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ExoMars Rover Operation Control Center Design Concept and Simulations

R. Trucco(1), L. Joudrier(2), P. Franceschetti(3), M. Martino(1), M. Trichilo(1)

(1) *ALTEC S.p.A*
Corso Marche 79, 10146 Torino, Italy
trucco.roberto@spacegate-altec.it
martino.michele@spacegate-altec.it
trichilo.michele@spacegate-altec.it

(2) *European Space Agency/ESTEC*
2201 AZ, Noordwijk, The Netherlands,
Luc.joudrier@esa.int

(3) *Thales Alenia Space Italia*
Strada Antica di Collegno 239, 10146 Torino, Italy
Paola.Franceschetti@thalesaleniaspace.com

INTRODUCTION

The ExoMars Rover Operations Control Centre (ROCC), that will be hosted in the ALTEC center (Turin – Italy), is responsible to conduct the Rover mission operations (including science operations) for the entire Surface operations phase, that nominally will last 180 sol after landing on Mars. Science team involved in mission operations will be located in the ROCC working in strict relationship with the Rover Engineering Team, while relying on additional remote support by their home base science teams. ESOC/MOC will support the ROCC for all communication management/scheduling related to the usage of the ESA communication infrastructure and NASA provided communication services (NRO, Nasa Relay Orbiter). ROCC operations process shall be based on day-by-day commanding of the Rover and PPL Instruments, to increase the return of the mission and to maximize the usage of the Rover during its nominal mission lifetime.
Before landing (starting from the pre-launch phase), the ROCC will provide remote support to ESOC/MOC (Mission Operation Center) assessing Rover & PPL (Pasteur Payload) data during the planned periodic checkout and addressing any issue affecting the Rover & PPL that could arise during this long period (supporting for example on-board software update if required). After Rover landing and the first communication session establishment between Rover and ground via NRO, an official operations handover occurs between ESOC/MOC and ROCC.
The ROCC development will follow a staggered approach implementing in each phase of the development cycle new functions and/or improvements of those already implemented, in order to use it in an end-to-end simulation environment that will include a Ground Segment Simulator (RGSS) (simulating the communication chain between the ROCC and the Rover), an high fidelity Rover software simulator and/or the physical models of the Rover to be operated within the simulator of the Mars terrain.
This paper describes the design concept of the ExoMars ROCC with evidence to the development activities supported by software simulators and physical models.

DESIGN CONCEPT OF THE ROCC

The ExoMars Overall Ground Segment is composed of the elements identified in Fig. 1, while Fig 1.1 reports the current mission communication scenario.

The Mission Ground Control consists of:

- The Mission Operations Centre (MOC) (located at ESOC, Germany),
- The Rover Operations Control Centre (ROCC) located at ALTEC, Italy,
- The Lander Operations Control Center (LOCC)
- The Science Data Archiving and Dissemination Centre located at ESAC, Spain.

The Mission Operation Centre (MOC) is responsible for the overall managing of the ExoMars mission starting from the Pre-Launch Phase up to the completion of the Entry, Descent and Landing Phase. At the end of these activities, and after the first communication session between the Rover and Ground, the responsibility of the Surface Operations Phase tasks will be transferred to the ROCC. MOC will manage / schedule all the communications links with the space segment. ESOC scheduling office will support the negotiation of NASA resources.

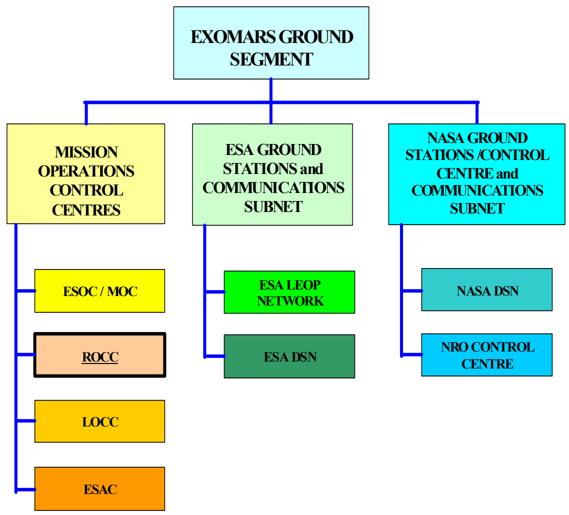

Fig. 1. Ground Segment elements

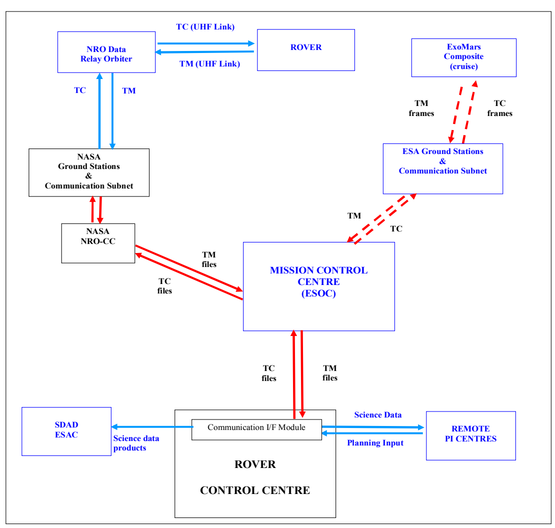

Fig. 1.1 ExoMars Rover Communication Scenario

The ROCC will be responsible for:

- Supporting the ESOC/MOC during the Interplanetary Cruise Operations Phase and Mars Orbit Phase for the periodic checkouts of the Rover. The ROCC is requested to remotely assess the transmitted data provided by ESOC/MOC. Possible corrective actions will be managed by the ESOC/MOC based on the input provided by ROCC;
- Full commanding the initial Surface Operations Phase, from the Rover activation until the Rover egress completion and basic functional check-out;

- Performing full Rover (including science operations) commanding and controlling along the Surface Operations Phase. Rover Module activity planning, command sequencing and commands validation will take place every sol between telemetry downlink to Earth and the next up-link opportunity of telecommands (TCs) to the Rover.
- Data dissemination to the scientific team for mission operation support;
- Post mission data product transfer to ESAC, not required to be performed in line with the Rover mission progress, but as per a different time schedule not impacting the Rover mission operation execution.

The LOCC will provide the support to the Humboldt Package operations. Communication resource sharing with the Rover will be coordinated by MOC.

The Science Data Archiving and Dissemination Center, will provide the long term archive of the scientific data collected during the ExoMars mission.

ROCC FUNCTIONAL ARCHITECTURE

The overall functional architecture of the ROCC comprises: Ground Communication Infrastructure, ROCC Operation Control System, Mars Terrain Simulator (where the Rover physical Models can be used) and Infrastructure Support.
The ROCC functional breakdown is reported in Fig. 2.

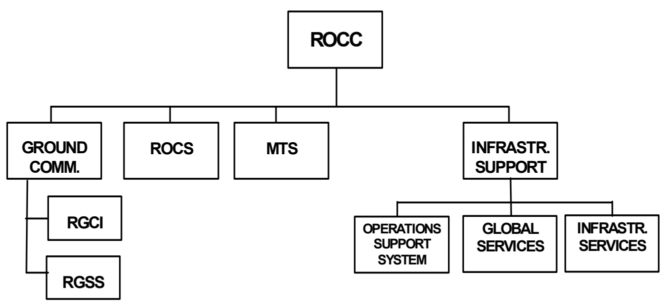

Fig. 2. ROCC Functional Architecture

The Ground Communication Infrastructure

The Ground Communication Infrastructure (Fig. 3) provides the ROCC with all the operational communications necessary to conduct Rover Operations, in particular in support of TM/TC, as required for the implementation of the selected communication scenarios. It includes:

- the MOC and ROCC communication nodes (with corresponding dedicated links) supporting any interface data exchange between ROCC, MOC and NASA centers.
- The ROCC Internet Communication Node providing the necessary capability to allow remote operations support by science team. Note that communications with ESAC are planned to be implemented using a VPN over the Internet connection.

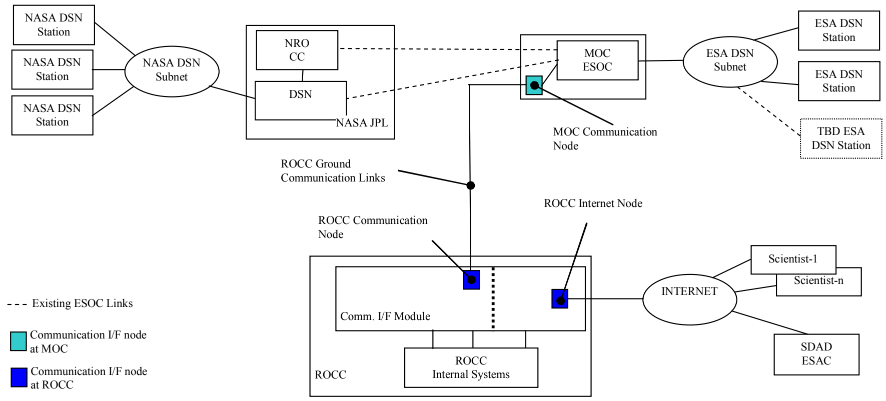

Fig. 3. Ground Communication Infrastructure

ROCC Operations Control System

The ROCC Operations Control System will provide the core capabilities in direct support of Rover operations, for telemetry receiving, processing and analysis, science and vehicle planning, simulation and sequence validation, on-board software management, command sequence uplink.
The major key drivers for the concept design of this system are the following:

- Provides the Rover Operations team and the Science Team with a "complete set of down-linked products that are essential for the assessment of the system and necessary for the subsequent sol(s) planning activity
- Provides the Rover Operations team and the Science Team proper tools for the assessment of the vehicle, the on-board systems and payload status, the navigation capabilities, as well as for the assessment of the executed on board plan.
- Provides the Science Team with a tool able to support distributed operation supporting the science objectives identification to be considered for the next sol(s) operations, and a collaborative science activity plan building. Each science team should be able to prepare its own input to be integrated and approved in a consolidated science plan before inclusion in the overall Rover plan.
- Provides the Rover Operations Team with proper tools for the preparation of the required Rover Activity Plan (including rover navigation and mechanism/arms movement) based on the science provided plan and engineering needs and constraints, its simulation, verification and final uplink to the Rover. This is considered a critical activity because the rover will interact with an unknown environment. Thus it is necessary to react in a very short time (within the next uplink opportunity, around 8 hours) and adapt plan and activities to the actual encountered conditions, always assuring the vehicle safety at the maximum level in order to not risk a mission loss. As a consequence, advanced capabilities need to be provided to the operators in terms of planning development that take in consideration mission, environment and resource constraints, generating constraints and error free plan to be up-linked to the Rover. Particular care shall be given to the robotic elements (navigation and locomotion system, as well as the arm and drill system) that strongly interact with the Martian surface. Also for the Rover Operations Team, the tool shall support collaborative activities performed by the different engineers.

The identified tools will be also used for managing end-to-end simulation activities with the Rover HW in the loop, and when necessary, in the Mars Terrain Simulator.
The overall ROCS architecture is presented in figure 4. Note that at the figure does not show the external interfaces related to the remote operations by the scientist.

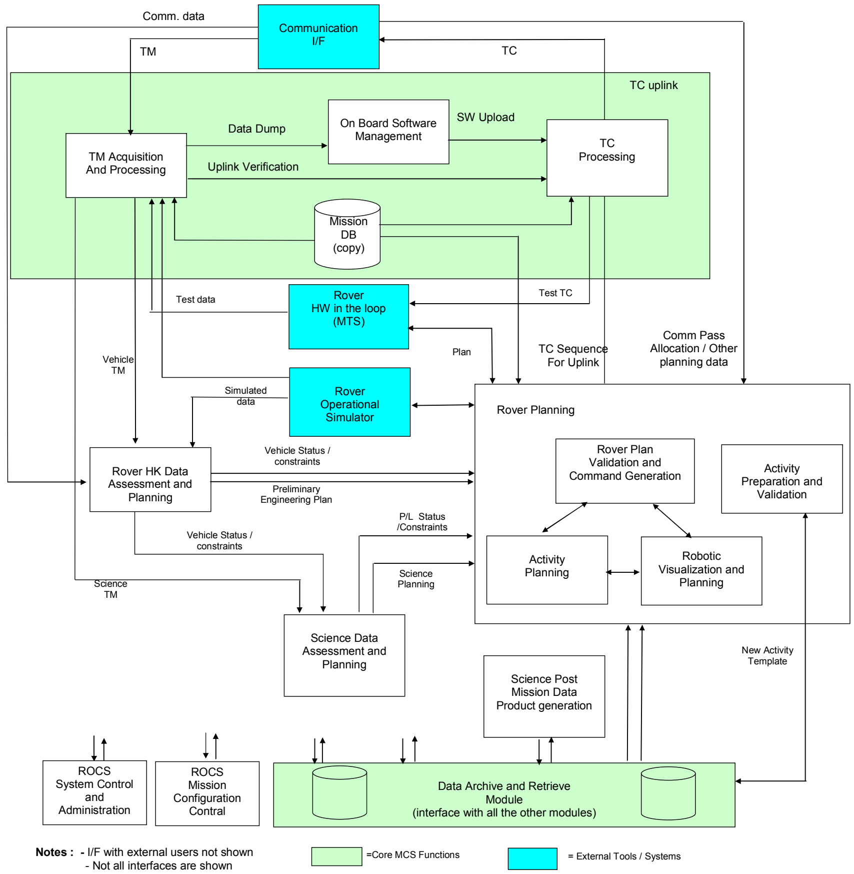

Fig. 4. Rover Operation Control system Architecture

From a functional point of view, the classification and breakdown of the ROCS system functions is the following:

- Core Mission Control System Functions
  - Telemetry (system and science) Data Acquisition and Processing
  - TC Processing
  - Rover OBSW Management and Configuration Control
- Data Analysis and Post Processing Functions
  - Rover HK Data Assessment
  - Science Data Analysis
  - Rover and science post mission data product generation
- Planning Functions
  - Engineering Activity Planning
  - Science Activity Planning
  - Rover Planning, including:
    - Activity planning
    - Robotic planning
    - Rover Plan Validation and Command Generation
    - Activity Preparation and Validation (supporting function)
- Rover Simulation and Modelling Function
  - Rover Simulators
  - Rover Models
- Common Functions
  - Data Archive and Retrieval (including data import/export and DB management)

In addition, two overall ROCS support function have to be considered:

- ROCS System Control and Administration functions supporting the ground operators in the overall ROCS HW and SW monitoring
- ROCS Mission Configuration, a function that allows the proper maintenance under configuration control of all the items that are critical for the mission execution (e.g. databases, models, algorithms, etc) and support the proper deployment in a controlled way in the mission environment.

The Mars Terrain Simulation (MTS) Facility

The MTS simulates the Mars Surface Terrain conditions aimed to replicate the Martian surface environment including:

- Adequate Martian Rock & Soil surface Physical Properties. Mandatory to properly set-up Lander petals opening, Rover egress, Rover locomotion motion and P/L operation capability, as final verification close out of the Lander and Rover performances tasks.
- Surface terrain obstacles/tilting platforms distribution representative of the Martian surface terrain
- Rocks shape & size, terrain composition and surface slopes representative of the actual Martian surface terrain
- Martian Rover Locomotion pattern/crossing distribution representative of the Mars surface journey with assurance of rehearsal Martian Locomotion operation
- Earth atmospheric Pressure (usage of anti g system for RM locomotion is advisable and/or an alternative solution be considered)

The overall MTS infrastructure is composed of the following elements:

- The “arena” where to simulate the Mars environment and Rover operations, Training, Education / Promotion and
- The control room;
- The laboratory where to prepare and manipulate the Rover;
- The terrains storage area;
- Hoisting and lifting equipment

In order to perform detailed troubleshooting, procedure / sequences testing and verification / validation, operation training, the ROCC will be equipped at least with one Rover model, with additional models under consideration.
The models will be provided with the necessary simulator sensor input as well as with any GSE necessary for their usage.
The Rover models and associated support equipment are considered part of the development phases, and delivered to the ROCC to be available for testing and simulations.

Infrastructure Support Systems

The Infrastructure Support Systems provide supporting operations capabilities to the ROCC necessary for mission operations, and includes:

- Operations Support Systems, that includes the necessary operations support capabilities like Voice Loops for operational communication among the ROCC operators and with external centers, Time Management for computer system synchronization and for display to the user of time information in different formats (UTC, Mars Time, Events Countdown, etc), Anomaly reporting and tracking system, Console log, Flight and Ground procedure management, Mission Database management, Rover Mission and System documentation archive, ROCC Operations Portal providing several capabilities to all ROCC user (local or remote) for easy access to above tools, capability for team organization and work management (schedule meeting, schedule of the tasks and monitoring of the evolution, etc.)
- Global Service, in particular the overall ROCC LAN, Office tools, Internet services (access, mail, web, ftp,. Etc)
- Infrastructure Service, i.e. the typical hosting facility services (space and furniture, power, air conditioning, access control, telephone service)

PRELIMINARY OPERATION CONCEPT

It is worth to recollect the distinctive features of ExoMars Rover mission to identify the guidelines defining the approach.
The baseline mission will last 180 sols and could be followed by an extension of additional 180 sols.

The mission has clear technology and scientific objectives to be achieved by a complex ensemble of payloads, with a strong interactions with the Rover Vehicle. The instruments of PPL need to be operated according to precise sequences and, despite implementation of some on-board autonomy capabilities, some "ground decision points" are defined at which the scientists will choose the following steps to be executed based on received TM data. These decision points strongly impact the vehicle activities in terms of locomotion (selected sites to visit), arm deployment, resource consumption.
Some of the instrument (notably the panorama-camera) outputs represent key element in defining the operations of the Rover. The Rover will move and operate in an "un-deterministic" environment with basic physical parameters changing quasi continuously according to motion of the rover itself, and due to daily and seasonal variations. The contact with the Rover by ground will happen via NASA relay orbiter only (see fig. 1.1) during limited slots occurring twice a day with characteristics (duration and data exchange) varying depending on the mission conditions (visibility of rover and relay satellites) as well as negotiation with communications responsible within NASA and ESA organizations. The results of preliminary evaluations made at system level to define the achievable telemetry seem "critical" in the sense that to receive the complete amount of data enabling operational decisions it will be necessary to limit the Rover and Pasteur Payload activities. Therefore, as Rover data reach the ROCC they must quickly be analyzed starting the process of evaluation and planning that will end with the sending of the Command (Activity Plan) to the rover for the execution of the next sol activities. The Activity Plan and Command Generation processes despite of being a critical and involving a substantial number of activities, specification, planning, scheduling and verification, that have to be performed in a very short time (less than 8 hours). The on-board Rover autonomy will allow only limited variation on the commanded activity plan as reaction to specific environmental conditions, availability of resources, and opportunities ensuring robust and reliable operation.

