Improving operational efficiency for the SuperCam instrument on board the Perseverance rover to support a shortened timeline.

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Abstract

The Perseverance rover landed on the surface of Mars on February 18, 2021, carrying on board 7 science instruments including the SuperCam laser camera. SuperCam is a remote sensing instrument suite combining laser induced breakdown spectroscopy, Raman and infrared spectroscopy as well as high-definition imagery and a microphone for acoustic sensing. By using these 5 techniques, SuperCam aims at determining remotely the atomic and mineralogical composition of Martian rocks and soils, allowing more efficient operations and optimizing the selection of samples for return to Earth.

After landing on Mars, the rover and its payload were operated on Mars time, 7 days a week, for the first 90 Mars days (or "sols") of the mission. During this period, the validation of all the functionalities and features was performed for each instrument. Within this commissioning period, an operational tactical shift, from data reception to command upload, lasted an average of 11 hours. After achieving the commissioning objectives and gaining experience in operating the rover, this timeline duration was progressively reduced to 8 hours per shift.

The Mars 2020 project's final goal is to reach a 5-hour timeline duration in order to maximize the number of operational days. This will also have the positive consequence of limiting the fatigue of the staff involved in Perseverance operations.

To achieve this objective, the Mars 2020 project has developed web-based tools shared with all instrument teams in order to be more efficient in telemetry analysis and activity planning. For the SuperCam instrument, we also benefited from the experience of the ChemCam instrument, a predecessor to SuperCam, on-board the Curiosity rover; in particular, we knew the operational constraints consuming operator time and energy during shifts. Another lesson learned is that automated tools can be a game changer to alleviate bottlenecks, gain efficiency, and then meet the 5-hour timeline. Automation is a key success factor in streamlining the operational process.

Keywords: Mars2020, Perseverance, SuperCam, Timeline, Performance, Operations, Efficiency.

Acronyms/Abbreviations

Mars Science Laboratory (MSL)
Laser Induced Breakdown Spectroscopy (LIBS)
Remote Micro-Imager (RMI)
Universal Time Coordinated (UTC)

1. Introduction

Since February 18, 2021, a second rover, named "Perseverance", has been exploring the Martian surface ~ 3730 km from its predecessor "Curiosity", which proved the habitability of the planet. Located in the ancient Jezero Delta and Lake system, the Mars2020 mission must search for fossil traces of ancient life. Acting as the rover's lookout, the SuperCam instrument, along with several other instruments, pre-selects the most interesting rocks and soils to optimize the selection of samples to be returned to Earth for further analysis.

Exploring a planet far from Earth generates constraints on the implementation of rover operability. A fundamental axis of the Mars2020 operational concept is to optimize the operation available time on Mars. Experience on Curiosity has shown that a 7-hour command development timeline can limit this purpose. Therefore, on Perseverance, the objective is to further reduce the timeline to 5 hours. This shorter duration allows flexibility to place it either just after the operations completed on Mars and the data are downlinked, or just before the rover carries out its next day of activities as the daytime at Jezero crater on Mars shifts relative to the daytime in the western hemisphere of the Earth, where operations are planned. A longer duration for operations development would not allow such flexibility without shifting the start and end of operations to greater extremes, or else losing some operation days.

Despite the complexity of the SuperCam instrument, capable of implementing 5 different techniques, the search for efficiency and operational performance is essential to achieve the project's goal. This article presents the various means implemented by the SuperCam team to speed up operations without sacrificing the flexibility of the activities, the safety of the instrument, and the science return.

2. Mars2020 Mission description

2.1. Mars2020 Mission

The Mars2020 mission is a planetary exploration mission developed by JPL, one of NASA's space research centers. Launched on July 30, 2020, the Atlas V541 propelled the one-ton Perseverance rover to the surface of the red planet. It is the successor to its older brother "Curiosity", which has been exploring the planet for 10 years in the Gale Crater looking for evidence of past habitability. The "Curiosity" rover, as part of the Mars Science Laboratory (MSL) mission, has proven the past habitability of Mars, meaning that billions of years ago, all the necessary conditions were present to sustain life if it ever existed. Did life emerge before Mars lost its magnetic field, most of its atmosphere and its surface water? The Mars2020 mission will try to answer this question with its rover "Perseverance" whose main goal is to search for traces of ancient life, called "biosignatures", in an ancient Lake/Delta system of the Jezero crater. This site was particularly chosen because it could have been a favorable place to preserve such signatures, with also a great geological diversity.

Equipped with 7 instruments selected by the international scientific community, Perseverance's mission is to collect samples of the Martian soil and rocks, to store them hermetically and then to deposit them so that they can be recovered and returned to Earth by future NASA-ESA missions. The analysis of the samples will be done on Earth in laboratories with instruments that are much more precise and accurate than those that can be embarked on a rover. With the help of cameras and spectrometers, it has a range of scientific instruments capable of identifying the most interesting sites in the most efficient way, providing context for the samples taken and carrying out a rapid initial chemical analysis. Born from an international cooperation, the rover carries 72 kg of payloads, distributed as follows (see Fig. 1):

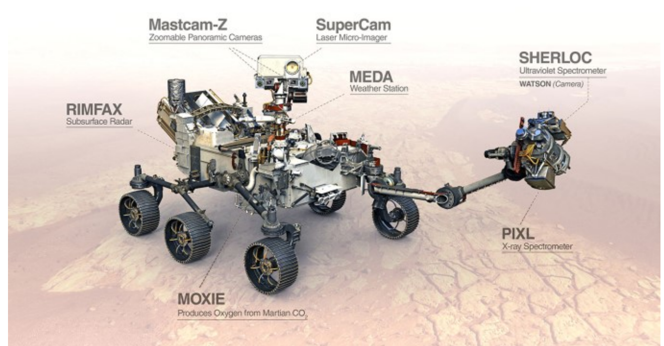

Fig. 1. The Mars 2020 Perseverance Rover, with the seven scientific instruments labeled. NASA/JPL-Caltech

