an ideal clock. RD4 and RD5 provide the details. The following explanation serves as an overview:

The onboard clocks are counters. They increment by one at a given interval. Both the MASCOT and the HY2 Clocks increment 32 times per second. Hence the resolution is 31.25 milliseconds. This also means that each time stamp has an error margin of ±31.25 ms based on the resolution. The elapsed time can be simply calculated by multiplication of the counter with 31.25 milliseconds.

The MASCOT Clock was synchronized with the HY2 Clock on the 1st of October at 19:16:30 UTC by a command, which has been released from the HY2 Timeline. That means according to the HY2 Clock. However, the time required for the command to go through HY2 Internal systems, to transmit to MASCOT, to receive at the OBC and to execute is unknown.

The HY2 Clock drifts ca. 1.2 seconds per day. This added up to the order of 450 seconds during the landing. The drift was measured by JAXA several times per day at irregular intervals depending on the opportunities. This information was used by the telemetry software SpaceMaster at MUSC to calculate the UTC of on-board events including a prediction of the further drift since the last measurement. As soon as a new measurement arrives, the measured drift might cause a small jump in time when compared to the so far predicted drift.

This method was the best possible effort during operations. All teams have used the raw OBC Timestamps or the UTC Timestamps of SpaceMaster for their evaluation. Therefore, this report always refers to the UTC Timing as calculated and recorded by SpaceMaster[1].

[1] There is room for further refinement of the timing, e.g. through interpolation of the measured drift of the HY2 Clock, which can make a difference in the order of a second. However, the author sees no benefit in further complication and disregards this post-mission analysis of the timing.

3 Preparation

3.1 Cruise Phase

MASCOT had a cruise phase of nearly 4 years. During this period, a large number of activities have been performed to prepare the spacecraft for the landing. Table 1 provides a listing with the timing. These activities include a number of checkouts, calibration activities, activation of the PRM, COM investigations, TM Corruption fix, SW Updates as well as battery depassivation activities. These activities are only listed in this report for completeness, but are not further explained. The landing site selection process did not require MASCOT Flight Operations and is therefore not included below.

Table 1: List of cruise phase activities

Name	Start Date	MFOP
Health Check 4	2015-06-18	
RF Test	2015-06-19	
Calibration 1 + PRM	2015-09-17	3
Data Dump 1 (CAM Data)	2016-01-31	4
Health Check 5	2016-07-14	6
Data Transfer Test 1	2016-07-15	7
Data Transfer Test 2	2016-10-29	9
Calibration 2	2016-11-10	8
Calibration 2 Data Dump	2016-11-13	8
Health Check 6	2017-05-09	10
CAM Data Transfer for CAL2 Data	2017-05-09	12
CAM Data Transfer for HC4 Data	2017-05-10	13
MASCOT SW Update 3.1 Part 1	2017-07-11	15
MASCOT SW Update 3.1 Part 2	2017-07-11	16
MASCOT SW Update 3.1 Part 3	2017-07-11	17
MASCOT SW Update 3.1 Part 4	2017-07-11	18
FSW 3.1.0 Performance Check	2017-08-01	19
Health Check 7	2017-08-08	14
Redump HC#7	2017-08-08	20
On Asteroid Phase Testing	2017-08-15	21
Redump OnA Night & HC7 Data	2017-08-22	23
COM Investigation	2017-08-23	22
Calibration 3	2017-11-21	24
MASCOT Data Redump	2017-11-25	25
MAM System Test	2017-12-05	27
DataTransfer Test B-1	2017-12-07	29

Data Transfer Test B-2	2017-12-11	30
Blind SW Upgrade 4.0	2017-12-13	28
PIM Bus Test	2017-12-16	31
FSW 4.0.1 Initialisation (Aborted)	2018-07-05	36
FSW 4.0.1 Initialisation (Repeated)	2018-07-13	36
Battery Depassivation #1	2018-07-14	35
Final Checkout 1	2018-07-26	34
Battery Depassivation #2	2018-09-15	38

3.2 Asteroid Phase

MASCOT has been designed to land on the asteroid Ryugu while it is at a very large distance from Earth. The two way signal travel time was ca. 36 minutes. This fact has shaped the operations concept since the very beginnings of the mission. Mostly, commanding cannot be performed quickly and interactively. Instead, long commanding sequences are uplinked to MASCOT or to HY2 and triggered by a small number of direct commands.

The term *TC Sequence* is used for blocks of commands on board MASCOT. They can be uplinked in commanding "files". Once they are expected to begin, they can be triggered with two commands, which are either sent directly from ground or time tagged from the HY2 Timeline. The commands within a TC Sequence can have relative timing to previous commands and might depend on the success of previous commands (interlocks).

The term *HY2 Timeline* refers to a commanding buffer on-board HY2 with an absolute time tag for each command. Once uplinked they are executed automatically when the time comes. The timing can be changed from ground by re-uplinking the whole timeline. JAXA has ground tools, which allows changes such as shifting all commands by 30 min quickly. Unlike MASCOT TC Sequences, there is no dependency to the success of previous commands. The only criteria is the timing.

During the cruise phase, MASCOT operations have been built around a relatively small number of direct commands and HY2 Timeline commands, while most of the commands were implemented in TC Sequences.

After separation, no direct commanding and no HY2 Timelines were foreseen for nominal operations. Instead, the on-board autonomy manager (MAM) triggered individual TC Sequences based on a number of triggers and a state machine definition.

After the separation, the operations team has chosen to interfere with the on-board autonomy in several occasions as explained in later sections.

The following activities have been performed for preparation of the final asteroid phase. The listing below provides only a very condensed overview for an understanding of the conditions prior to the separation. For more details, please refer to RD 1 and Appendix A: Pre-Separation Timeline.

3.2.1 26th of September 2018

- Warming up and power on
- On board SW Dump to ground
- Deleting all TC Sequences
- Up-linking final TC Sequences
- Copying the final on board SW to remaining buffers
- Testing the auto start TC Sequence for the On Asteroid (OnA) phase
- Cold reboot
- power off and cooling down

3.2.2 29th of September[2]

- Warming up and final power on
- Performing battery depassivation 3 (final)
- Performing the final checkout

3.2.3 First of October

- The optional power cycle for MAG and MARA were skipped.
- Final preparation procedure tl-MASC-1050 has been executed one hour earlier to avoid a potential conflict with HY2 Operations. No impact for MASCOT.
    - Installing the auto start TC sequence for the asteroid phase
    - Uplinking late-update parameters (TC Seq. 123)
    - Deleting all TM stored onboard MASCOT
    - Rebooting
    - Setting MASCOT Autonomy Manager (MAM) to idle mode
    - Forcing save Safe Guard Memory (SGM)

3.2.4 Second of October

- Separation heating
- Pre separation science starts MAG and MARA measurements
- Final configuration, which marks the **separation readiness** for MASCOT. This includes
    - Setting MAM into the separation mode, in which it waits for the separation signals
    - Enabling PEC change detection
    - Closing the battery switches (HY2 Power is still ON and feeds MASCOT due to the higher voltage)
- GO at Gate 1 and HY2 Descent begins at 20 km from Ryugu
- HY2 Descent slows down at 5km from Ryugu and GO at Gate 2

3.2.5 Third of October

- Enabling Non Explosive Actuator (NEA)
- GO at Gate 3 marks the point of no return for MASCOT followed by HY2's automatic descent and separation procedure

[2] Final power on was planned for the 30th of September, but it was executed exactly 12 hours ahead of original schedule at 12:10:02 UTC using the contingency process.

4 Descent & Separation

The decent maneuver of HY2 started on the 2nd of October, around 02:50 UTC about 40 minutes after the GO decision at Gate 1 and took ca. 23 hours until the separation.

The first 10:20 hours of HY2 descent were controlled by ground at a speed of 40 cm/s until 13:11. At this point in time, HY2 descended from the home position at 20 km to 5 km altitude after which the descent speed has been decreased to 10 cm/s.

Shortly after, around 13:50, the next GO decision was given at Gate2 on ground.

While HY2 continued its descent at the same speed, the final GO decision at Gate 3 was uplinked to the spacecraft from ground around 01:20 UTC. That is ca 22:29 hours after the descent has started. At this point in time HY2 was ca 658m above the surface of Ryugu.

This event was the point of no return for MASCOT. From now on, HY2 continued its descent and separation procedure completely automatically.

The event of passing below 60m altitude as measured by the LIDAR Instrument triggered the free fall phase. Two minutes later, the MASCOT Separation sequence MC-117 started (see Table 2).

The MC-117 switched the HY2 power to MASCOT and to the heaters off. The MASCOT Battery took over immediately. Exactly 8 seconds later, the same TC Sequence ignited the NEA at **01:57:19.161** UTC as measured by MAG with ± 76 msec precision. Among several telemetry parameters, this is the most precise way of telling when the separation happened.

