EXOMARS ROSALIND FRANKLIN ROVER OPERATIONS CONTROL CENTRE PREPARATION

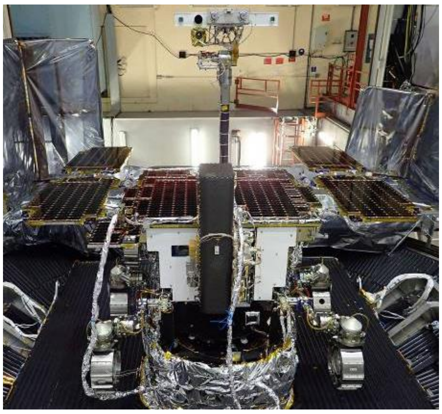
Luc Joudrier (1), Andrea Merlo (2), Diego Bussi (3)

(1) European Space Agency ESA/ESTEC, P.O Box 299, NL-2200AG Noordwijk, Netherlands
Email: Luc.Joudrier@esa.int
(2) Thales Alenia Space Italy, Strada Antica di Collegno 253, Turin, Italy
Email: name.surname@thalesalenisaspace.com
(3) ALTEC, Aerospace Logistic Technology Engineering Company, Corso Marche 79, 10146 Torino, Italy
Email: name.surname@altecspace.it
(3)

ABSTRACT

The development of the Rosalind Franklin rover and its control centre – The ROCC – Rover Operations Control Centre has been completed. This paper discusses the sequence of functional rover Integrated System Tests (ISTs) performed by the rover system prime manufacturer (TAS-I), the operational rover System Verification Tests (SVTs) performed by the ROCC (ALTEC), and some of the main functions of the Rosalind Franklin rover. Many of these tests; such as driving on rough terrain, deep drilling and sampling, as well as analysing a sample with instruments supporting the search for signs of life; were performed on the twin rover, Amalia, (the Ground Test Model or GTM).) on the Mars Terrain Simulator (MTS) at ROCC.
The results of these tests will enable the System Operations Validation Tests (SOVTs) to check the adequacy of the ROCC tools, functions, and ground processes supporting surface science exploration. The completion of these SOVTs is the starting step for the operators certification activities.
Due to the war in Ukraine and the suspension of the 2022 launch, the preparation of a new mission to land Rosalind Franklin on Mars has begun and the maintenance of the Rover and the ROCC facilities and competences is being studied.

1. BACKGROUND & ACKNOWLEDGEMENTS



Picture 1: Rosalind Franklin Rover (Proto-Flight Model-PFM) during Environmental testing at Airbus Toulouse (credit Airbus)

This paper assumes that the reader is familiar with the ExoMars Rosalind Franklin rover search for signs of life mission, with the rover main subsystems, and with its nine Pasteur Payload instruments. Please refer to [1] as necessary.

Information about the ROCC and its facilities, such as the Mars Terrain Simulator, designed to support functional testing and operations validation, can be found respectively in [6], [2] and [3].

The work reported here is the result of the efforts of the industrial team who built the rover models, Rosalind Franklin and Amalia, and the ROCC systems, as well as the payload, science, and ESA project teams.

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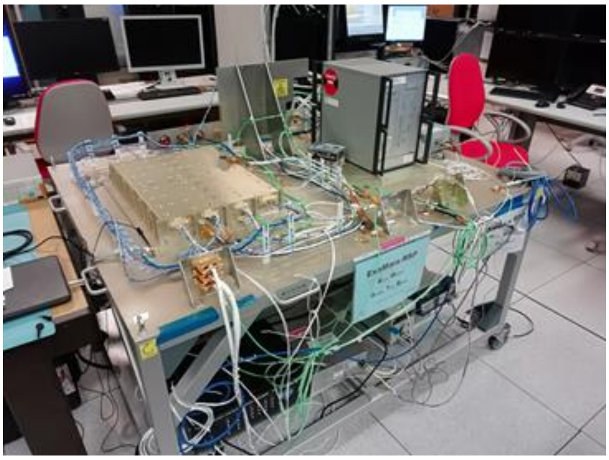
2. Rover ISTs & SVTs

The rover ISTs are a prerequisite for conducting the SVTs at the ROCC. These ISTs are functional tests to verify all rover functions. They were performed either on the proto-flight model (PFM), Rosalind Franklin, (see picture 1) or on the GTM, Amalia (see picture 3) using the rover's final SW. This is important because the checks previously carried out during PFM environmental testing were conducted with low level commands only, as the advanced commanding layers, such as the mobility software and the Mission Management Software (MMS), were still under development at the time. The ROCC SVT-2 was executed in January 2020 on Rosalind Franklin (PFM), at the end of environmental testing, when the PFM was still in Toulouse. Only simple cruise checks were executed, which demonstrated that the ROCC was already able to command and control the rover.



Picture 2: Rover Module Avionics Test Bench (ATB) in TAS-I – Turin

Usually, ISTs are prepared first on the Numerical Software Verification Facilities (NSVF) and then on the avionics test bench (ATB) or engineering test model (ETM), then run on the Amalia rover model (GTM), and thereafter on the Rosalind Franklin rover (PFM). However, a number of high-level activities cannot run on the PFM, such as advanced mobility or actual drilling, because of planetary protection issues. Hence, the Amalia rover was essential to demonstrate those capabilities.

ISTs require the installation of the on-board SW version which implements the functions to be tested during the different ISTs. Because the SW development teams deliver the on-board SW - after successful regression testing - in stages, ISTs have been performed in stages as well.Each time an IST was completed, an SVT was executed by the ROCC team to confirm that rover functionalities implemented on-board could be commanded and controlled from the ROCC.

The first two SVTs, SVT-0 and SVT-1a were conducted in December 2018 and June 2019, respectively on the ATB. They confirmed that the ROCC could send simple commands to the rover’s on-board computer (OBC) and receive rover-generated telemetry.