Therefore, the following guidelines can be identified:

- Allow, a strict interrelationship among the various teams (engineer and scientists) utilizing h/w and s/w tools enabling an optimum transfer of data (team definitions and tools) while avoiding confusion of roles and responsibilities;
- Enable implementation of different solutions coherent with the different phases of the rover life i.e. with their different objectives: mission success and mission exploitation (different solutions);
- Be fixed to a reasonable extent to be effective assuming a short time between data reception and sending of the telecommand (fixed schedule of events);
- Be flexible in order to adapt at changing conditions such as data availability, Rover operations phases (flexibility);
- Maximise the scientific exploitation of the mission starting from a limited amount of resources (optimisation of the science planning);

Ground operation timeline analysis

The current working assumption is to consider an approach similar to the initial NASA MER mission, in which both Rover engineer team and science team are working in an integrated way locally at the ROCC. Moreover, initial critical Rover operations are managed by the ground teams with a Mars time based schedule, synchronized with the two daily data downlink (one in the Mars night and the other in the Mars afternoon) that provide two reference points in terms of start and end of the ground activity for next sol planning and allowing fixed and repetitive ground process activities. Considering the criticality of working on Mars time schedule, the operations concept under study will take care of the best approach to move on an Earth based time schedule.
At the present time, considering the way in which the on-board planning is built (experiment cycle / measurement cycle, near-autonomous Rover operations concept) and the analysis about the communication between the Rover and ground, the following assumption related to the operations planning can be made:

- *Activity plan*: it is the flight plan that provide instruction and commands to the Rover
- *Tactical Plan*: it is related to the current experiment cycle sequences executed on board; it is the ground process that provides inputs/commands for the Rover after each data down-link and before the next communication link. It takes into account both Rover and payloads housekeeping and science data that could require multiple NRO passes and subsequent data merging at ROCC. Then the activity plan shall be surely updated at each "decision point", required to allow the completion of the next sequence when the Rover is "in wait" and its status is known, but it also can be updated daily if required by the assessment of the rover and payloads housekeeping data. Tactical plan can cover one or more sols activities.
- *Strategic Plan*: this is a long, multi-week, planning. It can be considered as the ground process to prepare the next experiments cycle. It incorporates negotiated support from all communications assets, keeps tactical activities

aligned with the mission objectives, track the status of mission objectives (e.g. number of target analyzed, distance traversed). Another function performed at the strategic level is team management and personnel scheduling. This activity is not impacted by the mission execution, but receives the input for long term planning. We assume that Rover active operations (including communication) last no more than 8 hours a day (TBC).

It is worth to highlight that, even if the ROCC will be able to support daily command uplink, this could not be always required. This statement is based on the assumption that the on-board software is able to manage autonomously (in nominal condition) segment of timeline between ground feedback. Thus planning / command uplink are nominally required at the end of an on board sequence. Moreover it is also expected that both the system and PPL will work with very high level commands thus not requiring large and complex command uplink list. This should occur only in the case of anomalies or unplanned behavior, where full control from ground is required.

Anyway, the ROCC operations timeline will be maintained on a daily basis, thus accommodating any required immediate re-planning activity.

- *Shifts schedule approach*: Team composition will guarantee 24 hours a day mission covering in a three shifts turn. Team composition will depend on the skill necessary to perform the specific activity requested by the operations process (e.g. telemetry processing, data assessment, planning, commands preparation and uplink).

  The profile of communication links available and the on-board Rover autonomy lead to a flexible concept of tactical plan with variable time allowed to define and update Rover activities. Then it is possible to schedule the shifts using both Earth and Mars time. Shifts are scheduled using local Mars time at least during the initial critical phase of the baseline mission. Use of Earth time could be implemented based on appropriate training and “Cross training” because team members should be able to trace a process from end to end, that is from uplink request to downlink data receipt, avoiding the needing to associate a specific type of skill and “corporate knowledge” to each shift.

DEVELOPMENT ACTIVITIES AND SOFTWARE SIMULATORS

Development and ROCC deliverable models

The ROCC development will follow a staggered approach implementing in each phase of the development cycle new functions and/or improvements of those already implemented. The objective is to use each version in an end-to-end simulation environment, that will include a Ground Segment Simulator (RGSS) (simulating the communication chain between the ROCC and the Rover), an high fidelity Rover software simulator and/or the physical models of the Rover to be operated within the simulator of the Mars terrain, improving the fidelity and reliability of the elements prior to the delivery of the final version of the integrated and tested ROCC

The Table 1.0 summarizes the deliveries of the ROCC along the project while the objectives supported by each ROCC delivery are summarized in the Table 2 reported hereafter.