Table 2: Final version of the separation sequence MC-117

#	Time from MC start [sec]	Contents of the Macro Command
0	0.0	Waiting
1	1.0	Change HY2 data rate from MASCOT to the highest rate
2	2.0	Enable HY2 Power supply ON/OFF
3	2.1	Turn OFF HY2 Power supply to MASCOT
4	4.1	Turn OFF HY2 Heater-A MASCOT-main
5	5.1	Turn OFF HY2 Heater-B MASCOT-backup
6	6.1	Get HY2 Heater-A control table
7	7.1	Get HY2 Heater-B control table
8	8.1	Waiting
9	10.1	Set ON MASCOT separation # +10s: HY2 macro starts (imaging MACOT, etc)
10	11.1	Set OFF MASCOT separation

11	31.1	Set ON MASCOT separation # as a backup
12	32.1	Set OFF MASCOT separation
13	33.1	Disable NEA for MASCOT
14	34.1	Set NEA for MASCOT to safety
15	42.1	Turn ON HY2 Power supply to MASCOT # For survival, in case of saparation failure

The operations team was able to receive the telemetry on ground with a delay of 18 min and 10 seconds due to the signal travel time.

The HY2 operations team confirmed separation from their side very shortly after the telemetry was received.

The MASCOT OBC generated the TM Packet "HY2 Report: MASCOT Separation Detected" at 01:57:24.201 and the On-board autonomy Manager (MAM) has changed from *Separation* to the *Descent* Mode at 01:58:08.

The MASCOT Team on ground has considered several additional indications for separation. Most notably the PEC illumination at 01:57:35 and the rapid change of the magnetic environment due to the increasing distance to HY2. Within minutes, the MASCOT Team has confirmed the separation and asked JAXA to release two commands to HY2 from ground:

1. Turn HY2 Power to MASCOT Off (which was turned back on automatically 32 seconds after NEA Activation by MC-117)
2. Switch the PCOM Energy Mode to "High Power".

At separation, HY2 and MASCOT were about 41m above the surface. HY2 continued its free fall for a very short time to gain some distance to MASCOT before firing its thrusters to ascend back to an altitude of 3km until the end of the MASCOT Mission.

Only about a minute after the ascent impulse, HY2 started a scanning maneuver to make pictures of MASCOT using the ONC Cameras. Due to this activity, the high gain antenna of HY2 was unable to point to Earth and the low gain antenna was used for communications to Earth. The data rate was too low to grant any telemetry for MASCOT in this timeframe (ca. 38 minutes between 02:20 and 02:58 UTC on ground).

Thanks to this successful maneuver, the ONC Team captured a number of images of MASCOT during its descent and bouncing on the surface of Ryugu and was able to reconstruct its path.

5 Overview after separation

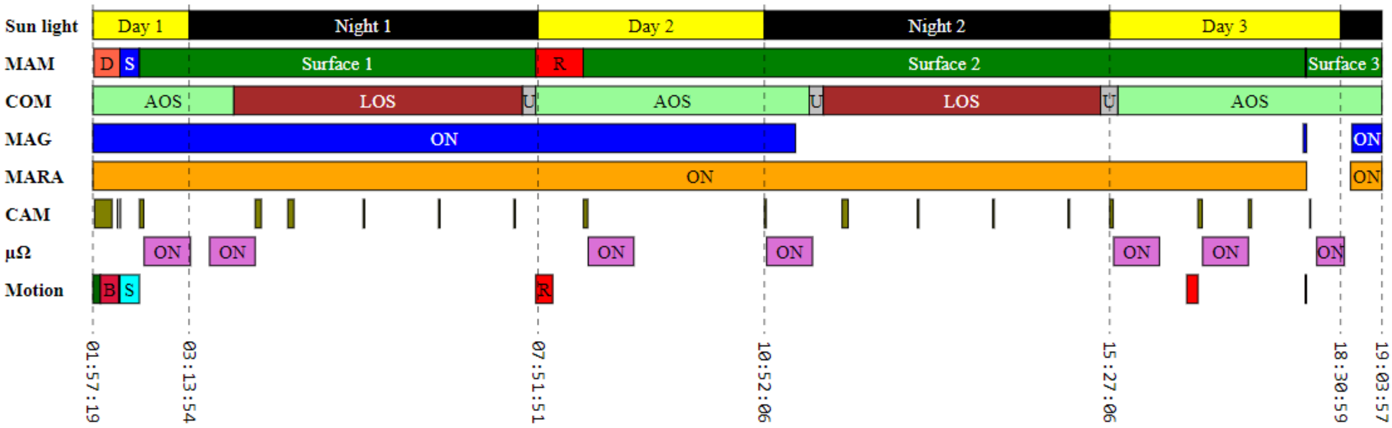


Figure 1: MASCOT Landing Overview (scaled) [UTC]

Figure 1 above shows the main events after separation until the end of the mission. The following abbreviations were used for short events:

D = Descent	B = Bouncing	R = Relocation
S = Self-righting	U = Unstable link	M = Mini-move

The following sections expand on the three individual days.

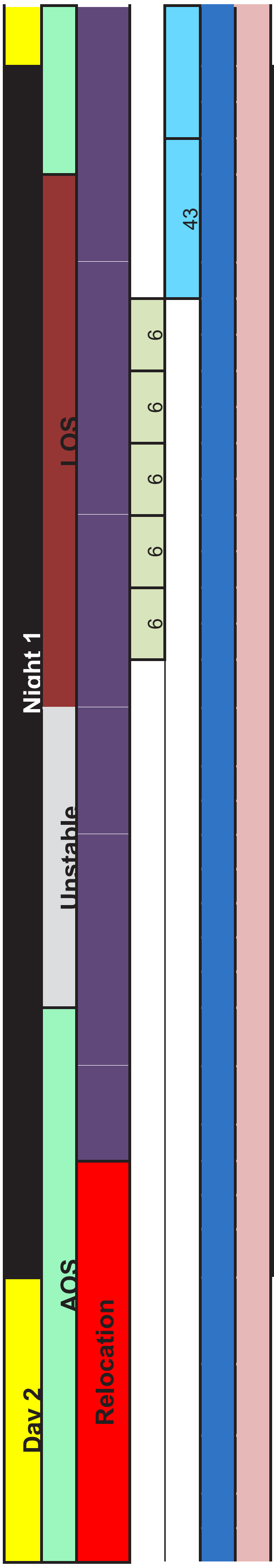
The Table 3 below is a listing of the main events based on telemetry packet names. It combines inputs from several MASCOT Teams.

Table 3: Short summary of events

Legend:

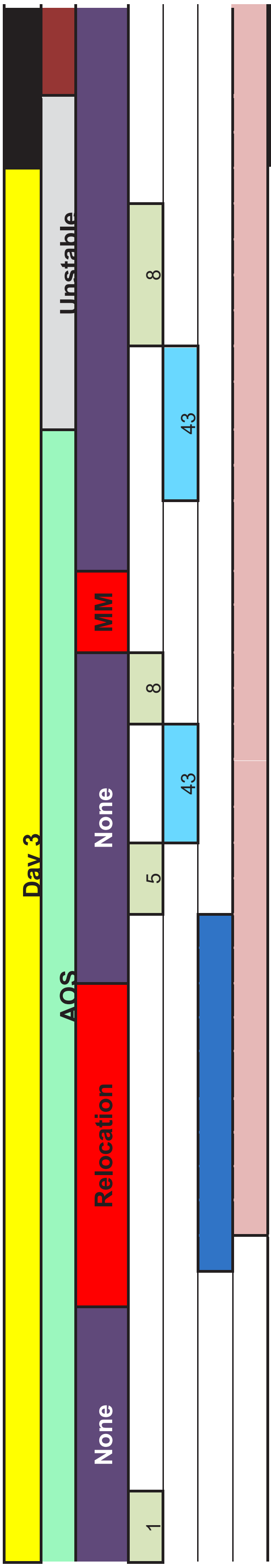
	Asteroid day		MAG is ON and measures		MASCOT is in motion
	Asteroid night		MARA is ON and measures		MASCOT is not moving
	AOS between MASCOT and HY2		Orange text indicates commanding	8	CAM took 8 pictures
	LOS between MASCOT and HY2		Red text indicates a problem	43	MicrOmega [μΩ] made 43 images

Sun	AOS	Motion	CAM	μΩ	MAG	MARA	Time 2018-10-03 [UTC]	Packet Name	Event	Comment
							01:57:12.000	Hayabusa 2 HK	HY Power Off (± 0.5 sec)	
							01:57:19.000	MAG Science Data	NEA Firing (± 76 msec)	
							01:57:19.161	MAG Science Data	Separation (± 76 msec)	
							01:57:20.000	Hayabusa 2 HK	Separation (± 0.5 sec). HCE A & B Sensors disconnected	Jump to 80.012 °C
							01:57:40.780	Battery Discharge Detected		
		Descent					01:58:05.342	PEC Illumination Change Detected	Separation (± 5 sec).	δPEC / δt = 100mV/s for -Y side and 22mV/s for -X side
							01:58:08.155	MAM State Transition	MAM starts descent mode	Separate to descent
							01:58:38.717	CAM ON		
							02:03:13.851	MAG Science Data	First Ryugu contact (± 76 msec)	
							02:07:25.992	RF High Power Authorized		
			20				02:08:02.960	COM RF Power Mode Transition	CCOM High Power Mode	
							02:10:24.833	OPS Measurement ON		
		Bouncing					02:10:36.833	OPS Contact Detected		
Day 1	AOS						02:12:27.706	CAM OFF		
			1				02:16:51.203	CAM ON		
							02:17:01.891	CAM OFF		
		None					02:18:52.139	MAM State Transition	Selfrighting starts. Side to soil is +Y. Desired side is -Z	Descent to upright
			1				02:19:06.295	CAM ON		
							02:19:15.889	CAM OFF		
							02:19:39.295	Mobility Manoeuvre Start	Selfrighting attempt	
							02:20:50.357	Mobility Manoeuvre Successful Completion		
							02:34:20.128	MAM State Transition	Surface 1 starts. MASCOT reports desired orientation while it is laying upside-down.	Upright to Surface
		None					02:34:27.190	CAM ON		
			8				02:34:33.815	OPS Measurement OFF		
							02:37:45.469	CAM OFF		
				43			02:38:08.062	MicrOmega ON		