- 9 engineering color cameras used for navigation, obstacle detection, maintenance etc…
- 2 color cameras called "Mastcam-Z" (USA) for 3D images and video,
- 1 "RIMFAX" radar (Norway) designed to probe the surface layers of the Martian soil,
- 1 meteorological station "MEDA" (Spain) allowing to measure temperatures, atmospheric pressure and various parameters such as humidity, radiation, dust, wind and infrared radiation.
- 1 X-ray fluorescence spectrometer "PIXL" (USA) for the chemical composition of rocks,
- 1 spectrometer, laser and camera "SHERLOC" (USA) to detect minerals and organic molecules in contact with the soil or rock,
- 1 spectrometer, laser and camera "SuperCam" (France/USA) to determine the chemical composition (atomic and molecular) of rocks and soils.

In addition to its scientific experiments, the rover carries two technological demonstrators for future missions, including the recovery of collected samples and the upcoming arrival of humans on Mars:

- 1 In Situ Resource Utilization (ISRU) "MOXIE" type equipment (USA) for the production of oxygen from the CO2 present in the Martian atmosphere,
- 1 reconnaissance helicopter named "INGENUITY" (USA).

2.2. SuperCam Instrument

The "SuperCam" instrument is a laser-imaging camera equipped with 5 techniques whose main role is to determine the composition of the atmosphere, soil and rocks at a distance of up to 7 meters in order to identify and pre-select targets of scientific interest and also provide the associated geological context [1, 2].

To achieve this objective, this Super Camera implements various techniques, which enhance and complete those already available on the Chemistry Camera (ChemCam) on board Curiosity, such as:

- Laser Induced Breakdown Spectroscopy (LIBS) and Time-Resolved Raman and Luminescence Spectroscopies (RAMAN) to remotely determine the elemental, molecular and organic composition by analyzing the light emitted by the plasma resulting from bombardment with short 5 nanosecond pulses from a red laser for LIBS (1064 nm) and a green laser for RAMAN (532 nm).
- Visible and Infrared Reflectance Spectroscopy (VISIR), which helps to characterize the mineralogical composition by analyzing the sunlight reflected by the rocks,
- A color Remote Micro-Imaging (RMI) camera, with an optical resolution better than 80 µrad, which provides information on the environment, the context, the texture and the morphology of the targeted rocks,
- A scientific microphone that allows to analyze the hardness and porosity of the rocks, the wind, but also to listen to the mechanism of other instruments such as "MOXIE" and "Ingenuity".

All of these technologies on board SuperCam are distributed on 3 distinct components (see Fig. 2):

- the Mast Unit (France), located on the mast of the rover, is mainly the optical part,
- the Body Unit (USA), located inside the rover's body of the rover, is composed of the spectrometers,
- the 35 calibration targets (France/Spain/Denmark) used for calibration located at the rear of the rover.

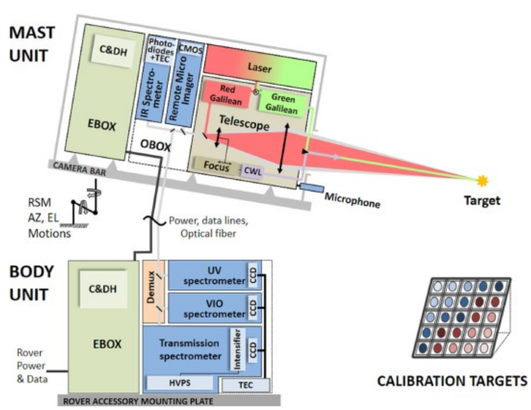

Fig. 2. The SuperCam instrument composition

3. Organization / Operational timeline

As the result of an international cooperation, the rover and its various scientific instruments are operated from several mission centers located on the American and European continents.

3.1. Operational constraints

Depending on the orbital configuration, the distance between Earth and Mars can vary between 55.7 and 401 million kilometers, inducing a communication latency of 3 to 24 minutes. In addition, every 26 months during the solar conjunction, the alignment of the Earth, Sun and Mars makes communication impossible between the rover on Mars and the operators on Earth. The duration of a solar day on Mars, called a "Sol", corresponding to the rotation of the red planet, is 24h 39min and 35s, compared to 24h for the Earth.

This context makes it impossible to control the rover in real time and generates a strong constraint in terms of its operability. A daily activity plan is sent to the rover and the data are retrieved using the Deep Space Network and relay satellites.

For the first 90 sols after landing, operations were carried out 7 days a week following the rhythm of the Martian days ("Mars time"), shifting 40 minutes every day on Earth in order to qualify all the rover's functionalities and instruments as closely as possible to the available day time on Mars. Following this "In-Flight Validation" phase, the operations were carried out on Earth time, progressively evolving from 7 days to 6 days and then 5 days a week. Operated from two continents, the time reference of the operations was chosen to be Pacific Standard Time in a time range from 6:00 AM to midnight, corresponding to UTC-8 in winter and UTC-7 in summer.

Although the Curiosity rover had a design life of 2 years, it is still operational and active on the Red Planet. Based on the legacy of ChemCam operations over the past ten years, teams alternate between the two rovers to ensure continuous support. Operations of the two French-American instruments, ChemCam and SuperCam, are conducted from CNES (Centre National d'Etudes Spatiales, in France) and LANL (Los Alamos National Laboratory, in the U.S.) with their respective science partners, alternating between the two rovers, so that each team operates one instrument one week, and the other instrument the other week.