Software simulators utilization

The utilization of software simulators will be applied all over phases Advanced C/D C, D and E for:

- Support design, development, configuration and verification (Advanced C/D, C, D): trade off implementation options and sustainable mission operations. Derive, evaluate and, successively, test specifications, design and configuration of system elements;
- Procedures and training (D, E1, E2): define rover and joint operation procedures within ROCC and ESOC. ROCC personnel familiarization, training and qualification;
- Rover data assessment (E4): evaluate, assess and calibrate HK and scientific data downloaded from Rover during surface operations;
- Rover Planning (E4): define and preliminary evaluate partial and complete Rover Activity Plans;
- Validate activity plans (E4): validation of the Rover Activity Plans before command uplink and execution;
- Anomalies analysis: evaluate contingencies and anomalies at planning and subsystem levels. Define recovery strategies.

The simulators need to be developed in a flexible and highly modular way to allow follow up of the evolution of mission needs and system design/development and the upgrading and replacement of each component as soon as more detailed and complete models become available.

The ROCC overall simulator system includes three integrated software: the Rover Functional (ROSEX) and, in Phase C/D, Operational Simulator provided by TAS-I, the ROCC Ground Segment Simulator (RGSS) and the ROCC Operations Control System (this is not a simulator but it is the real implementation of the ROCS functions to be exercised) . All these three sub-systems provide or will be connected with simulators to be used with the scopes explained above during next mission phases

Table 1. ROCC development and deliveries

Delivery	Date
ROCC BB 1 prototype	December 2007
ROCC BB 2 prototype	December 2008
ROCC BB 3 prototype	March 2009
ROCC-1	May 2010
ROCC-2 (and possible enhancements)	September 2010
	February 2011
	July 2011
ROCC-3 (and possible enhancements)	December 2011
	June 2012
ROCC-4 (and possible enhancements)	October 2012
	January 2013 (TBC)

Table 2. Objectives supported by ROCC deliveries

ROCC Delivery	Objective
ROCC BB 1 prototype (Phase B1 Bridging)	ROCC prototyping activities on planning concept. Prototype for interfacing Rover Functional Simulator 1
ROCC BB 2 prototype (Phase B2)	Prototype for interfacing Rover Functional Simulator 2 (SCOS-2000 compatible interfaces TBC) and possibly with the Rover Chassis & Locomotion & Navigation BB The prototype shall allow initial definition of some internal interfaces, of a rough operations approach, in turn helping in the full specification of the system requirements.
ROCC BB 3 prototype (Phase B2)	Evolution of the previous version of the ROCC BB2 Prototype taking into account the feedbacks originated by interface verification between ROCC BB2 Prototype and Rover Functional Simulator 2. This prototype interfaces with Rover Functional Simulator 3 (and possibly with the Rover Chassis & Locomotion & Navigation BB) The prototype shall allow the conclusion of Phase B2 activities related to the definition of some internal interfaces
ROCC-1 (Phase C/D)	To be used with the Rover Operational Simulator 1 (and possibly with the Rover Chassis & Locomotion & Navigation BB) External interfaces start being defined. Refinement of internal interfaces and operations approach. Further assessment and refinement of requirements.
ROCC-2 (Phase C/D)	The ROCC-2 will be used with the Rover Operational Simulator 2 (and possibly with the Rover Chassis & Locomotion & Navigation BB) Main external interfaces, expected to be defined and stable, are supported by this delivery Overall operations approach defined in detail is supported by this delivery.

ROCC Delivery	Objective
	The update of ROCC-2 will be used for the final RRIT Include also delivery of the ROCC Ground Communication Infrastructure.
	The final update of ROCC-2 will be used for SVT-0. Include also delivery of the ROCC Ground Communication Infrastructure. Major critical functionalities are implemented to support first SVT
ROCC-3 (Phase C/D)	The ROCC-3 will be used for testing with Rover GTM (also named RM FPM) Final external interfaces implemented. First realistic operational environment exercised with this delivery in SVT 1 using the RM FPM . Most critical functions have been implemented.
	The update of ROCC-3 will be used for SVT-2 using the Rover Module FPM (tbc). Refinement after the SVT1 execution of the implemented most critical functions.
ROCC-4 (Phase C/D)	Final delivery supporting the SVT3 All modules implemented at full level of functionality. All facility ready.
	Final upgrading of ROCC-4 to implement the outcomes of the SVT3

Rover Simulator (ROSEX)

The Rover Simulator ROSEX will be developed following a modular architecture, allowing:

- incremental approach: from trivial simulation, at the begin of the development, to more detailed simulation of each subsystem when the functional model will be refined during the ExoMars phase project;
- module replacement: the possibility to include the functional simulator of subsystem when they will be provided by the contractor;
- reuse of existing model: the possibility to reuse and tailor existing space subsystem model (for example, the orbiter satellite model).