02:47:48.031	Ground Commanding for PCOM arrives HY2	PCOM High Power Mode (± 8 sec)	RSSI jumps from 96 to 229
03:13:54.000	PEC Not Illuminated	First night starts	
03:15:03.448	MicrOmega OFF		
03:30:16.250	MicrOmega ON		
03:49:35.893	LOS Detected	LOS Begins	1st Night. 35 min 42 sec after day 1 ends
04:06:30.732	MicrOmega OFF		
04:06:34.013	CAM ON		
04:11:21.823	CAM OFF		
04:32:34.123	CAM ON		
04:37:23.995	CAM OFF		
05:32:34.767	CAM ON		
05:33:41.953	CAM OFF		
06:32:34.908	CAM ON		
06:33:42.315	CAM OFF		
07:32:34.985	CAM ON		
07:33:42.266	CAM OFF		
07:37:43.000	Ground Commanding for enforced relocation	6 TCs arrive at OME TC Queue	Wait for AOS
07:39:29.229	COM AOS Detected	Weak RF Link starts	Takes 10 more min. for stable link
07:39:44.761	LOS Detected		
07:45:16.225	COM AOS Detected		
07:45:41.224	LOS Detected		
07:47:48.223	COM AOS Detected		
07:48:03.223	LOS Detected		
07:49:42.221	COM AOS Detected		
07:49:43.221	LOS Detected		
07:49:58.221	COM AOS Detected	Stable RF Link starts	4 of 6 TCs (sufficient) arrive.
07:50:03.909	MAM State Transition	Relocation commanding arrives MASCOT	MAM: Surface to relocate.
07:50:11.596	OPS Measurement ON		
07:50:46.283	Mobility Manoeuvre Start	1st Relocation begins	
07:51:38.189	OPS Contact Detected		
07:51:49.939	Mobility Manoeuvre Successful Completion		
07:51:50.595	PEC Illuminated	Second day begins	12 min 21 sec after AOS during relocation manoevre
07:52:03.001	OPS No-Contact Detected	Series of proximity loss & detection	8 times no-contact and 7 times contact
07:53:25.218	LOS Detected	Series of LOS and AOS	2 times LOS and 2 times AOS
07:53:29.406	OPS No-Contact Detected		
07:53:41.781	OPS Contact Detected		

07:54:08.218	COM AOS Detected		
07:54:18.781	OPS No-Contact Detected		
07:54:31.187	OPS Contact Detected		
07:54:55.780	OPS No-Contact Detected		
07:55:08.186	OPS Contact Detected		
07:55:45.186	OPS No-Contact Detected		
07:55:50.216	LOS Detected		
07:56:34.591	OPS Contact Detected		
07:56:46.998	OPS No-Contact Detected		
07:56:59.404	OPS Contact Detected		
07:57:11.590	OPS No-Contact Detected		
07:59:09.214	COM AOS Detected		
08:02:57.180	OPS Contact Detected		
08:03:21.993	OPS No-Contact Detected		
08:03:29.596	GncMgr OPS PEC AttEst MotionStatus Processing Report	At rest? (± 4.562 sec)	PecNoChangeStatus changed to true
08:27:51.000	MAM State Transition	Surface 2. No self-righting required. Correct side	Relocate to surface. After ComeToRest timeout (35 min 30 seconds)
08:27:58.723	System Power Idle Mode Transition		
08:28:00.941	CAM ON		
08:28:06.160	OPS Measurement OFF		
08:31:23.626	CAM OFF		
08:31:46.438	MicrOmega ON		
09:08:06.910	MicrOmega OFF		
10:52:06.047	PEC Not Illuminated	Second night starts	
10:52:10.610	System Power Idle Mode Transition		
10:52:13.110	CAM ON		
10:53:25.921	CAM OFF		
10:53:58.701	MicrOmega ON		
11:16:53.465	MAG OFF	Turned MAG off to save energy	4 Ground TCs
11:27:50.049	LOS Detected		
11:30:21.486	MicrOmega OFF		
11:38:35.635	COM AOS Detected		
11:39:00.635	LOS Detected		
11:53:59.467	CAM ON		
11:58:49.463	CAM OFF		
12:54:00.232	CAM ON		
12:55:07.606	CAM OFF		
13:54:00.278	CAM ON		
13:55:07.558	CAM OFF		
14:54:00.512	CAM ON		
14:55:07.730	CAM OFF		



15:05:00.000	Commanding via HY2 Timeline	To abort TC Sequence 32. Sent 7 times at 5 min interval due to unclear LOS Duration	5 times too early. 2 TCs on time. Still NO SUCCESS
15:19:50.867	COM AOS Detected	Weak RF Link starts	
15:20:15.866	LOS Detected		
15:27:05.830	PEC Illuminated	Third day begins	
15:27:11.299	CAM ON		
15:27:39.674	COM AOS Detected		
15:28:09.673	LOS Detected		
15:29:55.703	CAM OFF		
15:30:19.202	MicrOmega ON		
15:30:47.577	Primary Voltage V_UPB Drop Detected		
15:33:39.075	COM AOS Detected	Stable RF Link starts	
16:06:43.674	MicrOmega OFF		
16:06:45.955	TC Seq Anomaly - Med: TCSEQ_EXEC_ABORTED_FOR_DISABLE_REQUEST		
16:28:29.657	Mobility Manoeuvre Start	Mini move starts	Ground TC
16:29:19.125	Mobility Manoeuvre Successful Completion		
16:37:25.650	CAM ON		
16:40:47.241	CAM OFF		
16:41:10.835	MicrOmega ON		
16:41:36.521	Primary Voltage V_UPB Drop Detected		
17:17:32.118	MicrOmega OFF		
17:17:36.024	CAM ON		
17:20:02.397	CAM OFF		
18:01:21.271	MAG ON		Ground TC
18:02:53.426	MAM State Transition	Relocation TCs arrive MASCOT	Surface to relocate
18:02:58.582	Mobility Manoeuvre Start	2nd relocation begins	
18:03:01.301	OPS Measurement ON		
18:03:46.457	Primary Voltage V_UPB Drop Detected	Due to Mobility actuation	Manoeuvre goes on
18:03:46.926	OPS Contact Detected		
18:03:50.426	MAM State Transition	EOL Begins	Relocate to EOL
18:03:54.362	CAM OFF		
18:03:54.769	MARA OFF		
18:03:55.362	MAG OFF		
18:03:59.487	MicrOmega OFF		
18:04:03.050	Mobility Manoeuvre Successful Completion	ONC-T Images show no visible reloaction (rocks?).	MASCOT ends up laying on side 2 (+Z). No self-righting due to EOL.
18:05:17.236	System Power Idle Mode Transition		
18:05:19.299	OPS Measurement OFF		
18:06:29.767	CAM ON		
18:07:05.360	CAM OFF		

	18:08:01.547	Execute TC Seq. 97	MAG OnBattery (139)	Ground TC
	18:10:59.264	System Power Idle Mode Transition	System Power Idle Mode 6	
	18:11:01.264	System Power Idle Mode Transition	System Power Idle Mode 1	
	18:12:02.356	MicrOmega ON		
23	18:12:22.450	Primary Voltage V_UPB Drop Detected	Due to MMEGA switch on	
	18:30:59.279	PEC Not Illuminated	Third night starts	
	18:34:00.058	MicrOmega OFF		
	18:34:17.214	System Power Idle Mode Transition		
	18:35:19.776	Standard HK	All Packet Store read write gaps are zero	All MASCOT Data uplinked to HY2
Night 3	18:37:34.430	Primary Voltage V_UPB Drop Detected		
	18:37:55.243	System Power Idle Mode Transition		
	18:37:57.243	System Power Idle Mode Transition		
	18:38:58.054	MARA ON		
	18:40:09.147	MAG ON		
	18:40:38.428	Primary Voltage V_UPB Drop Detected		
	19:03:56.000	Standard HK	Last TM Packet	

6 Day 1 and Night 1

6.1 Descent and bouncing

The first "day" for MASCOT starts with separation from HY2 and ends when MASCOT doesn't see the sun light anymore. In other words, the terms *day* or *night* are not bound to a geographical location on the asteroid. They depend only on the PEC Sensors.