One of the challenges of these high-level functional tests with Amalia was to have available on time the required validated onboard SW version and adequate functional rover hardware. Since the Amalia rover is not a full engineering qualification model (EQM) at system level, but a reconstruction of a rover system based on subsystems QMs and sometime EMs, this resulted in a number of limitations inherited from each units development and dependency with the completion of the software qualification run on the ETM. For example, the Solar Array Assembly (SAA) and the mast and its cameras were integrated on Amalia from the ETM bench. It was later understood that the co-processor (EM), Actuator Drive Electronic (ADE) units (EM) and power control and distribution equipment (PCDE) units (EM) were inadequate to support the full imaging acquisition by the rover cameras or to fully command the motors in closed loop, and required the (E)QMs in use in the ETM for software qualification at rover developer level (Airbus UK). A refurbishment of Amalia was then scheduled prior to be in position to run the remaining ISTs. This then imposed reordering the initial IST plan (see picture 5) into the final one (see picture 6).

Picture 3 : Amalia Rover (Ground Test Model – GTM) in TAS-I cleanroom – in Turin

The first ISTs took place in the TAS-I clean room. They covered the activities we would perform in cruise, *i.e.* the cruise check-out. Then the Post Landing To Egress (PLTE) phase was rehearsed with the rover on its stand (*i.e.* wheel deploying and turning in the air). Activities related to drill deployment, drilling and sample delivery concluded this set of ISTs. Of course, relevant instruments like PanCam, ADRON, ISEM and CLUPI were included in these tests. They were the first ones to use meaningful Activity Plans (APs). Please refer to [2], [4] for more information about the ExoMars Rover and its control concepts. The SVT-1b2 tested similar activities, but with commands prepared by the ROCC team using the ground tools and procedures.

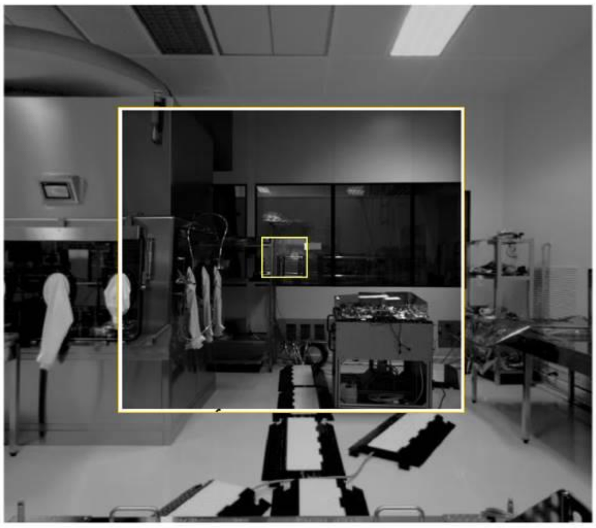


Figure 4: Picture of superimposed right NavCam, PanCam WAC and PanCam HRC images showing their respective relative field of views during IST in the TAS-I cleanroom.

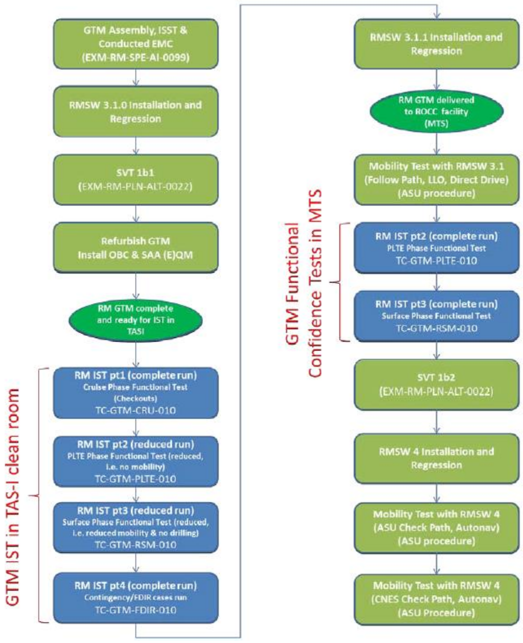


Figure 5: Initial Planning of ISTs with Amalia

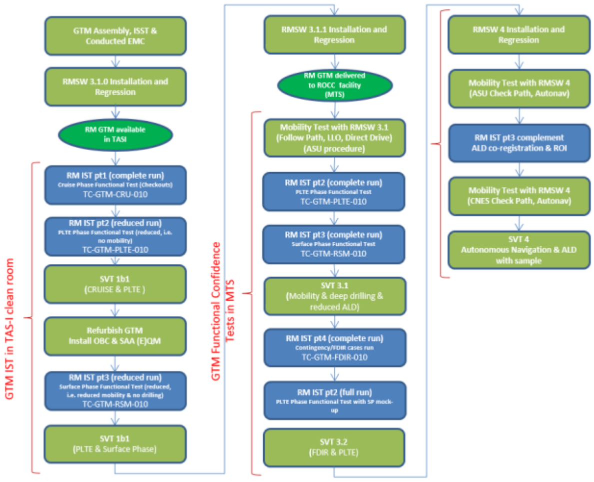


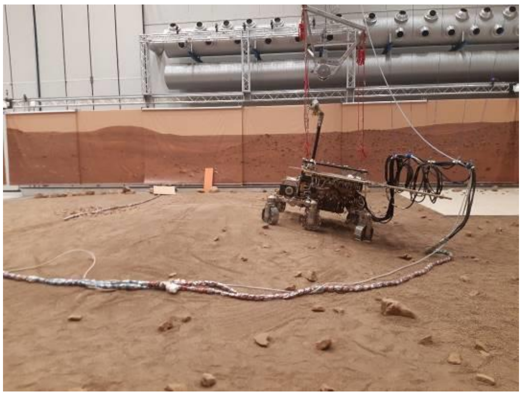
Figure 6: Actual execution of ISTs & ROCC SVTs with Amalia

The second batch of ISTs took place after the rover was refurbished and transferred to the Mars Terrain Simulator (MTS) at ROCC, in ALTEC, Turin (IT) [3]. The MTS is a terrain specifically prepared to support the testing of the Amalia rover's mobility and drilling capabilities. Since Rosalind Franklin is not designed to sustain Earth's 1g environment, its ~300kg twin, Amalia, requires a weight offloading system to adjust to the equivalent martian gravity: the so-called Rover Unloading Device (RUD) see picture 7.