All of these operational constraints affect the availability of the international teams to jointly pilot the rovers and their instruments.

3.2. General operational organization

Every day, more than 100 people from around the world, meet to plan activities for the next few sols and collectively decide on the best observations by the rover to perform the next day. To achieve this common goal, JPL acts as the conductor, coordinating the teams of each instrument and mechanism on the rover.

Science Planning on Perseverance is organized around four overlapping planning processes, ranging from long-term predictive planning to short-term reactive planning (see Fig. 3). The article [3] describes these processes and their respective challenges in detail.

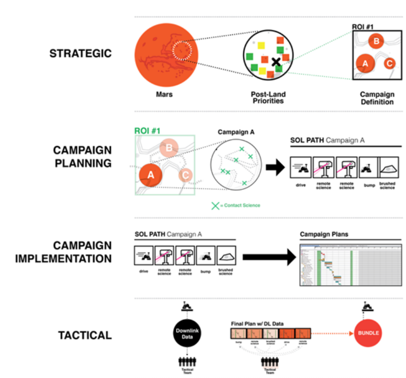

Fig. 3. Four science planning processes

The planning is based on components, which group together a set of activities of one or more instruments, pre-configured to achieve a scientific objective. These components facilitate the elaboration of the "Look Ahead Plan" defined in "Campaign" to predict the plan for the next few sols.

From this, a "Tactical" plan is then developed to adjust the next day's sol plan, reacting to the latest scientific results received and the status of each subsystem.

Using a simulation tool called "ASTTRO", the targets are defined on the basis of the latest images received from Mars, and then automatically linked to the activities in the JPL's "COCPIT" planning tool. A real-time synchronization of all the operational planning and simulation tools allows the teams to assemble jointly and simultaneously all the desired scientific activities.

A tactical operational timeline is defined with all the meetings and milestones required to achieve this reactive planning and the associated sequences – a set of command lines allowing to perform an activity (see Fig. 4). Four decision-making meetings punctuate the development of the Uplink plan, allowing its maturity to be advanced through fixed milestones:

- "Kickoff" meeting : Uplink start-up meeting with presentation of the plan from the predictive planning.
- "Target proposed" milestone: targets must be defined at the beginning of the Declare Plan.
- "Declare Plan" meeting: Report on the health status of all instruments and rover mechanisms in order to re-adjust and jointly decide on the activities that can be executed on the following sols.
- "Plan locked" milestone: 30 minutes before the Reconciliation, the plan and its parameters are frozen.
- "Reconciliation" meeting: Review of the fixed plan and the sequencing of the planned activities.
- "Seq delivered" milestone: 1hour before the Seq Report Walkthrough, the sequences must be delivered.
- "Seq Report Walkthrough" meeting: Final review of the sequencing of all sequences introduced in Masters and SubMasters.

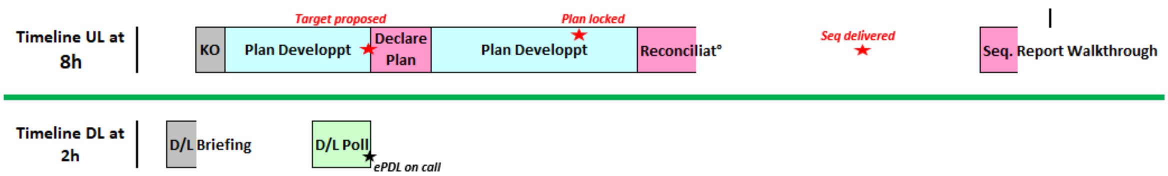

Fig. 4. Uplink and Downlink tactical operational timeline

On the Downlink side, two meetings are dedicated to obtain a health check of all systems and subsystems before planning the next set of activities by the rover:

- "Downlink briefing" meeting: Downlink start-up meeting with a reminder of the plan previously sent to Mars.
- "D/L Poll" meeting: Synthesis meeting of all the instruments and rover in order to provide the Uplink side a complete assessment of the rover's status.

To program SuperCam and its five onboard techniques, the operational teams rely on 19 engineering, science and calibration activities. From a combination of all these activities, 52 "components" have been developed to meet a specific science or technical need.

3.3. Supercam operational process

The SuperCam operational process is organized around 6 roles:

- PEL (Payload Element Lead), responsible for the operations of the programmed sol N, she/he coordinates the strategic and tactical uplink as well as the downlink by defining the priorities and ensuring that the scientific needs, defined in Campaign, are met.
- sPDL (Scientist Payload Downlink Lead), in charge of carrying out an initial quantitative and qualitative analysis of the scientific data received.
- ePDL (Engineer Payload Downlink Lead), responsible for assessing the health of the instrument, she/he analyzes the anomalies and the execution of the sequences with the associated products received.
- sPUL (Scientist Payload Uplink Lead), in charge of scientific activities in tactical, she/he discusses the choice of the target, refines the pointing and configures the raster and the associated parameters in the activity.
- ePUL (Engineer Payload Uplink Lead), responsible for the safety of the instrument in operation (laser safety, collision, sunsafety, thermal...), she/he adjusts the parameters and generates the associated command sequences to deliver them.
- CI rep (Campaign Implementation rep.), in charge of the strategic elaboration of the Look Ahead Plan (N+1, N+2, N+3 etc...), she/he defines the scientific objectives according to the strategic discussions.