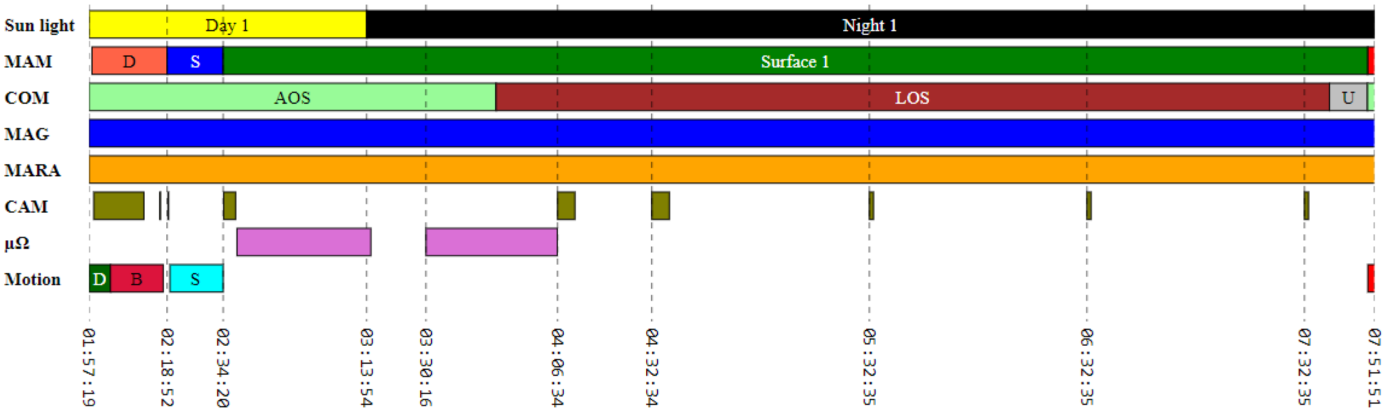


Figure 2: MASCOT Landing Day 1 & Night 1 (scaled) [UTC]

After separation, MASCOT was in free fall for ca. 6 minutes. Based on the MAG Measurements, ONC Pictures and PEC Sensors, it appears that it entered the shade of a bigger rock for a short time and made the first physical contact with Ryugu by bouncing off that rock.

15 minutes after the first contact, MASCOT came to rest. During the 6 minutes of free fall and the 15 minutes of bouncing, the MAM was in the descent mode. In this timeframe it switched the packet store for CAM and MicrOmega to PS3. Then the CAM generated 20 science products within ca. 14 minutes.

Additionally, the CCOM switched to high power mode at 02:08 automatically. Note that the ground command to switch the PCOM to high power mode arrived later at HY2 at 02:48, after which the RSSI jumped from 96 to 229.

The OPS Sensors of the GNC have been turned on 730 seconds after entering the descent mode based on fixed timing. This turned out to be ca. 7 minutes after the first physical contact with Ryugu.

6.2 Self-righting

When MASCOT came to rest at 02:18, it was lying on the +Y side to soil. Since the desired side is –Z, the MAM Mode changed from descent to upright. That event triggered several TC Sequences to change a number of configuration parameters, activated CAM for taking a single picture and eventually triggered the self-righting maneuver.

Unfortunately, when MASCOT came to rest again, MASCOT determined the side to soil as –Z, while it was actually lying with the +Z side to soil. This wrong outcome of the sensors and on-board algorithms was due to the low reflectance and the rough terrain. Since MASCOT believed it is lying on the desired side, the MAM triggered surface operations.

This situation was confirmed on ground by various alternative information sources ranging from antenna selection to CAM Images and temperature measurements [RD6]. However, none of these were evaluated on-board.

6.3 Surface Day 1 Location 1 Operations

Now that the MAM was in surface mode, it changed the Packet Store (PS) to be used from PS3 to PS2, which increases the uplink priority of the CAM & MicrOmega Science Data. I.e. New science data of these two instruments, which is recorded from now on, would be uplinked to HY2 earlier than any remaining data in PS3. Note that science data produced by MAG & MARA have always been recorded in PS1 and had therefore always a higher uplink priority.

Immediately after the new setting, the CAM has been turned on and the sequence "*CAM Day1 Seq1*" has been executed, which produced 8 science products within ca. 4 minutes, before It has been switched off.

Next, MicrOmega was switched on, which executed the sequence "*Mmega Option0 (Master)*". The instrument produced 43 science products within 37 minutes before it was switched off again.

Note that these measurements did not serve their actual scientific purpose, because they were measuring the deep space instead of the surface.

6.4 Surface Night 1 Location 1 Operations

The first night started about a minute before MicrOmega has finished its measurements. The MAM has not interrupted this sequence (as planned). It did interrupt the higher level TC Sequence "*MAM_Surface1-A Day (Master)*" and started "*MAM_Surface1 Night (Master)*" as soon as MicrOmega has finished its measurements and was turned off.

The night sequence turned MicrOmega on again at 03:30. About 19 minutes later, while the instrument continued measuring, the link to HY2 was lost as expected due to the geometry of the two spacecraft.

During this session, several anomalies occurred, which were related to missing subcubes in MicrOmega science data as reported in event packets "*MicrOmegaMgr Info: Image Missing During Compression*" and "*MicrOmegaMgr Info: Image Replaced*" (not shown in Table 3).

MicrOmega finished around 04:06 and has been switched off nominally. It was followed by five CAM Activations, which generated 6 images each. The first two activations took ca 5 min each and the last three about a minute due to the different camera settings.

The overall night 1 sequence was finished at 07:34. The LOS Phase ended only 5 minutes later.

During this LOS Phase, the OBC toggled between COM Main and Redundant as well as the antennas as expected.

As for the surface operations in the previous section, MASCOT was still lying upside down and the measurements were not useful.

6.5 First relocation

As planned, the operations team has not received any data at all for about 40 minutes after separation due to HY2's scanning maneuver. By the time the operations team received extended HK Data and confirmed the situation, MASCOT entered the asteroid night and short after lost the link to HY2 as expected.

During the asteroid night and LOS, the team forwarded six commands to JAXA for a relocation maneuver to be executed as soon as possible. These commands arrived at HY2 short before the end of the night. That also means they arrived short before the link between the two spacecraft has been re-established. Therefore, they were stored in the TC Queue of the OME. The OME was programmed to forward such commands to MASCOT as soon as the radio link was available. The OME responsible has confirmed the correct number of TCs as well as the correct number of bytes in the OME TC Queue.

Once the link was established, MASCOT returned TC Acknowledgments for four TCs with the SSC 352, 353, 354 and 355. The TC Acknowledgements for SSC 350 and 351 are missing in this timeframe (neither positive nor negative). Therefore, it seems that the first two of the six TCs were disregarded by MASCOT due to the weak link during the LOS to AOS transition, which took ca. 10 minutes until 07:50.

The remaining 4 TCs have been received well, executed and acknowledged. The loss of the first two was bearable, because the actual intent was to execute only 2 commands. Each of these was repeated 2 more times to increase the redundancy. This preventive measure has paid off. See RD3 for more details.

The immediate MAM Reaction is visible in the HK Telemetry. It changed its state from surface to relocation at 07:50. The related commanding from the OBC to the mobility mechanism did not succeed immediately due to an anomaly. However, the FDIR mechanism was able solve the situation in two steps by first repeating the commanding and then restarting the unit. The FDIR took about 43 seconds, after which the mobility arm started moving.

Almost immediately after MASCOT started relocating, it was illuminated by the Sun. Therefore, this motion is further described in section 7.