Picture 7 Amalia Rover with the Rover Unloading Device (RUD) on the Mars Terrain Simulator (MTS)

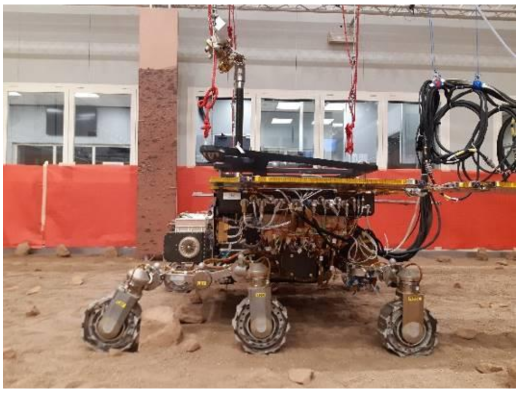
The RUD is a pneumatic jack that provides the necessary adjustable pull force coupled to an articulated frame ensuring alignment with the rover's centre of gravity, even in tilted orientations. The rover is directly attached to a very rigid plate where three strings link to the above articulated frame. A number of sensors allow monitoring the RUD's attitude, as well as the pressure in the pneumatic jack. In addition, the RUD is attached to a crane that is manually controlled by an operator. The velocity of the crane matches the slow rover pace (nominal 40m/h) to allow the operator to follow easily, without creating any noticeable drag. Finally, the RUD is also holding a balanced beam to support at the rear, and for a few meters only, the rover's umbilical that looks like a long tail. Note that an operator is necessary to manage the umbilical every few meters.

With an early mobility test, TAS-I confirmed the basic operations of the GTM with the RUD. They exercised direct drives, point turns, and also the guidance, navigation, and control (GNC) mode called LLO (Locomotion & Localisation Only) that uses visual localisation "VisLoc" (ref to [13]). Testing continued with the first full closed loop mobility - remotely supported by the rover manufacturer Airbus UK, whose engineers could not travel due to COVID rules. Tests following a path (trajectory control with on-board relative localisation) on various types of terrains were successfully executed. We improved the visual localisation response by hiding repetitive patterns with rocks near the terrain border walls, covering featureless walls on one side and by managing better the umbilical.

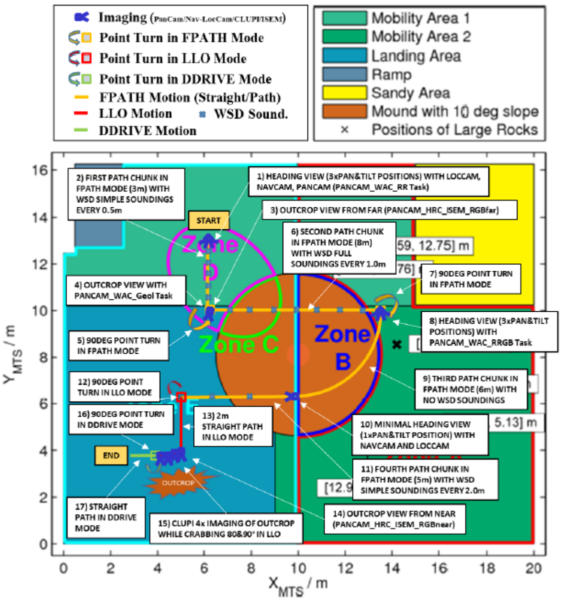


Picture 8: Amalia rover during point turning over the hill (10deg slope)

Another test performed was the automatic standing required in case the deployment actuators would back drive during the last 2.3m segment of locomotion. This functionality was introduced when the wheel-walking functionality was added (see picture 27). It requires the deployment actuators to move from 0deg (vertical) to 30deg down to the end stop (loose latch concept). In extreme situations, it was identified that some back-driving of the deployment actuators could occur – hence the need for an auto-stand-up function to put the rover in a "straight" position that maximizes its ground clearance.



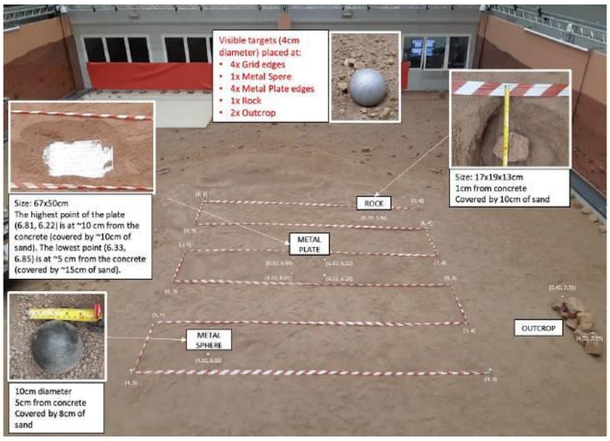
Picture 9: Amalia rover performing auto-stand-up against a rock.



Picture 10: graphical summary of the activities performed by Amalia to rehearse survey instruments combined with mobility.

With gained confidence over the trajectory control performances of the rover, TAS-I proceeded with functional testing of the instruments, combined with the mobility: the MTS was divided into several zones with various types of rocks and slopes (the hill in the middle of the terrain was kept from previous mobility confidence tests) – see picture 10. For each leg of the trajectory, different mobility commands were used, with the WISDOM ground penetrating radar being triggered at various distances. A NavCam panorama was taken and, at each stop, the survey instruments were triggered: PanCam Wide Angle Cameras (WAC) and PanCam High Resolution Camera (HRC) combined with the IR spectrometer ISEM. Finally, a close-up imager CLUPI mosaic of an outcrop was acquired using the special rover crabbing motion. The overall sequence rehearsed the geologic survey phase that is required once the rover reaches a new site.

The mobility system was also used to precisely place the WISDOM ground penetrating radar every 10cm over a grid of 5m by 5m (see picture 11). Such grid allows the scientists to reconstruct in 3D the subsurface and to identify subsurface layers that could be worth sampling with the rover drill. Since the MTS terrain has only about 20cm depth of soil, metal reflecting items were buried in order to trigger the WISDOM radar and close the loop between the sensed and actual detection locations.



Picture 11: preparation of the WISDOM Grid with metal items buried at specific places with positions well recorded – thanks to the target tracking of the MTS facilities. A rock was also specifically buried for later drilling.

Picture 12: Drilled rock buried in the MTS terrain that allowed to de-risk the deep drilling to be performed in the drilling facility.

Deep drilling is one of the special abilities of the Rosalind Franklin rover mission. It is needed to access material preserved from the ravages of ionising radiation, in the hope that they may hold clues to the possible past presence of microorganisms. The mission’s landing site, Oxia Planum, has a geology dominated by the presence of ancient clays, sedimentary deposits that are typically form by the aqueous alteration of volcanic particles. These clays are interesting because they indicate the long-presence of liquid water and because they also can trap organic molecules very effectively. The deep drilling IST was therefore an important moment in the functional validation of the system.