The figure below details the SuperCam operational process, involving all the actors presented in the previous paragraph (see Fig. 5). The "Tactical", with the "Downlink" and "Uplink" parts, as well as the "Campaign Implementation" are performed in parallel in order to promote reactivity and flexibility between each process.

Subject to the various milestones and operational meetings defined in the timeline, the objective of all the operational actors of SuperCam is to assess the good health of the instrument and to analyze the data received in order to program the scientific activities of the next sols according to the defined scientific objectives. The targets and activities are then selected, refined, parameterized and translated into command lines that can be interpreted by the instrument. For this purpose, several planning, piloting and programming tools are available to the actors to ensure the presence of SuperCam in the activities planned for the rover on Sol N. The engineers are then responsible for the correct programming of these commands in accordance with the various safety rules of the rover and the instrument, carrying out all the necessary checks.

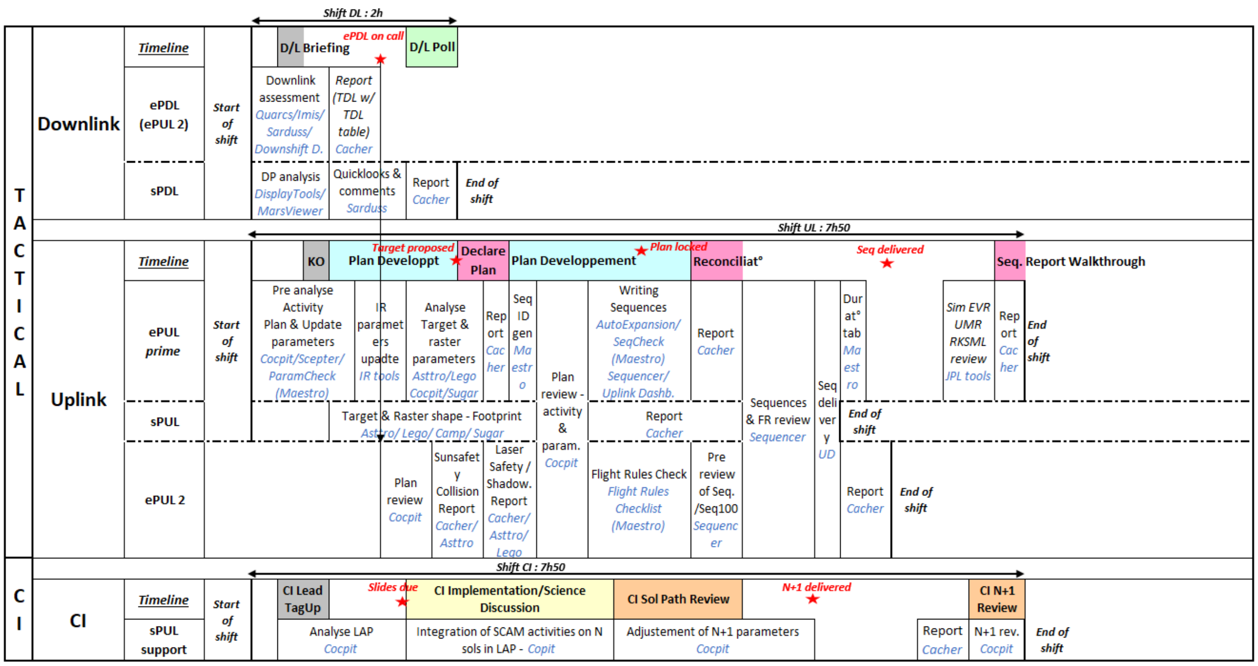

Fig. 5. Operational Tactical and Campaign timeline

4. Optimization of operating time with Perseverance on Mars

The experience acquired over the years on MSL has allowed to progressively reduce the operational timeline to 7 hours, which today constrains the useful operating time of the rover on Mars.

4.1. Objectives and challenges

Feedback from MSL has been incorporated into the development of the Mars2020 operational concept to maximize the useful operation time of Perseverance on Mars. To operate the rover efficiently, it is necessary to have received the latest scientific and technical data in order to program it every day as close as possible to the actual rover situation.

The existence of a difference of about 40 minutes between the rotation period of the Earth and Mars implies a progressive shift between the programming of the operations on Earth and the realization of the activities on Mars. Indeed, every 37 days, it becomes necessary to resynchronize the ground segment with the rover by neutralizing one Earth day, called the "Soliday".

This shift also means that for several sols, operations are conducted without the visibility of the last scheduled activities on Mars. In fact, the data arrive too late to be taken into account, even if the start operations on Earth is shifted as much as possible in the acceptable interval. These sols are qualified as "Restricted" because the programmed activities are then limited (see Fig. 6). This constraint can be overcome by reducing the operational timeline from 8 hours to 5 hours.