6.6 TM Packet Stores

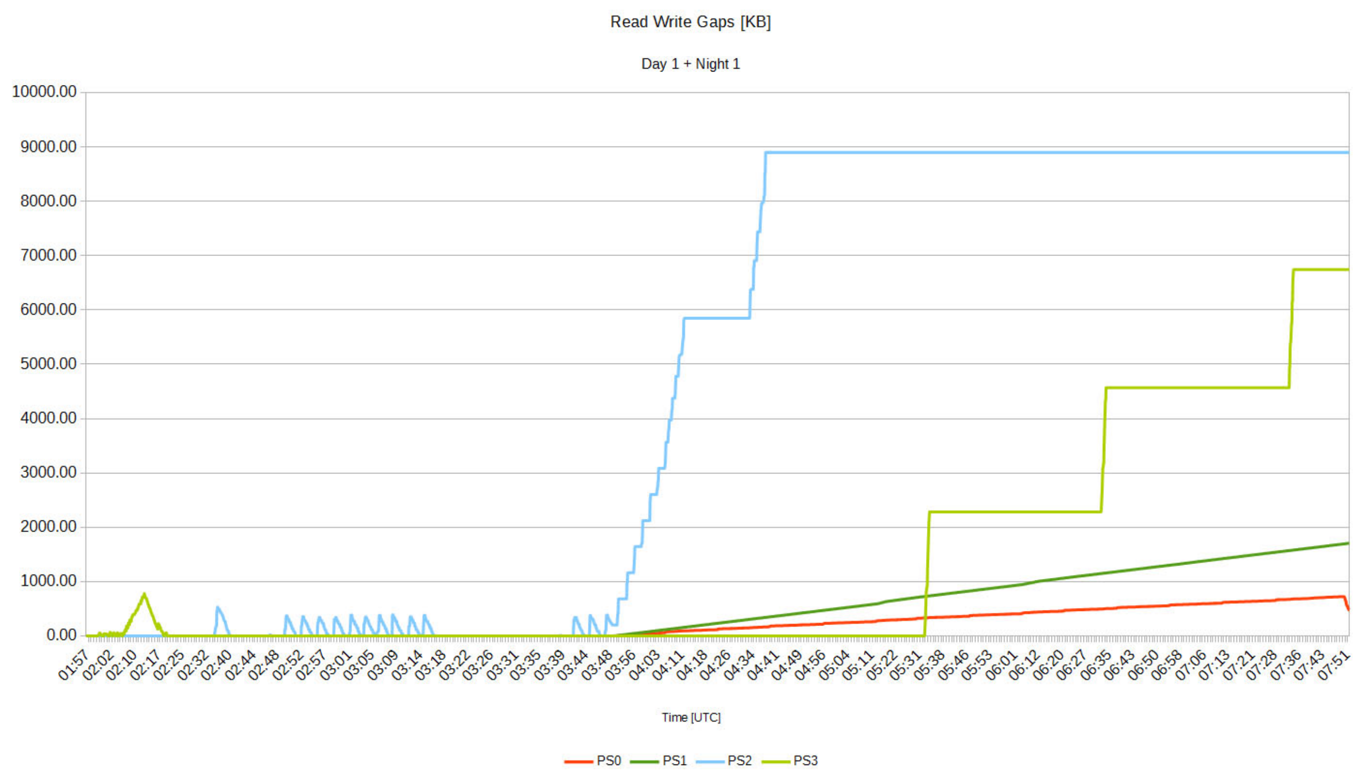


Figure 3: Read Write Gap Day 1 + Night 1

Figure 3 shows how the four TM Stores (data buffers) of MASCOT were utilized. The *read/write* gap is the difference between the amount of data, which is stored in the buffer and the amount that is already uplinked to HY2.

Note that the four packet stores were large enough to store all the data, which was generated after the separation as shown in Table 4.

Table 4: Packet store occupation [%]

	PS0	PS1	PS2	PS3
At Separation	6.3	2.7	0	0
At the end	12.5	11.8	18.8	16.5

At the first half, Figure 3 shows all four curves close to zero with small peaks of PS2 and PS3 when CAM and MicrOmega were producing relatively large amounts of data. The achieved real bitrate was up to ca. 31Kbit/s and high enough to uplink almost all data in real-time.

The first LOS occurs around 03:50, ca. 36 minutes after the first night begun. From now on, MASCOT is unable to uplink data and the read/write gap grows accordingly rapidly.

Since PS0 contains relatively small amounts of standard housekeeping (HK) and extended HK data, the red curve is rising slowly and almost linear.

PS1 contains MAG and MARA science data. The dark green curve is also rising linear and slightly steeper than the red curve as expected.

The remaining two curves contain CAM and MicrOmega data, which are produced in pulses. The timing of the peaks fit to the activities of the two instruments when compared to Figure 2. The data store used for these two instruments has been set to PS2 when MAM triggered surface operations at 02:34. Accordingly, the blue curve is rising and the light green curve of PS3 stays constant until 05:32, when the MAM switched the selected PS for the two instruments back to PS3 as defined in the night 1 sequence. After that point in time, PS2 stays constant and PS3 accumulates three more pulses of CAM Data as expected.

7 Day 2 and Night 2

7.1 Relocation

MASCOT was already in motion when the second asteroid day started. That is the point in time when the PEC Sensors were illuminated.

The motion started due to the commanded first relocation (see section 6.5) at 07:50. Because of the motion, several OPS Contact and no contact events have been detected by MASCOT within several minutes. The operations team assumes that the physical motion mostly stopped at 08:03, when the PEC Illumination Parameter "*PecNoChangeStatus*" changed to true. However, the MAM never observed the PEC & OPS Conditions, which define the settled status. About 14 minutes later (at 08:28), the *ComeToRest* counter expired, which is 35 min 30 seconds after the relocation started. The expired counter forced the MAM State change from *Relocate* to *Surface*.

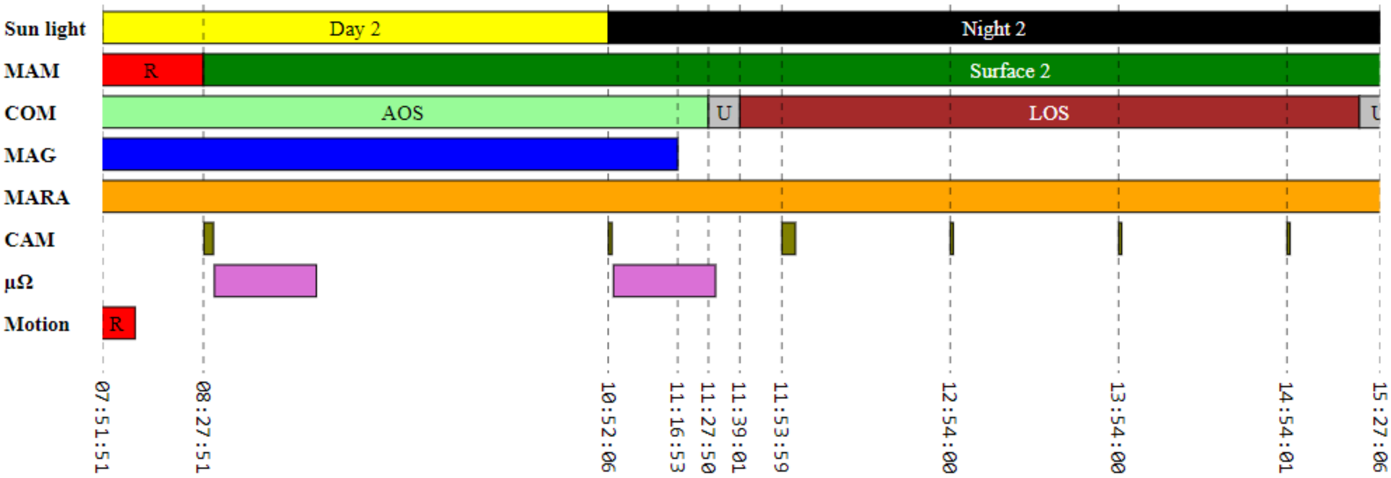


Figure 4: MASCOT Landing Day 2 & Night 2 (scaled) [UTC]

At this point in time, the GNC has detected the –Z side to soil. The PEC Sensors at the +X, +Y and +Z Sides were clearly illuminated and the other three were clearly dark. Additionally, the top antenna (P2) was selected. These were already strong indications that MASCOT came to rest on the desired side (-Z). A self-righting maneuver was not necessary.

7.2 Surface Day 2 Location 2 Operations

The first scientific action back in surface mode was for CAM to make 8 pictures. These pictures have also confirmed the correct orientation.

In Figure 5, the impact on the data amount in PS2 is visible in the peak at 08:29. This is followed a steep downwards curve meaning that the CAM data was being uplinked to HY2 and reduced the read/write gap.

Almost immediately after this CAM session was finished, µΩ was turned on. The saw pattern, which follows the CAM data uplink, shows when µΩ created scientific output and how that data was uplinked to HY2.

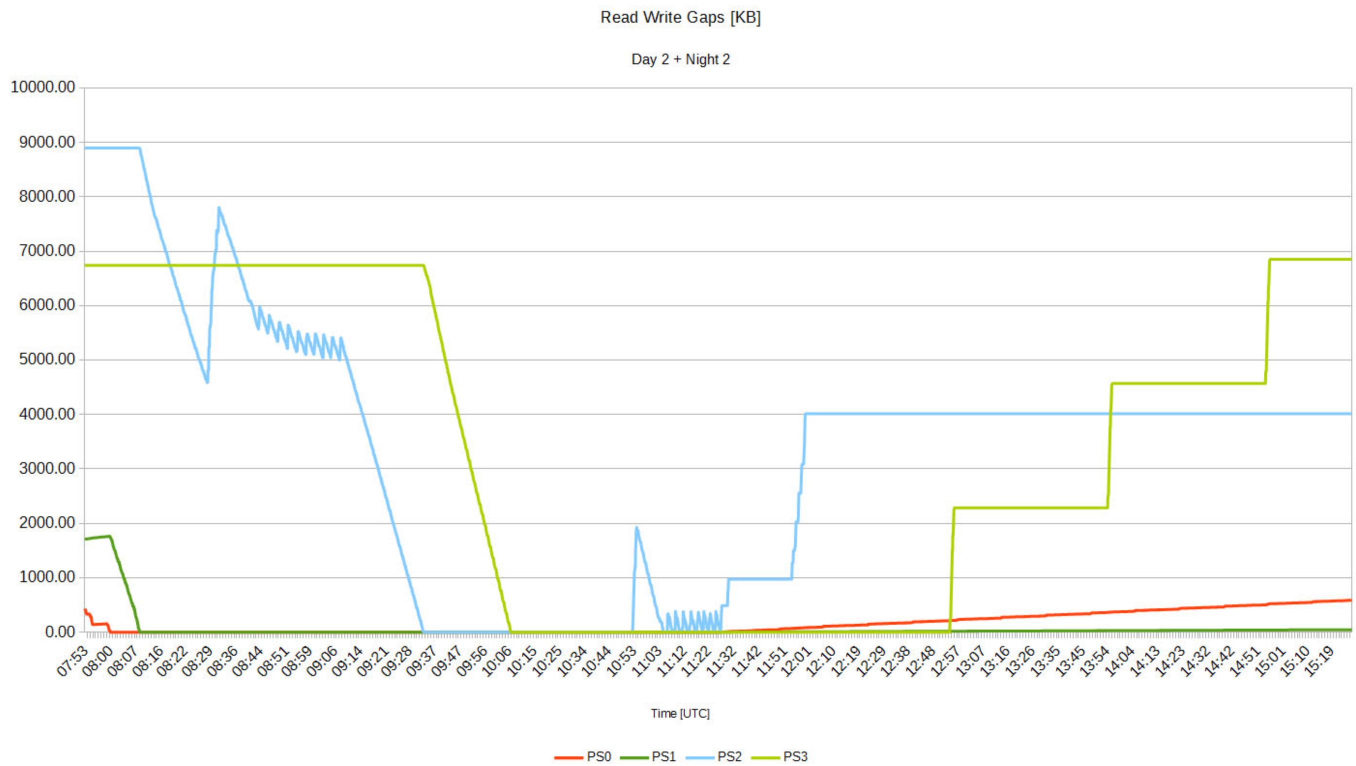


Figure 5: Read Write Gap Day 2 + Night 2

Once the PS2 Data Uplink has finished at 09:37, the reaming CAM Images from the previous LOS Phase in PS3 were uplinked in about half an hour. In other words, all MASCOT data up to this point in time has been uplinked to HY2.