The functional architecture of Rover Module Simulators is composed of three main functions:

- Rover Module, simulated at unit level, considering as units the parts that are seen as a single component from the point of view of the software; examples of units are: one camera, a set of accelerometers, a wheel control system, a battery, etc.
- Environment of the Rover that interacts with the rover: examples of this are the shape of the terrain, day/night, sun illumination, etc.
- MMI: a set of 3D Tools needed by the operator to understand visually kinematics of the rover and its moving part position and attitude. The visualization tools are a key aspect to evaluate the robotic arm actuations.

The ROSEX Simulator will be developed using an incremental approach: starting form the first basic issue to the following issues which will be enriched in terms of functional model refinement. Basic versions of all models, implementing only the main functionalities, will be realized and replaced by sub-contractors modules as soon as they will be ready.

ROCC Ground Segment Simulator (RGSS)

The RGSS provides a simulation of the communication chain between the ROCC and the ExoMars Rover, at the present stage via the NRO. The RGSS shall be designed as an evolving system, providing in its initial version (prototype version) the tools required for analysis of the communication scenarios with the Rover (resource analysis, etc.), validation of the interface between the RGSS Rover and the Rover functional simulator, and validation of the interface between the ROCC and the ground segment during the ROCC development.
The simulator shall be extended at a later stage to provide more accurate link quality modeling, and to replace some of its simplified internal components by more sophisticated external simulators (Rover Simulator, etc.), in order to provide a level of simulation appropriate for mission preparation, staff training, and command sequence validation.

ROCC Operation Control System (ROCS)

The ROCC Operations Control System is composed by:

- TM acquisition and Processing module. This module receives the TM packets and processes them to the appropriate level to generate products to be further analysed by the engineering and science teams.
- Rover HK Data Assessment and Planning module. This module allows the Rover engineering team to analyse the Rover system status, specify a Communications and Activities Skeleton Plan, specifying all mandatory Rover engineering activities, provide a Preliminary Engineering Plan with engineering activities that are not mandatory, validate the engineering activities by making use of the simulator.
- Science Data Assessment and Planner module. This module provides two basic capabilities: science products analysis and science activities editing.
- The Rover Planning contains the modules for the uplink part of the Tactical Operations Process: Activity Planning, Activity Plan Validation, Command Generation and Robotic Visualisation and Planning.
- Activity Preparation and Validation module for the specification and testing of Activities to be incorporated to the Activity Template Library
- TC Uplink that covers the processing and ancillary functionality for uplink process of telecommands and activities.
- Simulator module. The Rover Planning, Rover HK Data Assessment and Planner modules use the simulator for different purposes. The simulator is used by the different components for verification purposes.
- On-board SW Maintenance module performs the operations related to the on-board software images, patches and configuration control

- Post-Mission Science Product Generation module. It integrates different type of data with the required format to be exported to the SDAD.

Finally a set of Supporting Functionalities: Data Archive and Retrieve, System Control and Administration and an additional external Communications Interface.

ROCS simulation capability during the Rover surface mission will be focused in two levels:

- Quick Response Simulations: performed by internal ROCS tools and by using also a 3D robotic visualization capability, they are useful for preliminary evaluations of resource availability, kinematics and tasks sequence.
- High Fidelity Simulations: performed externally by ROSEX, their output are visualized by ROCS and used for activity plan construction and validation.

ROCC Integrated Simulator System Breakdown

The simulators interfaces will be implemented by maintaining the same approach adopted for the mission configuration. Particular attention will be paid for the ROCS interface with RGSS which will reproduce the operational interfaces. The overall ROCC Integrated Simulator System breakdown is shown in Fig. 5.