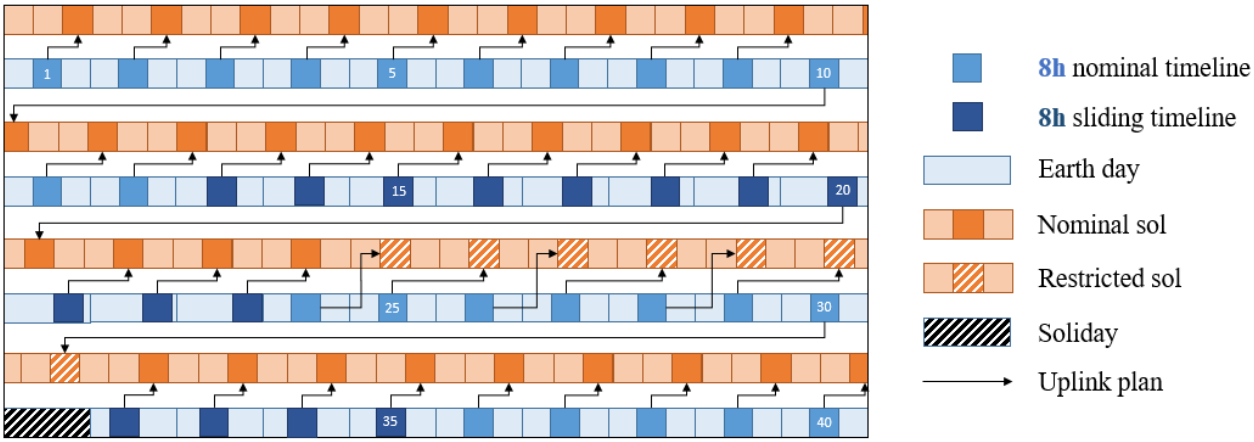

Fig. 6. "Restricted" sols induced by a 8 hours daily operational timeline

Since the objective of the Mars2020 operational concept is to optimize the use of the rover on Mars, a reduction of the timeline to 5 hours is necessary to avoid these "Restricted" sols (see Fig. 7). To reach this objective, specific means will have to be deployed at all levels.

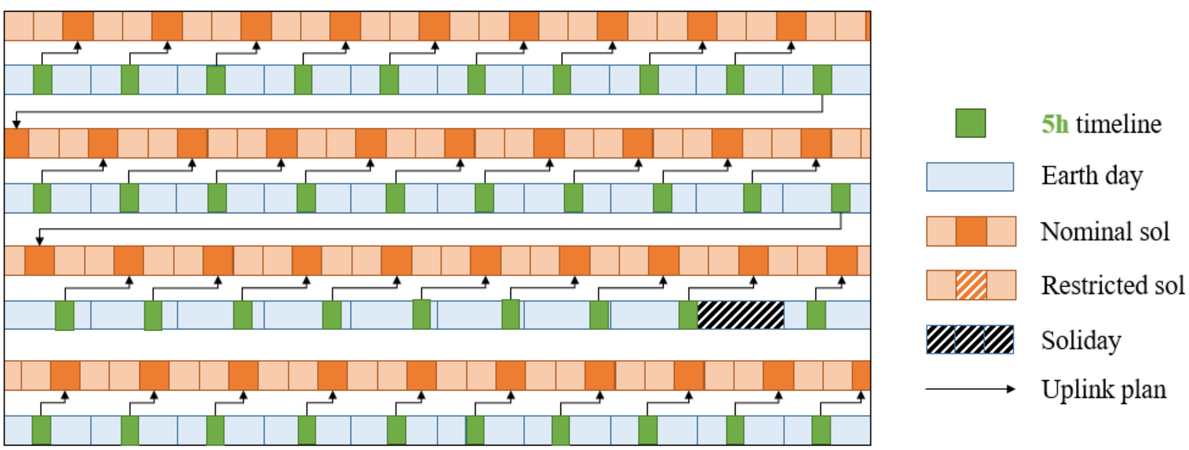

Fig. 7. Optimization of operating time on Mars with a 5 hours daily operational timeline

4.2. Current status of the operational timeline

Since the end of the "in-flight validation" phase, the operational timeline has been progressively reduced to reach the target of 5 hours in the next few months. The experience gained on the previous rover and the operational concepts introduced on Mars2020 have made it possible to reduce the average duration of Perseverance operations from 11 hours to 8 hours in only 18 months. The operations of both rovers are now almost equal in duration.

The first milestone of 8 hours was achieved by compressing the duration of meetings and, above all, reducing by half the time required after sequences delivery, which include the preparation of the master and sub-master (the parts of the plan including all instrument and sub-system sequences) and all the safety rule verifications. The time at which targets are to be selected, "Target proposed" milestone, has been brought forward to allow more time for adjustment of plan parameters and preparation of sequences, thus decompressing the first bottlenecks identified in the process (see Fig. 8).

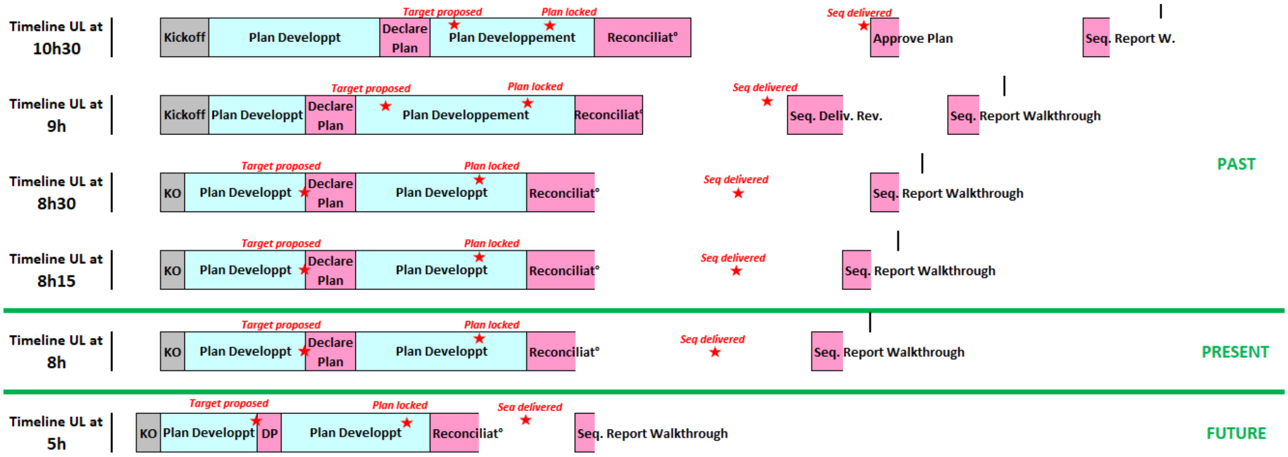

Fig. 8. Evolution of the uplink tactical operational timeline

In order to reach the 5-hour objective, it is now essential to gain in effectiveness and especially in efficiency, by seeking a real operational performance given the increasing compression of effective working time.