7.3 Surface Night 2 Location 2 Operations

The second asteroid day ended at 10:52. MAM has started the sequence 41 "*MAM_Surface2 Night (Master)*" accordingly. As expected, CAM made the next 8 night images as it can be seen both in Figure 4 Figure 5.

The night sequence continued immediately with µΩ measurements. These ended short after the AOS to LOS transition started at 11:28. Most of this µΩ data was uplinked as the second saw pattern of Figure 5 proves. The small remainder was stored in PS2.

The MAG Team had proposed to switch off their unit to save energy in favor of other instruments. The operations team has prepared and sent 4 TCs to switch off MAG. These TCs arrived at MASCOT around 11:17 while µΩ was measuring.

The remainder of the night sequence continued as planned with 4 more CAM Sessions. As expected, the CAM Data was accumulated in PS3 due to the current LOS Phase and the switch from PS2 to PS3 according to the TC Sequence.

Note that at 11:57, which is 10 hours after separation, OBC reported "*Parameter Monitoring: EOL Timeout elapsed*". That means from now on, the OBC was allowed to react on voltage drops as they occur by switching to End of Life Mode. This transition did not happen during night 2, but the next day.

The entire night sequence was completed at 14:55. No further automatic actions happened until the next sun rise.

Meanwhile, during LOS between HY2 and MASCOT, the operations team uplinked new commands for the next day. These were received by HY2 during night 2. See section 8.

8 Day 3 and Night 3

8.1 Surface Day 3 Location 2 Operations

The MAM was programmed to start the TC Sequence 32 "*MAM_Surface3 Day (Master)*" as soon as the sun rises. This sequence would first start a CAM and then start a µΩ session.

During the previous asteroid night (and LOS Phase), the µΩ PI requested the operations team to exclude µΩ from this TC Sequence such that a mini move would be performed prior to the µΩ Session.

Since this was technically impossible, the team has chosen to stop the entire TC Sequence 32 and uplinked a HY2 Timeline to do so. It contained seven times the same command to be released in 5 minutes intervals starting at 15:05.

Since the location of MASCOT on the asteroid was not precisely known during the operations, the timing was a rough estimate.

Due to the LOS between the two spacecraft until 15:20 and the unstable link until 15:34, the first TC (SSC = 360) was never received by MASCOT. There was neither an acknowledgement nor a rejection for this SSC. There is no evidence for when the OME has sent it to MASCOT.

The next 5 of the 7 TCs were queued in the OME until the stable link was established at 15:34. The OBC reported acceptance and execution.

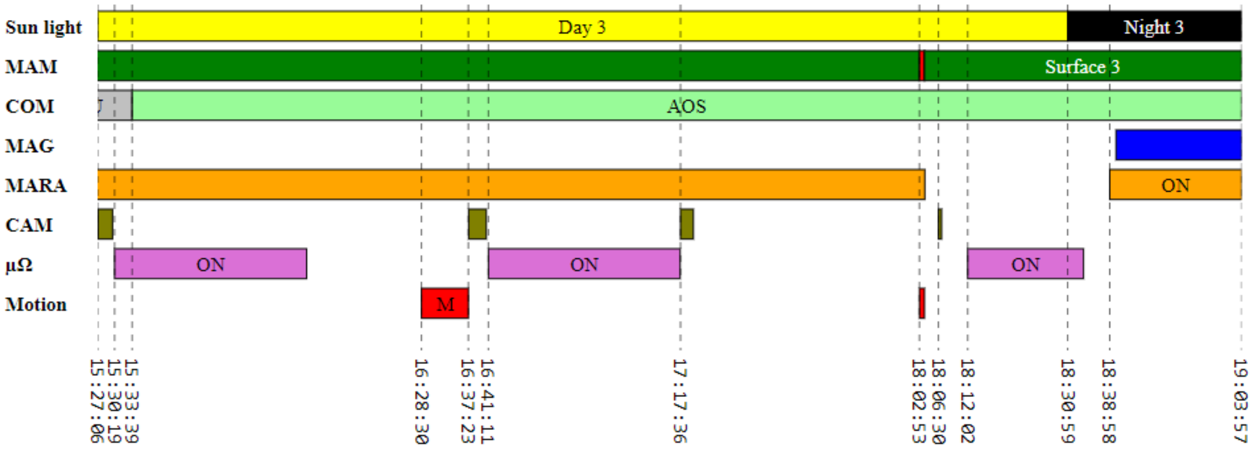


Figure 6: MASCOT Landing Day 3 & Night 3 (scaled) [UTC]

However, MASCOT was illuminated by the sun earlier, at 15:27. This event triggered the TC Sequence 32 and µΩ has been turned on already at 15:30. Therefore, when the TCs arrived 4 minutes later, the OBC didn't interrupt the TC Sequence 32 immediately, but delayed that until the µΩ Sequence (107) was finished at 16:07.

For the same reason, the seventh and last TC of this timeline, which arrived at 15:35, didn't make a difference.

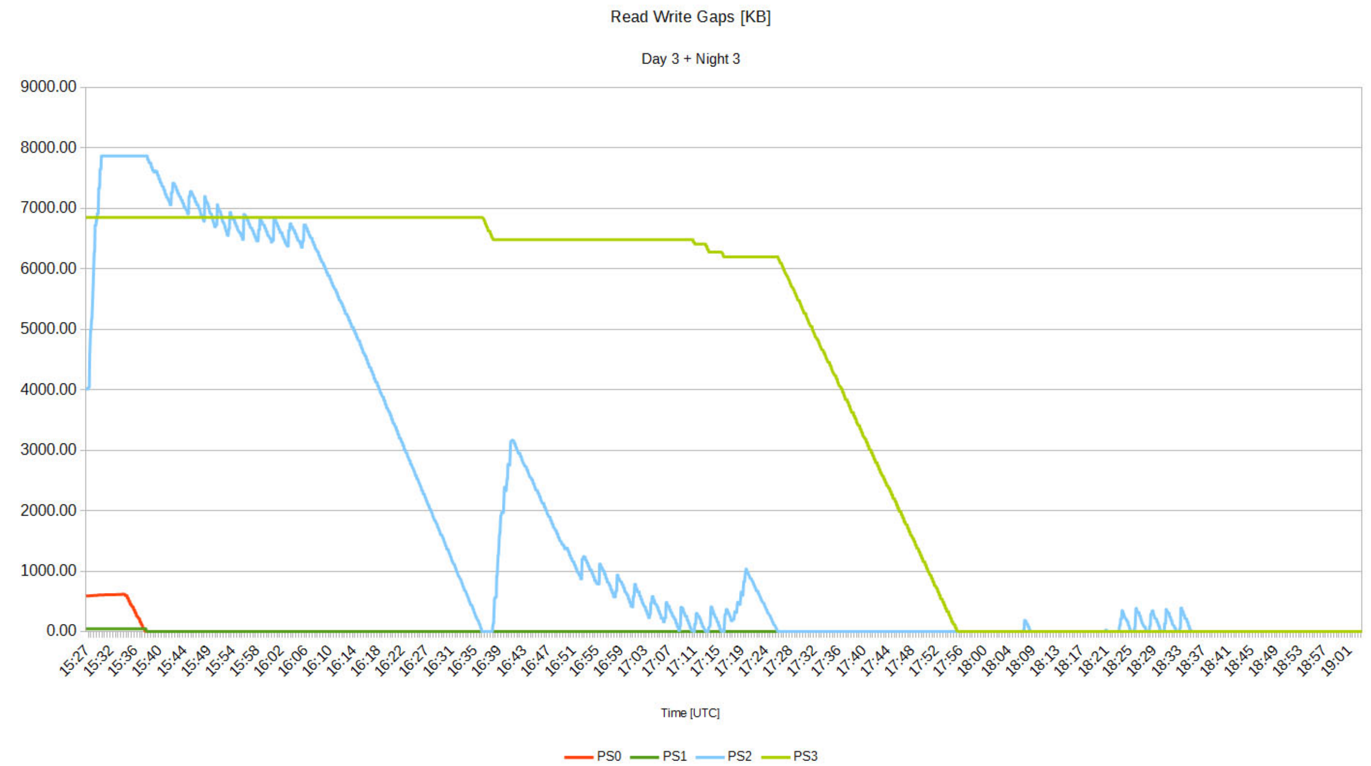


Figure 7: Read Write Gap Day 3 + Night 3

8.2 Mini move

The operations team uplinked direct commands to trigger the mini move maneuver, which started at 16:28. This time, there were no anomalies while OBC was commanding the mobility unit. The minimal impact on the PEC Illumination indicates that the mini move was very small as intended and the side to soil remained the same.