For this, ROCC MTS has a special facility with a well that can be filled with layers of materials (see picture 19) and even tilted to test extreme drilling conditions (see picture 13).

Picture 13: ROCC MTS Drilling facility with well tilted to 8deg and Rover suspended on the RUD on top of the plateform.

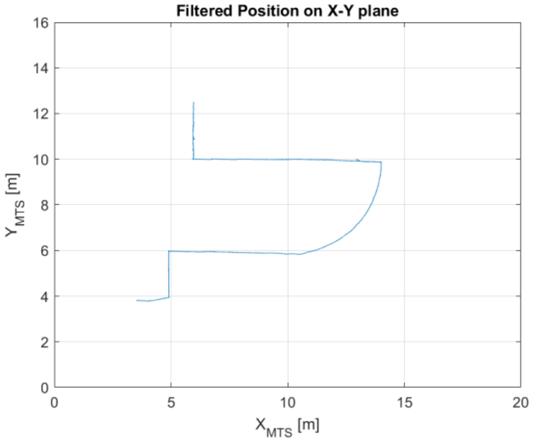
Picture 14: Amalia Rover on the drilling platform facility with drill deployed.

The drilling with four rods was executed, commanding the Ma_MISS IR instrument at various depths. The drill successfully acquired a sample from the rock buried in the well at 1.7m depth and delivered it to the core sample transport mechanism (CSTM), a sort of hand that extends from the front of the rover to receive a sample from the drill and transport it to the analytical laboratory drawer (ALD) in the rover's body.

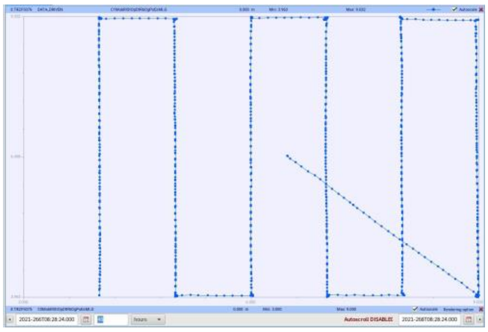
Picture 15: Drilling on-going with drill fines accumulating into a cone of material that could be imaged by the PanCam Rover Inspection Mirror (RIM) and CLUPI.

Picture 16: Sample delivered to the CSTM was also imaged by CLUPI and PanCam HRC imagers as foreseen by the scientists to happen during the mission.

At this stage, the large part of the IST campaign was successfully achieved. The ROCC SVT3.1 could then be performed re-using parts of the IST pre-tested sequences, but generated this time, with the ROCC tools and commanded from the ROCC itself instead of a step by step commanding from the AIT Team. Of course, telemetry and data post-processing were also the focus to confirm ground observability capabilities. For the scientific instruments, measurements of calibration targets were included where necessary to allow representative post processing by the science teams. The instruments teams were involved in the preparation of the reported IST and SVT tests, so that useful and representative measurements could contribute to their mission preparation.



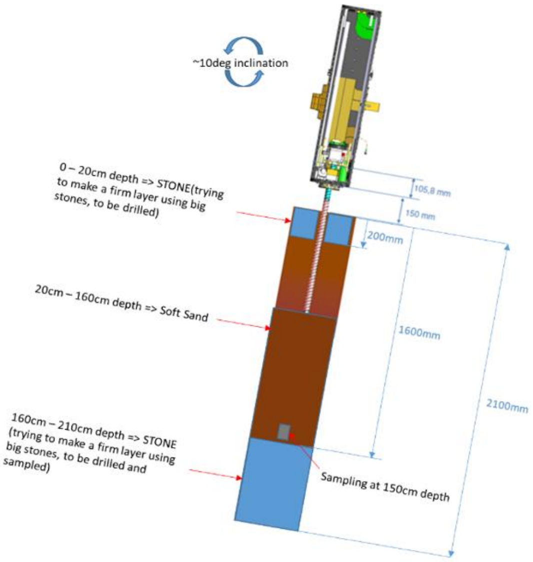
Picture 17: Relative localisation plotted by the ROCC of the rover survey trajectory ref to picture 10.



Picture 18: Relative localisation plotted by the ROCC of the WISDOM grid ref to picture 11. The trajectory toward the centre of the grid represents the rover placement for drilling.

In particular, post-processing of the science data using developed pipelines, including their decompression and generation of raw data products to the archive-format PDS4 was achieved. Examples are provided below and were key to the ROCC Readiness Review, which output was needed to the overall ESA System Qualification and Flight Acceptance review.

Picture 20: two holes in the rock from IST and SVT.



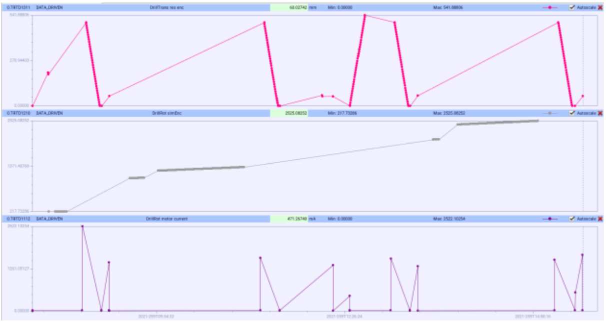
Picture 19: drill well configuration for the SVT.

Deep drilling in the same hole of the IST was performed as part of the SVT. This was initially thought to be the easiest without needing to displace the rover. However, some misalignment induced by mounting and unmounting a mechanical clamp to remove a large backlash on the drill placement mechanism created unexpected difficulties, similar to what everyone can experience drilling at home in an overlapping hole. Especially, the fine motion necessary for Ma_MISS measurements were failing to converge. These difficulties were finally overcome by re-tuning some thresholds. This experience with the EQM drill mechanisms, which has endured all the qualification campaign, gave a glimpse of the type of re-tuning that might be necessary toward the end of the mission. The drill positioner backlash was known and foreseen to be refurbished.

The capabilities to perform the vertical survey, *i.e.* to sample in the same hole at depths 50cm, 100cm, 150cm and 200cm, were also tested as the drill rods were retracted each time and the hole was re-entered without any difficulties. These tests were executed over several consecutive days like it is foreseen on Mars.