4.3. Operational performance improvement

Improving operational performance consists of seeking effectiveness and efficiency by relying on relevant means to achieve the set objective (see Fig. 9). The implementation of means at the system and sub-system levels will be the key to success in order to reduce the timeline to 5 hours while guaranteeing the execution and safety of operations.

This search for operational performance involves identifying bottlenecks in each process in order to deploy the necessary means and resources.

The experience acquired on MSL made it possible to know, well before the landing, what would be one of the major bottlenecks in the operational process of Supercam: the writing of the sequences.

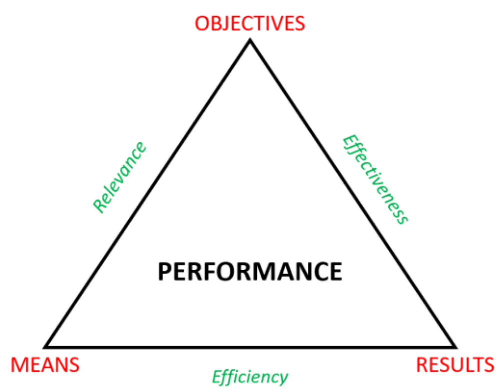

Fig. 9. Performance Triangle Gilbert 1980

Other bottlenecks have been progressively identified with the experience acquired since the landing of Perseverance. Indeed, during the "Plan Development", the period between the target selection and the time when the plan is locked is very limited and depends on the discussions around the choice of the targets. Thus, as mentioned in the previous section, the "Target proposed" milestone was brought forward to give more time to verify the plan parameters and to start earlier the preparation of the sequences.

Another optimization to deal with this bottleneck consists to increase the human resources. This is achieved by reassigning the ePDL downlink role to support the ePUL uplink tasks as soon as possible: SuperCam's ePDL is now declared "on-call" quickly after performing its instrument health check and switches to Uplink. This grouping also allows for the parallelization of tasks within the Uplink process between the two roles, such as the Sun-Safety, Collision risk, and safety rule checks that are mandatory prior to sequence delivery. Therefore, Flight Rules verification is now performed by the ePDL in parallel with the writing of the sequences done by the ePUL, thus allowing to achieve the "Seq Delivered" milestone.

These changes of the SuperCam operational process must be combined with the development and implementation of internal resources and tools to achieve the 5-hour timeline objective.

5. Implementation of relevant means to improve performance

To reduce the timeline to 5 hours for optimizing the useful time operated on Mars, it is essential to acquire the necessary tools and means that can improve the performances while continuing to ensure the good realization of the operations.

5.1. Automation : Key success factor

The automation of the tools and processes implemented represents a real key success factor in the search for efficiency and operational performance. It allows to speed-up the execution of tasks located at the bottleneck level by eliminating non-value-added tasks that do not require human analysis. It thus reinforces reliability by avoiding errors and ensures the security of operations by automating the programming of activities and the control of compliance with flight rules. Considering the complexity of the instrument, the fine control of the parameterization of the activities in the planning is left to the expertise of a qualified operator in order to gain in flexibility.

On the human side, automation also helps to reduce fatigue and stress during operations. This interest is not negligible in order to preserve the resources of the project and thus ensure the continuity of the operability of the two rovers on Mars. However, the delegation of tasks to automated tools presents certain disadvantages such as the loss of operator knowledge, but also the costs and constraints of development, availability, robustness and validation of these tools.

5.2. Development of automated tools

Automated tools have been developed to target tasks of varying criticality that have been identified at the bottleneck level to gain in effectiveness and efficiency.

In the previous section, we saw that the writing of sequences had a major impact on the process since MSL. To address this issue, several tools were developed before landing, responding to different degrees of complexity in the implementation of the instrument's techniques. Based on the MSL feedback, a first tool called "Sequencer" was developed to meet the needs of most of the Perseverance activities, allowing the automatic generation of commands from the parameters of the activities in the tactical plan. This tool is used to develop the engineering activities of SuperCam such as the ON/OFF of the instrument but also to program its calibration activities.

On SuperCam, for more complex scientific activities involving several combined and/or chained instrumental techniques, a dedicated tool called "MAESTRO" has been developed to automate the elaboration of sequences from the activity plan (see Fig. 10). Indeed, this tool allows to check the plan, the sequence and the parameterization of the activities in compliance with the safety rules and the operational procedures, then to automatically generate and verify the associated command lines. The verification of the rules is based on 51 Check Rules and 38 Flight Rules implemented in the two modules "ParamCheck" for the plan verification, and "SeqCheck" for the sequence verification. "MAESTRO" is thus the main Uplink tool for the elaboration of the sequences of the scientific activities of SuperCam.
It also includes other features such as:

- automatic generation of the unique identifier of the sequences, called "SeqID", with the description of the activity and the associated techniques ("SeqID generator" module),
- the generation of the activity duration table ("Duration table" module),
- the comparison between two sequences or two activities ("Sequences Diff" and "Activity Diff" modules),
- the assisted production of the Flight Rules checklist ("Flight Rules Checklist" module),
- the automatic calculation of the integration time for infrared spectra taking into account the sequencing of the plan activities ("Compute integration time" module).