8.3 Surface Day 3 Location 2

At 16:37, nine minutes after the mini-move, MASCOT received further commands from ground to restart the whole TC Sequence 32, which was interrupted before the mini move. All instruments made measurements at a very small relocation / reorientation. Obviously, this excludes MAG, since it was switched off. The sequence finished nominally at 17:20.

The execution of the sequence is also clearly visible in Figure 7. The peak of PS2 read/write gap from zero to 3 MB was caused by the first CAM Session. The following saw pattern is again the µΩ Measurement and the sequence is concluded by a smaller CAM session with 5 images or 1MB.

8.4 Second Relocation

After the successful completion of the sequence 32 "*MAM_Surface3 Day (Master)*", the operations team was aware that the mission was close to its end. Since the separation, more than 15 hours had elapsed. The estimated life time of the battery was 17 hours. The OBC had already registered several voltage drops. There was no chance that the battery would survive the upcoming LOS phase.

At this point in time, all instruments already had the opportunity to make various measurements and all data was uplinked to HY2 and thus secured.

In these circumstances, the MASCOT Community has decided to perform a second relocation maneuver and to switch MAG back on.

The associated technical risks were mainly related to the expected switch to the End of Life (EOL) as soon as the mobility arm would operate. This mode switch would first turn off all instruments. For MAG, that would mean to miss the opportunity to measure during the relocation.

The MASCOT Community decided to accept this risk and to perform the relocation. The corresponding commanding arrived at MASCOT starting at 18:00.

According to the mobility data, the unit completed the expected move as desired. The GNC Data shows clear signs of motion including a shade period of ca. 3 minutes.

However, the later HY2 Images do not show any relocation. It is assumed that MASCOTs motion was blocked by a rock such that the relocation was very small.

Although the mobility arm was able to perform its motion, the voltage dropped as expected and the MAM switched to EOL Mode.

MASCOT ended up upside down with the +Z side to soil. Due to the EOL Mode, MASCOT made no self-righting attempt.

With the expectation of complete battery depletion at any moment, the operations team has not interfered anymore.

Therefore, the MAM continued with its EOL Program. This includes the power idle mode 6, in which redundant units and GNC Sensors are switched off.

This was automatically followed by a single CAM Session without LEDs and a short μΩ session.

During this μΩ session, MASCOT entered the third night. However, the AOS phase continued.

Since the battery was surprisingly still not depleted, the MAM continued by going back to the less restrictive power idle mode 0 and turned MAG & MARA on. Since MASCOT was lying upside down, this measurement was not useful for any of the instruments.

MASCOT entered LOS at 19:04 and the mission has been officially declared as finished.

The MASCOT Team has nevertheless checked if there was any new telemetry at the beginning of the new estimated AOS Phase. As expected, there was none.

9 Conclusions

The evaluation of the MASCOT Mission w.r.t operations requires a listing, comparison and weighing of the achievements and failures. The latter is subjective.

The failures:

Although the GNC HW worked fine, the wrong side determination after the first self-righting attempt shows that the overall chain of HW, algorithms and software failed to cope with the extremely rugged landscape of Ryugu. MASCOT came to rest in a situation, in which the PEC at the +Z side has seen sunlight although it was facing down and the –Z Side has not detected light, because it was facing the sky (instead of the soil). This was confirmed by CAM Pictures, antenna selection and MARA Temperatures. However, these were not evaluated by the on-board algorithms. It is likely that the side detection system would have worked in a less rugged environment.

The first relocation maneuver has solved this problem. The manual commanding from ground has ensured that the relocation took place as soon as possible and this reduced the loss of precious time for three of four instruments. At the second location, CAM and MARA were able to work flawlessly. Unfortunately, μΩ seems to have found itself in an inadequate geometry to make good measurements. The successful mini-move maneuver has not helped μΩ.

Last, but not least, the second relocation seems to have worked based on the mobility telemetry. MASCOT moved[3] 11,6cm. MASCOT has ended up again with the wrong side down as correctly detected by the on-board software. However, due to the maneuver, the battery voltage dropped so far that the MAM switched to end of life mode and hence, a self-righting attempt was not performed. Again, μΩ remained unable to measure.

The manual interventions to the "autonomy" of the MAM have achieved the intent to a good extent with some set-backs and side effects (See RD3). However, looking at those undesired results from the big picture, their negative impact can be considered as minor.

The achievements:

- The MASCOT Hardware kept working in good condition from launch to end of life.
    - MASCOT Separation worked flawlessly
    - The battery performed better than expected
    - The mobility mechanism worked as expected

[3] Paper published by Tra-Mi Ho et al at Planetary and Space Science 200 (2021) 105200 "The MASCOT lander aboard Hayabusa2: The in-situ exploration of NEA
(162173) Ryugu"

  - The CCOM Redundant Unit had reduced sensitivity while receiving data. This was discovered short before launch and it was decided to fly the unit nevertheless. The issue was not severe. Additional measures by preferring CCOM Main in operations and in FDIR have worked out well.
  - There were concerns regarding the PCDU performance once operated together with the battery flight spare unit, the associated anomalies were seen in the TVAC tests at MASCOT system level. A potentially catastrophic end to the mission was inferred when high power users such as µΩ, CAM or Mobility were used. However, fortunately, the FM Battery turned out to be the best-performing by a margin of several %. After the results of extensive tests with the FS in TVAC simulating an on-asteroid mission, the simple battery depassivation procedure given by the battery provider was replaced by a challenging battery depassivation sequence, a specially timed TC modification for the operation of MMEGA was developed to reduce its power consumption by turning off some sub-units by serendipitous side effects of MMEGA's internal hardwired TC logic, the Mobility drive was thus limited to some 20% of its actual motor power capacity, and the battery was heated to the maximum tolerable temperature before separation which the reversed orientation of MASCOT during the first night helped to maintain longer than nominally expected.
- The MASCOT Software evolved in about three years of cruise phase. Massive data loss and corruption problems occurred in OME. These issues were fixed before the asteroid phase by improving both OME and MASCOT SW.
- The OBC HW and SW have worked as designed and required.
- Three of four instruments were able fulfil their scientific goals.

The ground segment supported the flight operations as expected from the antenna to the displays. Only occasional bad weather conditions at the antenna caused some delays during the cruise phase.

Given the harsh rugged surface of Ryugu and the comparison of the above achievements versus failures, the MASCOT Landing can be considered as mostly successful.

10 Emergency commanding

10.1 Relocation 1 Manual TCs

The first relocation was commanded by two direct TCs, which were sent 3 times each for additional insurance that they arrive. They were communicated by voice loop as the backup TCs at line 8338 and 8269 of the manual procedure.

8337 # Disable TcSequence 30 (0x1E)
8338 TC128_2_DIS_TCSEQ 0x191E

8268 # Set Surface [0] = 0
8269 TC8_135_SET_BASIC_TYPE_PARS 0x190100E9030C00700000000000000000

However, the TC at line 8338 has been modified manually at at JAXA's commanding console such that it would stop TC Seq. 102 instead of TC Seq. 30 (from 0x191E to 0x1966). The TC at line 8269 was not modified.

8338 TC128_2_DIS_TCSEQ 0x1966

By the time the 6 TCs arrived HY2, there was no link between HY2 and MASCOT, since MASCOT was at the night side of Ryugu. The 6 TC have been queued in the OME TC Buffer and sent to MASCOT as soon as the link was established.

However, since the link was unstable within the first 10 minutes, the first two TC were not recognized as TCs by MASCOT. Since the same TC was sent three times, the loss of two TCs had no consequences.