During drilling, it was interesting to monitor the rover's vibrations and movements, which is fitted with flexible wheels. Logically, when the drill was reaching harder material, the rover was slightly raising and tilting up, exercising extra force on the drill.

Picture 22: ROCC Main Control Room during SVT



Picture 21: example of TM plots at ROCC showing the rod motion and main internal activities during one of the drilling sols (drill rate is about 50cm per sol). This confirmed ROCC capabilities monitor the drilling activities.

In the meantime, an IST focusing on the ALD was performed as a continuation of the deep-drilling and sampling ISTs. In the Amalia rover, the ALD EQM has limited functionalities for the MOMA instrument, but the MicrOmega and RLS instruments are fully functional. During this IST that rehearsed operations without injecting a sample, a number of necessary software updates were identified that would require later retest.

The following important IST/SVT campaign was to cover the Fault Detection, Isolation and Recovery (FDIR) mechanisms and to rerun the PLTE phase using the lander mock-up with the rover actually driving down the ramps using the fully integrated Amalia. Note that a very large deployment and egress qualification campaign had been performed already with the LVM (Locomotion Verification Model). The LVM mobility system was then "transferred" to the Amalia rover. The purpose of this IST/SVT was to run an operationally realistic sequence allowing to acquire relevant situational awareness to confirm the data volumes for downloading at the end of each PLTE sol. This test validated the concept of egressing (*i.e.* driving off the ramps) in multiple steps that could be used in case the egress situation was more difficult than the one qualified.

The only difference in the nominal operational sequence was that both sides of the solar arrays had been deployed at the beginning without the RUD, instead of only the right side. Then the RUD was attached for rover mobility system deployment.

The figures 23, 25, 26 show the sequence of front egress. A similar test was performed with the rover egressing backwards.

Figure 23: initial configuration at landing after ramps deployment (only the front ramps inclined of 20deg with flat floor are available on the landing mock-up)

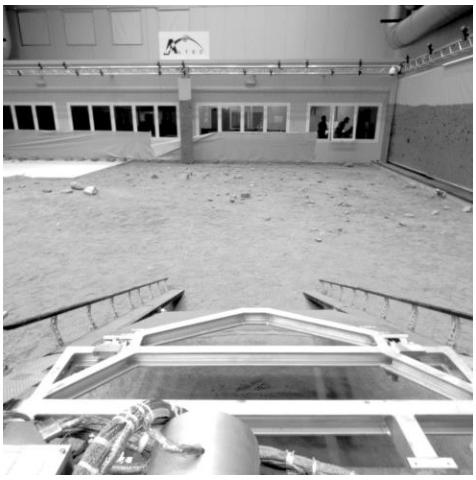
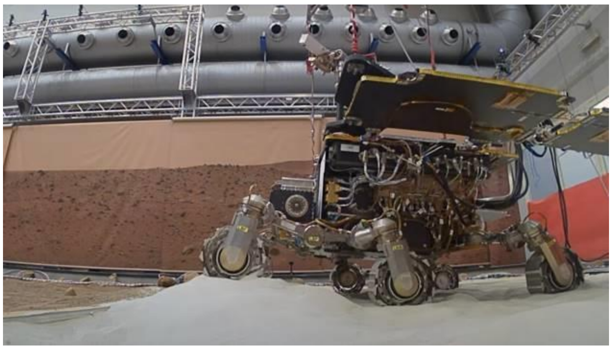


Figure 24: LocCam image of the deployed ramps

Figure 25: Rover configuration after solar arrays deployments and mobility deployment

Figure 26: Rover configuration at the end of the ramps

In addition, the wheel walking functionality was also tested (picture 27). Wheel walking makes use of the deployment actuators in the 30deg actuation range to move step by step, in a coordinated way, with wheel rotation on all six legs – see video published on ESA website [7]. This provides ultimate mobility capabilities, although it is very slow (2m in 20 minutes). It is key to escape from a sand trap or to climb a steep sandy slope.



Picture 27: Rover escaping a sand trap with wheel walking functionality

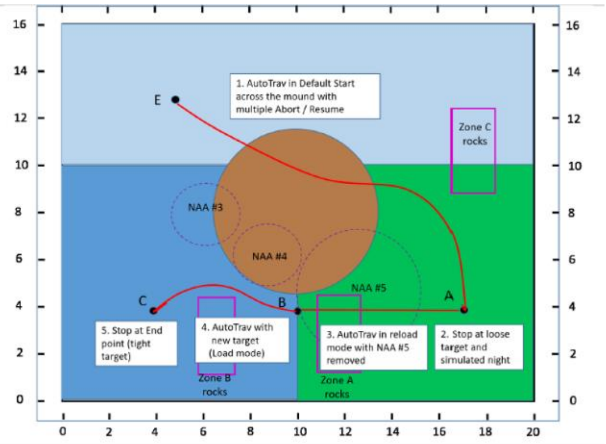
For what concern FDIR, all the types of anomalies and failures were triggered. ROCC operators analysed each situation from the telemetry and successfully commanded the associated recovery. That activity completed the ROCC SVT3.2 with Amalia.

In the meantime, TAS-I has been using Amalia for investigating issues and preparing activities on the PFM. Some testing of the Autonomous Navigation SW by Airbus UK was also successfully performed, clearing the way for uploading the final flight SW to the PFM Rosalind Franklin.

This led to the execution of the ROCC SVT5 on the PFM. The foreseen activities of rover check-out during cruise were successfully executed, as well as communication using the rover UHF system, providing good confidence in ROCC capabilities before start of the launch campaign.

TAS-I continued to test ALD activities both on the Amalia and Rosalind Franklin rovers. In particular, the co-registration between the MicrOmega and RLS instruments, that is fundamental for enabling the so-called combined science. After crushing the ingested sample, dosing the resulting particulate matter to the ALD refillable container, and imaging it with MicrOmega, a programme developed by MicrOmega team, is used to analyse IR absorption bands at every pixel. This is used to identify regions of interest for the instruments with lasers to interrogate—RLS and MOMA laser desorption mass spectrometer (LDMS). Such on-board autonomy is unique to this mission, and extremely powerful scientifically. It allows to identify and investigate the most promising mineral grains for mineralogy and organic chemistry composition. By using all three instruments on the sample, the team can acquire important information for guiding more detailed probing on the following sols, leading possibly to the decision of filling an oven (consumable !) and using the MOMA gas chromatograph mass spectrometer (GCMS) instrument.