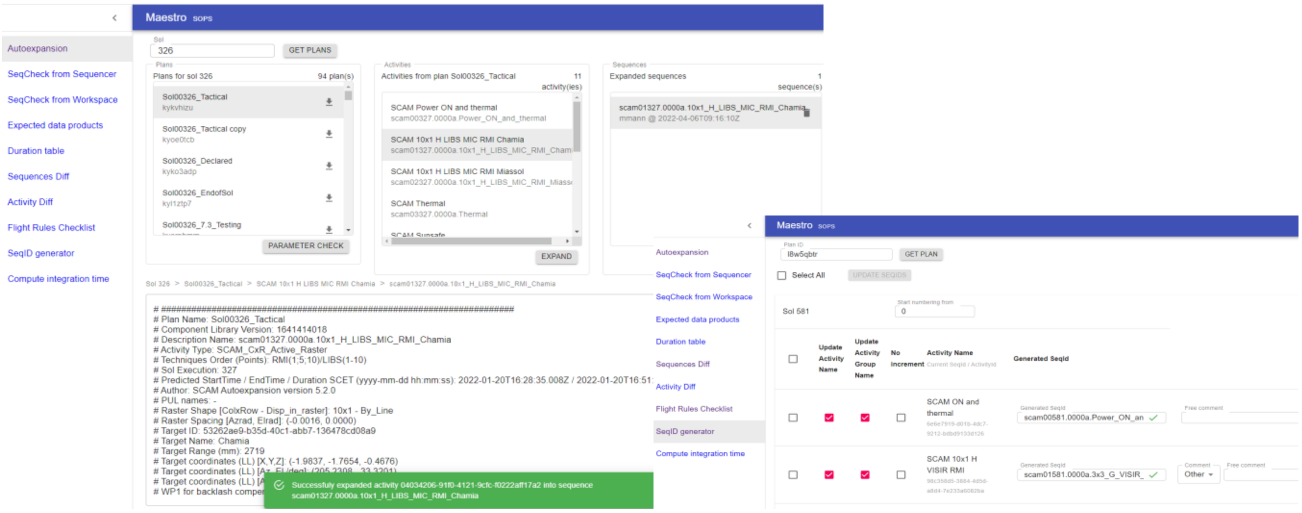

Fig. 10. SuperCam "MAESTRO" tool-based – "Autoexpansion" and "SeqID generator" modules

Another tool, called "SUGAR", was developed to refine the number of autofocus and RMI needed according to the target position to improve the design of the generated rasters.

In order to speed-up the downlink assessment, automated tools have been developed to quickly perform the health check of the instrument and extract the associated scientific data. This allows the ePDL to switch to the Uplink side more quickly.

The "QUARCS" tool provides a summary of the status of the instrument by gathering the main parameters from HouseKeeping Telemetry and the results of the activities performed (see Fig. 11):

- Nominal final state of the instrument (OFF, Healthy and SunSafe) to allow programming on the Uplink side.
- Comparison of the temperatures reached in all subsystems with the expected ranges.
- Summary of the activities performed with diagnostics and execution times, as well as the status of the products received compared to those expected (images and spectra).

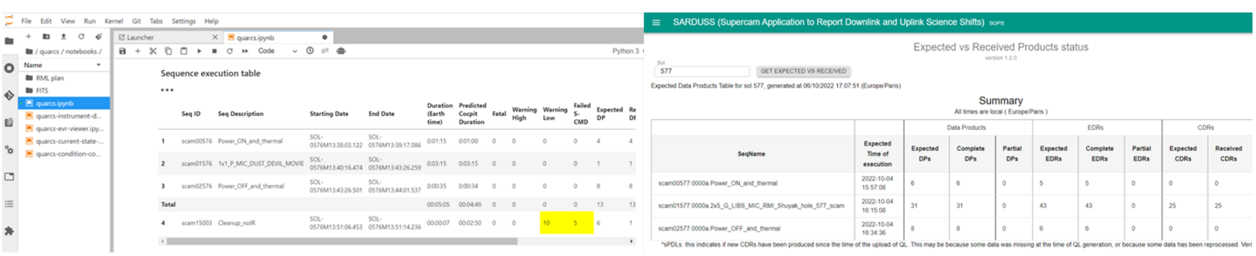

Fig. 11. SuperCam Downlink tools "QUARCS" and "SARDUSS"

In addition, the "SARDUSS" (SuperCam Assistant to Report Downlink and Uplink Science Shifts) currently provides two features to help SuperCam sPDL, ePDL and sPUL in their shifts (see Fig. 11):

- An overview of what products are expected for the downlink on a given sol, and a comparison with the actual products available on the JPL servers. This expected-vs-received comparison is done at different product levels (binary data products, uncalibrated, calibrated, mosaics, quicklooks), so it also provides clues to major issues in the science pipeline.

- The sPUL Report Helper parses a tactical plan, and extracts the most significant parameters on each SuperCam sequence that could impact the science. SARDUSS reformats this information so that it can be copied into the CACHER report, saving significant time for the sPUL.

Finally, the "SuperCam Display Tools" are a set of standalone tools written in Python that are used by the science team to retrieve, visualize and analyze SuperCam data, at different processing levels. Amongst the various features, they allow to create an automatic synthesis of the science products obtained for a SuperCam sequence. This collection of plots, tables, and figures in this synthesis, called "Quicklook", are commented by the sPDL to report on the science outcome of an observation.

The tools developed at all levels of the SuperCam process make it possible to achieve real operational performance, actively contributing to the objective of reducing the timeline to 5 hours.

5.3. Processes automation

As we learned the operations on Perseverance, the operational processes on the Uplink and Downlink sides could be documented and detailed in the ePUL, ePDL, sPUL and sPDL procedures.