10.2 Aborting TC Seq. 30

tl-MASC-cont_abort_TcSeq30

```
# Repeat TcSeq 30 abort each 5 min for 30 min
2018-10-03 15:10:00 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:15:10 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:20:00 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:05:00 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:25:00 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:30:00 TC128_2_DIS_TCSEQ 0x1920
2018-10-03 15:35:00 TC128_2_DIS_TCSEQ 0x1920
```

10.3 Turning MAG off

dcsm-MASC-cont_MAG_OFF

```
# Switch MAG OFF
TC8_1_PERFORM_FUNCTION 0x198106
#
# Disable MAG diagnostic
TC3_8_DIS_DIAG_PAR_RPT_GEN 0x190121
#
# Set MAG Inoperable - SourceId = 3
TC8_1_PERFORM_FUNCTION 0x39812B00
#
# Disable MAG FDIR
TC19_5_DIS_EVENT_ACTION 0x1902057E10DA057E10DB
```

10.4 Mini-move

dcsm-MASC-cont_MiniMove_Day3

```
#  Start MiniMove Manoeuvre - SourceId = 3
TC134_130_MMC_EXEC_LOW_MAN 0x39000000012C019F000411F41901
#
# *** wait 8 minutes ***
#
# Enable TcSeq 32 - Surface 3 Day
TC128_1_ENA_TCSEQ 0x1920
#
# Start TcSeq 32 - Surface 3 Day
TC128_5_EXEC_TCSEQ 0x1920
```

10.5 Second relocation

dcsm-MASC-cont_Start_Relocate

```
# Set MAG to Operable
TC8_1_PERFORM_FUNCTION 0x39812B01
#
# Enable MAG diag
TC3_7_ENA_DIAG_PAR_RPT_GEN 0x190121
#
# Switch MAG ON - TcSeq 97
TC128_1_ENA_TCSEQ 0x1961
TC128_5_EXEC_TCSEQ 0x1961
#
# *** wait 1 min ***
#
# Set MAM to RELOCATE - SourceId = 3
TC8_1_PERFORM_FUNCTION 0x39812905
```

11 Appendix A: Pre-Separation Timeline

The following is the as planned timeline. The real operations followed the plan very closely. Only the timeline tl-MASC-1050 has been executed one hour earlier.

Date	Station	Time	Duration	Event	*Remarks*	Upload Time-line	Execute Time-line
28. Sep	UDSC	**23:30**		**BOT**	*The pass starts the previous day in UTC*		
28. Sep	UDSC				*No MASCOT Activities*		
28. Sep	UDSC	**07:30**		**EOT**			
28. Sep	MAD			**BOT**			
28. Sep	MAD				*No MASCOT Activities*		
28. Sep	MAD			**EOT**			
28. Sep	GDS	**16:00**		**BOT**			
28. Sep	GDS		0:05	Uplink timeline	*Warming up MASCOT*	tl-MASC-1001	
28. Sep	GDS		0:05	Uplink timeline	*OME-E Power-On and Set-up*	tl-MASC-1002	
28. Sep	GDS		0:05	Uplink timeline	*MASCOT Power-On*	tl-MASC-1003	
28. Sep	GDS	20:00	16:10	**Warming up MASCOT**	*MINIMUM duration 15 hours*		*tl-MASC-1001*
28. Sep	GDS	**23:40**		**EOT**			

Date	Station	Time	Duration	Event	*Remarks*	Upload Time-line	Execute Time-line
29. Sep	UDSC	**23:30**		**BOT**	*The pass starts the previous day in UTC*		
29. Sep	UDSC				*LOS due to the Taifun. No MASCOT Activities*		
29. Sep	UDSC	**07:30**		**EOT**			
29. Sep	MAD			**BOT**			
29. Sep	MAD	12:00	0:10	**OME-E Power-On**	*During LOS. OME Mode 3*		tl-MASC-1002
29. Sep	MAD	12:10	0:10	**MASCOT Power-On**	*During LOS*		tl-MASC-1003
29. Sep	MAD	12:10	3:50	MASCOT Self Heating	*MINIMUM duration 03:50*		
29. Sep	MAD			**EOT**			
29. Sep	MLG	**14:00**		**BOT**			
29. Sep	MLG	14:00	1:00	Spacecraft operations	*Assumed 1 hour*		
29. Sep	MLG	14:24	0:05	Dump category 0x79 data	*Assumed 30 min after the pass beginns*		

		15:00	0:20	Ground check	*Verify Mascot Switch-On status*		
		15:20	0:05	**GO for depassivation 3**			
		15:25	0:01	Set OME Mode to 4			
		15:26	0:05	Uplink timeline	*Battery Depassivation 3*	tl-MASC-1004	
		16:00	2:50	**Battery Depassivation 3**			*tl-MASC-1004*
		16:00	0:05	Uplink timeline	*Uplink while tl-MASC-1004 is running*	tl-MASC-1005	
		18:50	0:15	**MASCOT Power Cycle**	*Replace depassivation boot sequence with cruise*		*tl-MASC-1005*
		18:47	0:05	Dump category 0x79 data			
		19:28	0:46	Ground check			
		20:14	0:05	**GO for final checkout**			
		20:19	0:23	Uplink timeline		tl-MASC-1007	
		21:00	2:17	Final checkout			*tl-MASC-1007*
		22:00		**EOT**			

		Time	Duration	Event	*Remarks*	Upload Timeline	Execute Timeline
30. Sep	UDSC	**23:30**		**BOT**	*The pass starts the previous day in UTC*		
		23:17		End of final checkout			
		07:30		**EOT**			
	MAD	**08:40**		**BOT**			
				Data downlink, cat. 0x79, then cat 0x7A			
		14:50		**EOT**			
	GDS	**16:00**		**BOT**			
					LOS. No MASCOT Activities		
		00:05		**EOT**			

		Time	Duration	Event	*Remarks*	Upload Timeline	Execute Timeline
01. Oct	UDSC	**23:00**		**BOT**	*The pass starts the previous day in UTC*		
				Data downlink, cat. 0x79, then cat 0x7A			
		07:30		**EOT**			
	MA			**BOT**			

					LOS. No MASCOT Activities		
				EOT			
	GDS	**16:00**		**BOT**			
				Data downlink, cat. 0x79, then cat 0x7A			
			0:00	**OPTIONAL: GO for MARA Power Cycle**	*Only on request !*		
			0:05	Uplink timeline		tl-MASC-1055	
			0:14	**MARA Power Cycle**	*MARA Power Cycle*		*tl-MASC-1055*
			0:00	**OPTIONAL: GO for MAG Power Cycle**	*Only on request !*		
			0:05	Uplink timeline		tl-MASC-1056	
			0:12	**MAG Power Cycle**	*MAG Power Cycle*		*tl-MASC-1056*
			0:00	**GO for final preparation**			
			0:05	Record category 0x79 read pointer			
			0:05	Uplink timeline	*Uplink for immediate excution*	tl-MASC-1050	
		19:00	0:18	**Mascot Final Preparation**	*Install asteroid phase boot sequence + Force SGM Save + Reboot + Set MAM IDLE Mode + Force SGM Save*		tl-MASC-1050
				Dump category 0x79 data	*Either complete data or starting at the last recorded pointer position*		
			0:05	Set OME Mode 3	*If required by JAXA*		
		00:05		**EOT**	*The pass ends next day in UTC*		

		Time	Duration	Event	*Remarks*	Upload Timeline	Execute Timeline
02. Oct	UDSC	**00:00**		**BOT**			
			0:00	**GO for separation preparation**			
			0:05	Uplink timeline	*Separation Heating at NEA_ENA1 - 04:00:00*	tl-MASC-1009	
			0:05	Uplink timeline	*PreSepScience at NEA_ENA1 - 01:07:00*	tl-MASC-1010	
			0:05	Uplink timeline	*Final Configuration at NEA_ENA1 - 00:15:30*	tl-MASC-1011	
				Dump category 0x79 data	*Either complete data or starting at the last recorded pointer position*		
			0:05	Record category 0x79 read pointer			
		3:01	0:00	**Gate 1**			
		08:04		**EOT**			

	MAD	**08:40**		**BOT**			
				Dump category 0x79 data			
			0:05	Record category 0x79 read pointer			
		13:26	0:00	**Gate 2**			
		16:20		**EOT**			
	GDS	**16:00**		**BOT**			
		19:58	4:00	**Mascot Separation Heating**			*tl-MASC-1009*
				Set OME Mode 4			
		22:48	0:41	**Start Mascot PreSepScience Sequence 240 (0xF0)**	*Execute at NEA_ENA1 - 01:07:00* *Sets MAM to idle mode* *Starts TC Seq. 240 (0xF0)* *Start+00:01:00 MARA operation starts* *Start+00:02:00 MAG operation starts*		*tl-MASC-1010*
				Dump category 0x79 data	*Either complete data or starting at the last recorded pointer position*		
			0:05	Record category 0x79 read pointer			
		23:40	0:15	**Start Mascot Separation Sequence 005 (0x05) by MAM**	*NEA_ENA1 - 00:15:30* *Enable PEC change detection* *Close Mascot Battery switches*		*tl-MASC-1011*
				Dump category 0x79 data	*Either complete data or starting at the last recorded pointer position*		
			0:05	Record category 0x79 read pointer			
		00:05		**EOT**	*The pass ends next day in UTC*		

		Time	Duration	Event	*Remarks*	Upload Timeline	Execute Timeline
03. Oct	UDSC	**23:45**		**BOT**	*The pass starts the previous day in UTC*		
		23:55		Execute NEA_Flight1 and NEA_ENA1			
		00:51	0:00	**Gate 3**	*Point of no return*		
		01:55		60 m reached. Trigger free fall			

		01:58		NEA Powered	*MASCOT 50V lines off* *HCE Ch64A, Ch64B - OFF* *MASCOT separation* *NEA disable* *MASCOT power-on at X + 10sec*		MC-117
		01:58		Separation (as defined by FD)			
			0:00	GO for PCOM High Power Mode			
			0:00	GO for MASCOT Power Lines OFF			
		08:25		**EOT**			

	AOS	Gate x	GO / NOGO Decision	Logical separation, may over-lap in time
	LOS	Power-On	Major On-board activity	

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