The IST/SVT-4, being prepared at the time of writing, will complete the functional validation campaign. It will cover ALD activities, such as crushing the sample (the one already acquired during the previous IST–see image 16). It will, in particular, demonstrate the autonomous navigation capabilities of the two solutions available: one developed by Airbus UK and the other by CNES.



Picture 28: example of test with CNES Autonomous Navigation. Non Allowed Areas (NAA) can be set by the ground for the rover on-board planner to avoid these areas whether they are navigatble or not.

Picture 29: Amalia arriving to the target C running CNES Autonomous Navigation [14] during the confidence testing prior to SVT-4.

ROCC and rover engineers were involved also in a number of specific tests aiming to validate:

- The interfaces of the ROCC with ESOC, which controls the overall mission until successful rover egress and coordinates data relay support from ESA and NASA orbiters
- Rover interactions with the Surface Platform during cruise and PLTE as part of the ESOC lead SVTs jointly performed by ESOC and ROCC
- End-to-End communication capabilities throughout the involved control centres, orbiters and both spacecraft during the different mission phases.

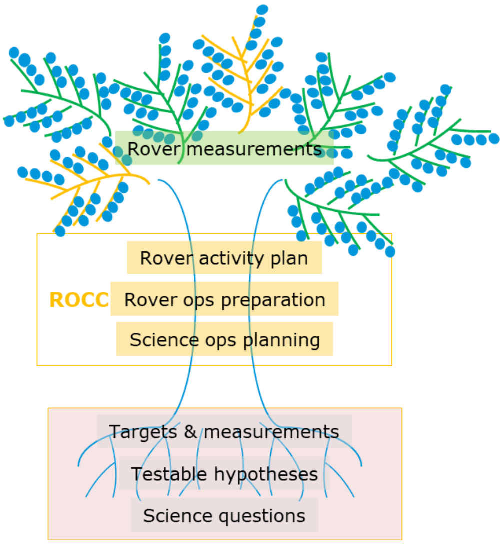
The necessity of solving hardware or software anomalies discovered during testing required some re-planning, leading to splitting the ROCC SVTs to be able to progress also with the operational preparation. The excellent collaborative spirit at ROCC between Thales Alenia and ALTEC teams allowed to gain time and even perform some IST activities together with the SVTs.

3. ROCC operational processes

While SVTs validated the capabilities to command and control and retrieve telemetry, the organisation of the ground operations for data post processing and planning of Activity Plans (APs) was another important aspect to consider. It involves of course the science team who defines, with the support of the control team, the scientific measurements to be executed on the surface.

Conceptually, the operations preparation can be compared to a tree (see picture 30) with the roots representing the scientific hypothesis that the science team aims to study – search for traces of past life is the clear objective of the mission, but such high level quest can be decomposed in a set of multiple criteria that can be scored – see [1] and [9].

The trunk of the tree represents the coordinated operations achieved by the ROCC team that is composed of the Science Team (ST) and the Control Team (CT). These processes have been defined by each team and coordinated and reflected in the ROCC Ground Control Procedures.



Picture 30: concept of operation preparation involving the science objectives as the roots leading to scientific measurements as the leafs or fruits.

The surface operations are organized into phases:

1. the PLTE (post landing to egress phase) that was extensively tested in IST and SVT and would nominally last between 10 and 13 sols.
2. the commissioning phase that would last a month after landing

3. the Experiment cycles (ECs) and Vertical Surveys (VSs) that each aim to visit a selected site and analyse one or more subsurface samples.

Each of these ECs is organized into logical phases that correspond to a meaningful multi-sol goal in terms of planning:

1. drive to the site
2. survey the site to understand its geology and locate possible drilling locations
3. subsurface survey using the WISDOM penetrating radar and ADRON
4. drill and acquire a sample at depth
5. analyse the sample into the ALD

We can recognize the various groups of activities rehearsed as part of the ISTs and SVTs. Such phases represent the main branches of the tree (picture 30), subbranches representing the APs for each of the sols. Ultimately, the leaves or fruit correspond to the measurements that can support the scientific validation of the hypothesis (the roots!).

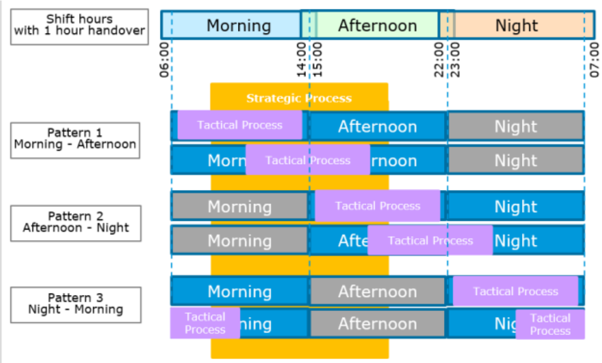
The ROCC is a “Rover Activity Plan factory” that aims to deliver commands daily for upload to the rover via a Mars orbiter. These commands are grouped into an AP that is interpreted on-board – please refer to [2] and [4] for more details about the commanding concept of Rosalind Franklin rover.

A number of constraints are essential for the operations concept. The main one being the communication with the rover through an orbiter twice every sol: in the night/morning to upload the AP, and in the afternoon/evening to download the acquired data. Accounting for the data availability latencies, this leaves between 4 to 8 hours for the ground processes to execute. With such limited time, there is no chance to substantially rework the AP.

It was then decided to shift all the preparatory work and brainstorming to the preceding sols, allowing only limited changes to the plans based on the rover status received from the latest telemetry. This created a clear cut between the strategic activities, *i.e.*, all processes that can be performed prior to receiving the rover telemetry and the tactical activities, *i.e.*, the processes that lead from analysis of fresh data to the AP sending.

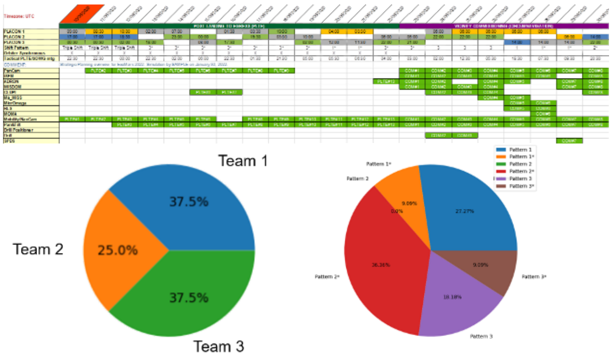
Note that because of the natural shift of daytime between Earth and Mars and the variable overflight of the orbiters, tactical planning activities are foreseen to be performed in shifts. This scheme is a compromise between the difficulty to follow Mars time for ground operators and the necessity to ensure adequate staffing to keep high efficiency during the foreseen relatively short nominal mission of 7 days per week for about 7 months.