In addition, operational checklists propose a summary of the main actions to be performed for each position (ePUL and ePDL) in order to be more efficient and secure operations.

Moreover, technical summary sheets, called "CheatSheets", have been created to allow operators to quickly find a reference in the technical documentation. All of these documents allow securing the operations while gaining in efficiency.

The automation of part of the Uplink process at the Flight Rules production level has also been implemented to complete the automatic generation of sequences, thus alleviating the identified bottleneck. In fact, SuperCam currently has 92 Flight Rules to analyze and verify each sol in order to ensure the proper execution of activities in accordance with flight safety rules. The goal is to make this verification faster and more efficient without compromising safety.

The "Flight Rules Checklist" module is divided into several steps to progressively check the Flight Rules (FRs) by integrating those automatically checked by JPL tools and/or by our complementary internal tools (see Fig. 12):

1/ Identification of the activities included in the plan to quickly sort out the FR to be analyzed
2/ Automatic check of all FRs that cannot be violated by using automatic sequence generation
3/ Report of errors and/or violations analyzed by JPL tools (54 FR checked by "SEQER" and "SOCCER")
4/ Automatic check of the FRs that can be analyzed by "ParamCheck" and "SeqCheck" (38 FRs checked by the internal modules of "MAESTRO")
5/ Manual check of the remaining 12 FR that need human analysis.

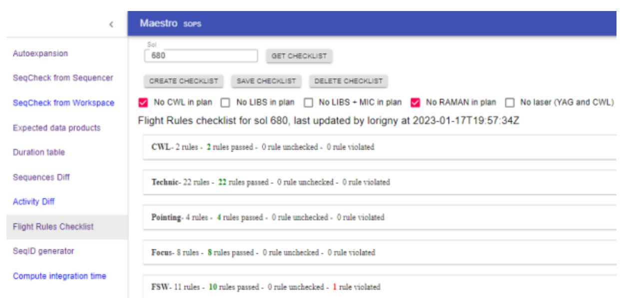

Fig. 12. SuperCam "Flight Rules Checklist" tool

The automation of the Flight Rules analysis has been crossed and almost doubled by the JPL tools "SEQER" and "SOCCER" as well as those of "MAESTRO" in order to reinforce the security of the operations. With this process improvement, flight rules verification is simplified with only 12 remaining FRs to be manually checked by the operator, which represents a real efficiency gain in the entire SuperCam operational process.

Finally, a Wiki has been set up to list all operational best practices and to centralize documentation and tools useful for SuperCam operations.

5.4. Strengthening training and operational coordination

The progressive implementation of all the automated tools and processes presented above generates a major drawback in terms of loss of knowledge and information in the operational teams. Indeed, despite all the benefits presented, the substitution of human tasks by automated systems must be compensated by training and coordination meetings.

The transmission of operational information between all the scientific and engineering actors, as well as between the French and American teams, is an essential element in order to ensure the safety and proper execution of the operations. Therefore, several weekly and bi-weekly coordination meetings are organized at all levels, instrument and project, in order to share technical and organizational information (see Fig. 13):

- GCOM (Martian Operational Coordination Group) between engineers and scientists in France and Los Alamos,
- Handover is a weekly meeting to switch operational leadership between the French and American teams. This allows the transfer of all information about the operations performed during the previous week.
- SCAM OpsLead (SuperCam Operational Leads) between SuperCam Operational Leads and Principal Investigators (PI).
- IO OpsLead (Instrument Operational Leads) between all Instrument Operational Leads and JPL coordinators.

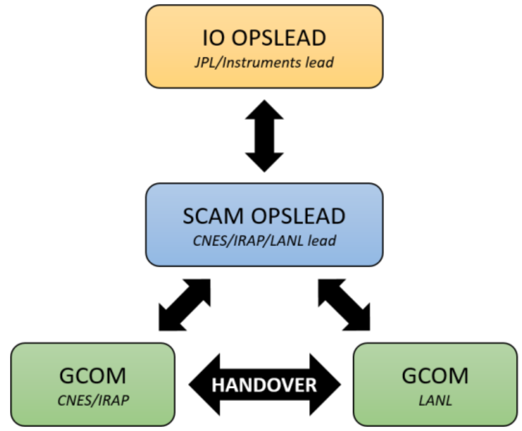

Fig. 13. SuperCam coordination meeting

In addition to the importance of communication within the teams, continuous training ensures the learning of new tools and specific technical subjects. This is essential to maintain the quality of operations. Similarly, training for newcomers provides a solid foundation of technical and operational knowledge. This ensures that the operational team does not lose its skills due to turnover and the implementation of automated tools.

Therefore, a dedicated training environment, copied from the operational context, was created at JPL to facilitate learning.

6. Conclusion

The operational implementation of relevant means with automated tools and processes on SuperCam has allowed to fit with the evolution of the timeline according to the objectives set by the Mars2020 project. In order to improve the operational efficiency of the SuperCam teams, the automation of these processes has been a real key success factor.

Continuous efforts to improve operational performance at all level of processes and tools will help achieve the common goal of a 5-hour timeline to optimize the operating time of Perseverance on Mars.

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Thanks to all the French and American teams, SuperCam and JPL, for their dedicated and passionate investments to progress the rover with perseverance on Mars in search of traces of ancient life. Thanks also to all the actors of the operations, scientists and engineers, who have been working day and night, depending on their continent, for several years to operate the two rovers Curiosity and Perseverance. Last but not least, a huge thank you to all the tool developers who are helping us to improve our operational performance in order to optimize our operating time on Mars.

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