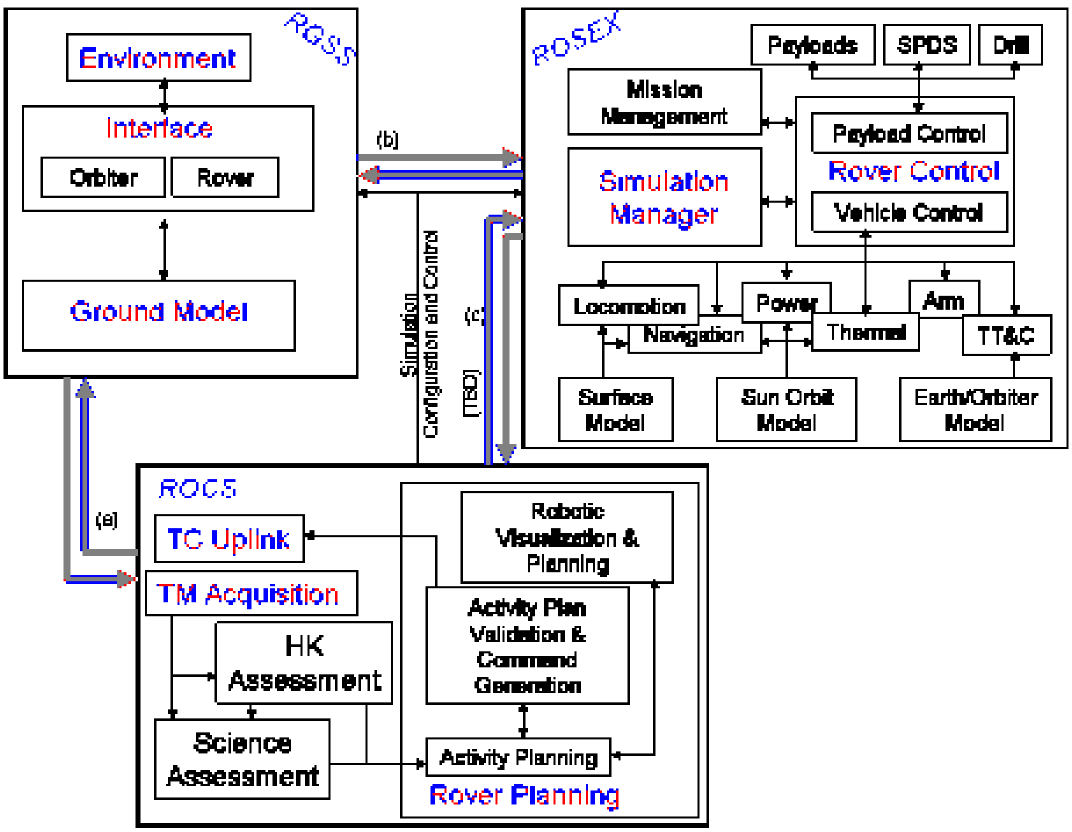

Fig. 5: Overall ROCC Simulator general architecture

Simulators utilization and simulations cases

The main simulations cases and relative ROCS/RGSS/ROSEX connection are listed below:

- ROCC architecture design: simulations made autonomously by RGSS, ROCS plus ROSEX or with the full ROCS/RGSS/ROSEX chain during Advanced Phase C/D and Phase C/D. They can be used to analyze the communication scenario and support subsystems designs trade-off.
- Test and training: full simulations with ROCS, RGSS and ROSEX and by using also MTS (which will take the ROSEX place) will be essential during procedure definition, tests and training. Real ground segment subsystems

could replace some of the RGSS modules. Injection of controlled failures during simulations of the rover command execution will be considered in order to test and certificate ROCC operators.

- Data assessment and planning: during Rover surface mission engineers and scientists will have to assess rover data and plan activities for next sols. Preliminary or partial simulations performed by internal ROCS tools, ROCS/ROSEX or ROCS/RGSS/ROSEX will allow operators to verify and interpret data and make a first selection of the possible next rover actions.
- Activity plan validation: after formal verification (if present) the complete rover activity plan will be validated by deep and complete simulations, for this purpose ROCS will use ROSEX or RGSS/ROSEX .

DEVELOPMENT ACTIVITIES AND PHYSICAL SIMULATORS

The physical simulators involved in the development activities for the ROCC are essentially the Rover Ground Testing Model (GTM) and Mars Terrain Simulator**.** The development activity will be carried out with the performance of a group of verification testing on the Mars Terrain Simulator with the Rover GTM including Martian surface Egress verification (nominal and off nominal cases), Martian surface Locomotion operation (Rover attitude and position determination, Rover mobility, nominal and off nominal cases) and Martian surface Navigation Operation (trajectory determination and control, placement of the Rover at a specific target position and orientation for in situ examination of rocks and soil, location identification for Drilling and Drilling/Sampling task operations).

CONCLUSIONS

The ROCC is an important part of the Ground Operation in particular for the support to the initial Surface Operations Phase and for the performance of the full Rover commanding and controlling (including science operations).
As reported in the description, the ROCC follows a staggered development approach based on software models and physical models. The progressive improvement of the software models (composed by ROCS functions, RGSS simulator and RGCI simulator) grouped in the ROCC simulator permit the risk limitation during the real operation phase. Similarly the utilization of the physical models (MTS and Rover models) will increase the confidence in this area and will prepare the team for the validation of the operations together with the potential support to troubleshooting during the operational phase.