The objective is also to limit the number of operators that are mandatory during tactical shifts and allow a greater number during normal working hours for the strategic activities (see picture 31).



Picture 31: defined pattern for the tactical shifts aiming to ensure presence of operators when telemetry arrives, while strategic activities are performed during normal working hours with a larger scientific community.

Some concepts of strategic planning have been developed and a simple tool implemented by ESA, called SAMPLE, in order to link the intended rover activities, the communication opportunities with the rover and the needed staffing. This allowed to draw statistics about the frequency of needed shift patterns and devise a preliminary scheme for the number of operators necessary to support the operations over two fixed shifts per day, while complying with the labour laws regarding required resting periods. Of course, the two-fixed-shifts scheme requires hand-over activities, however, we could see that in one third of the time, only a single shift was necessary to cover the tactical work.



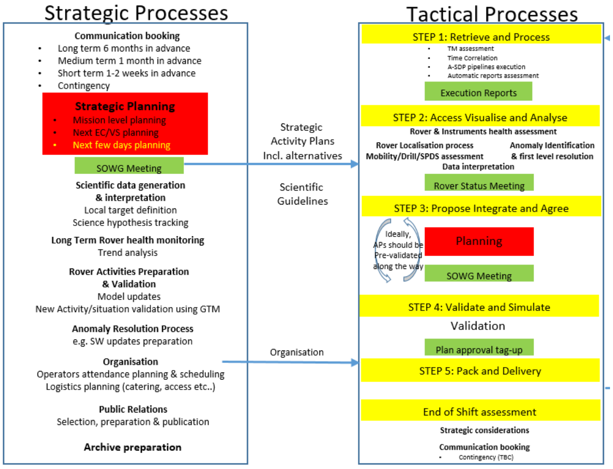
Picture 32: example of SAMPLE Tool output in terms of strategic planning of ROCC teams shifts accounting for orbiters communications constraints and required role attendance (payloads) to support the ground processes.

While the tactical processes had been identified well in advance, see [8], the strategic processes rely heavily on the scientific community in terms of which targets to explore and how.

In the last years, these processes have been further clarified and even put to the test through the Rover Science Operation Working Group (RSOWG) - a working group established among all the ExoMars rover operations stakeholders and lead by the ESA project scientists.

In addition to the geological mapping of the landing site, one element that RSOWG worked on at first was the definition of science targets. These represent the ultimate interface between what the scientists would like to observe and what the control team should be using to support rover activity planning. The naming of targets goes well beyond the planning, as it is used later also in the archiving process and the scientific publications.

In principle, the science targets are defined as part of the strategic planning, while the planning targets can be defined either during the strategic planning (in this case would likely correspond to a science target too) or during the tactical planning cycle and may possibly, at a later stage, be also named as a science target. A hierarchy was defined to cover all the scientific needs -please refer to [10] for more details.



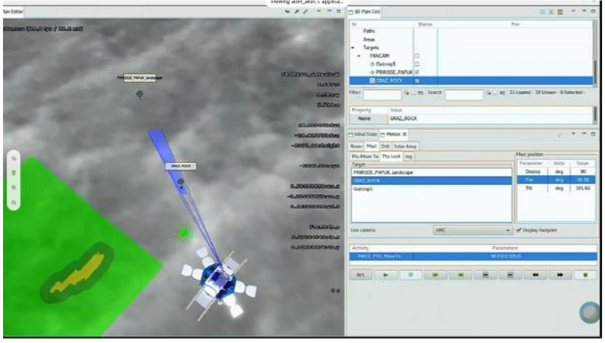
Picture 33: Strategic and tactical processes with their interactions.

The science team, led by the ESA project scientists, clarified the organisation of the science processes, in particular the tasks and roles to be taken by the science community, *e.g.*, science team lead, map keeper, journal keeper, long term planner, tactical liaison etc…

Such organisation was gradually tested during operational simulations especially covering the strategic activities for which science maps, analysis and expertise are key. Those simulations had to be run remotely because of the COVID situation at the time. ROCC operators supported the process with the ROCC tools, in particular the planning tools and the Rover Visualisation and Planning Tool (RVP). The ROCC logging tool and documentation repository were used and provided some realism.

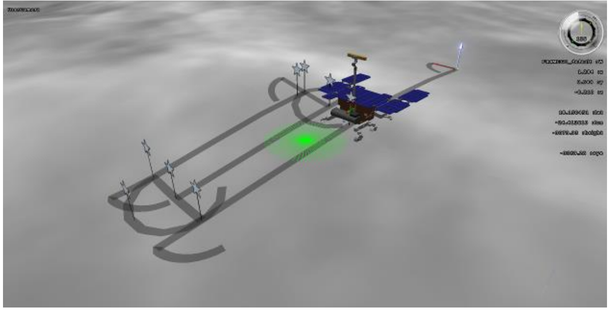
The topics covered by the RSOWG simulations were the following:

1. initial strategic planning at sol#3 after landing, assuming the landing position is known on the map to some accuracy. The input data used the imaging and context of the EXOFIT test campaign performed in the Atacama desert (CH) [12]. The strategic plan of this simulation was then reused for the following simulations.



Picture 34: view with RVP tool of HRC imaging of a target nearby during RSOWG Sim#1

2. Imaging at a site near an outcrop. Well known images from NASA MER mission were used to provide the context of a real outcrop.
3. On the same site, evaluation of different alternative options e.g. additional survey or perform a WISDOM grid with aim to drill.



Picture 35: view with RVP tool with path planning for a WISDOM grid during RSOWG Sim#3

4. Strategic decision making after the first analysis of a sample.

For strategic mobility planning, the concept of creating a Strategic Mobility Plan document that can be shared within the ROCC Team was rehearsed. The purpose is to keep aligned and visible all the mobility plans and their associated justification with the science objectives. Hence, beyond the use of the ROCC tools like RVP and ROCC GIS, the mobility plans are easily accessible to the whole community and will support necessary dynamic updates as part of the strategic process.

In order to prepare these simulations, some simple role plays had been run within the ESA rover operations team. Then, a subgroup of the RSOWG was nominated to prepare the actual simulations. A significant effort was spent by the science simulation officers (at least two per payload teams) to prepare scientifically compelling data for the instruments being used in each of the simulations. This strategic material will have to be made available to the ROCC simulation officers in the future simulations and will likely be reused. Such preparation already fostered the very important cooperation between the teams that peaked during the actual simulations – all run remotely – where more than 100 people participated actively.

All these process rehearsals allowed to freeze the organisation of the science team and identify the interfaces with the rover control team. This was reflected in the Science Operations Plan (SOP) and in the ROCC User Manual and Ground Control Procedures.

Beyond the ROCC SVTs that focused on being able to command and control the rover, the System Operations Validation Tests (SOVTs) validated the adequacy of the operational ground processes. *i.e.*, the ground procedures and the tools. A ROCC SOVT was successfully executed for the cruise activities, as well as a joint SOVT with ESOC, which confirmed that ROCC was ready for the cruise operations.
An SOVT rehearsed also with ESOC the orbiter communication planning and booking following :

- the long term (6 months in advance preliminary allocation),
- medium term (1 month in advance booking confirmation)
- short term (1 week in advance final confirmation enabling orbiter programming).

Further SOVTs covering the tactical and strategic operations on surface are still to be executed after the ROCC SVT-4. Those SOVTs will make use of the data acquired as part of the SVTs and will thus be run within an operational context. All the roles will be mainly played by operators of the ROCC and should lead to increased maturity of the GCPs. It is understood that GCPs will likely be adapted along the way when simulations with the whole team including the scientists will be initiated.

4. Training & Simulations

In terms of training and simulations preparation, COVID has definitely been a challenge. The initially foreseen hands-on experience of the payload teams at ROCC had to be transformed into a remote walk-through of the ROCC tools.

Thanks to the Learning Management System (LMS), people have been able to familiarize themselves with the mission and the tools through on-line lessons that can be taken at any time. When it became clear that on-site presence at ROCC for training would be impossible or restricted for an undetermined amount of time, ALTEC produced short video lessons that replaced the initial on-site training possibilities and complemented well the remotely executed simulations.

In parallel, the Training & Simulations Plan was continuously refined. Nominal and contingency scenarios have been prepared by the simulation officers, first for the certification of operators for the cruise phase and then for the whole ROCC Team for the surface phase. For each operator role, blocks of mandatory courses have been defined together with the minimum number of simulations (nominal & contingency) to be attended to achieve certification for that operator role. Three phases of the mission have been considered with specific simulations prepared:

1. the cruise, where a very limited number of operators are necessary, as the checkout activities are pre-prepared (no planning) and post-processing is performed “off-line” without need of any immediate reaction.
2. PLTE, where the sequences have been rehearsed already, but an agile planning will be required to cope with any unknowns or surprises that operators might face after landing. The scientific strategic planning in this case is initialized but has limited influence to the objective of having the six-wheeled rover on the Martian soil.
3. The surface, that begins with a commissioning phase within the first 30 sols of the mission and continues with the full execution of the parallel strategic and tactical processes. Similarly to the executed early RSOWG simulations mentioned earlier, the surface simulation campaign will cover the main operationally relevant situations involving mobility, drilling and sample analysis.

This plan preparation was quite a challenge since the amount of people to be trained is very large and many operators are necessary to cover the two tactical shifts and therefore need to be certified.

Beyond defining a scientifically compelling environment, one of the other challenges was the preparation of contingency situations, *i.e.*, inject failures and recorded telemetry to be provided as training case. The Amalia rover is suitable for contextual situations, *e.g.*, for triggering specific mobility behaviour, but is not suitable for a number of failures, *e.g.*, involving instruments or redundant units which are present on the PFM but not on the Amalia rover model. The Software Validation Facility (NSVF) is also used by simulation officers to prepare those contingency situations, but preparing and running simulations with the NSVF takes a very long time and execution cannot be accelerated. The Rover Task and Actions Planning Simulator (ROSEX-TAPS) [4] is checking the logic and the resources but without running the actual Rover on board SW and is therefore not generating telemetry that can be injected back into the ROCC tools [8].

It is hence not possible during simulations to run the resulting commands and Activity Plans from the planning activities performed by the trainees with those models and facilities. Therefore, the training will mainly consist of exercising the ground processes based on prepared situations and debriefing the trainees on how they behaved.

5. Conclusions

An overview of the activities performed by the industrial and scientific teams in support of the ROCC preparations has been presented from Integrated System Tests (ISTs), System Verification Tests (SVTs), System Operations Validation Test (SOVTs) and training & simulations that will lead to operators' certification. One peculiarity of the preparation was the involvement of the large science team through the RSOWG that lead the strategic process definition.

Many challenges have been overcome by the teams, linked to resolution of known and discovered anomalies and to availability of hardware and software. The Amalia rover (Ground Tests Model) has been a work-horse for all of these system tests that have been performed over a period of one year at the Mars Terrain Simulator of the ROCC. The other benches have been essential to prepare and de-risk activities on the PFM Rosalind Franklin.

One lesson learned is that all these benches are slightly different from the PFM, whether from a configuration point of view or frome.g., presence of redundancies or not, or actual capabilities e.g. Engineering Models without retrofit of upgrades performed on EQMs or FMs and calibrations. Hence, the ground tools should take into account this fact that several very similar but yet different rover models are to be controlled in parallel for the same mission.

The concept of Activity Plans (APs), which are prepared from high level tasks and actions and interpreted on board, has shown its advantages throughout the whole development, i.e. during functional analysis, software implementation, system validation and operations preparation. Furthermore the AP concept supports the ground operations concept of defining and refining the Activity Plans during the science strategic planning off-line and adjusting tactically after assessment of the latest rover situation within just a few hours.

The preparations have been very rich from the personal point of view, with contributions from many teams from the industry and the science community [10] as well as from ESA, giving a glimpse into what will be the actual operations.

The next steps will be to run operationally meaningful simulations, where the rover operators actually learn how to handle situations only through rover acquired telemetry, and to understand and define any necessary adjustments.

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