ExoMars 2018

Landing Site Selection

User's Manual

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1 INTRODUCTION AND SCOPE

Establishing whether life ever existed, or is still active on Mars today, is one of the outstanding scientific questions of our time. The ExoMars Programme seeks to timely address this and other important scientific goals, and to demonstrate key flight and *in situ* enabling technologies underpinning European and Russian ambitions for future exploration missions. The ExoMars Programme is a cooperative undertaking between the European Space Agency (ESA) and the Russian federal space agency, Roscosmos.

Within ESA, ExoMars is an element of the Aurora Exploration Programme, an optional programme executed under the supervision of the Programme Board for Human Spaceflight, Microgravity and Exploration (PB-HME). In addition, the ESA Science Programme also participates to ExoMars. The objective of the Aurora Programme is to explore Solar System objects having a high potential for the emergence of life. Aurora aims to develop technologies and address scientific questions in a step-wise fashion, seeking to advance the level of technical and scientific readiness with each successive mission.

Within Roscosmos, ExoMars is part of the Russian federal space programme and is supported by the Russian Academy of Sciences.

To prepare for future exploration missions and to support the Programme's scientific objectives, ExoMars will achieve the following technology objectives:

- **Entry, Descent, and Landing (EDL) of a payload on the surface of Mars;**
- **Surface mobility with a Rover;**
- **Access to the subsurface to acquire samples;**
- **Sample acquisition, preparation, distribution, and analysis.**
- **Qualification of Russian ground-based means for deep-space communications in cooperation with ESA's ESTRACK;**
- **Adaptation of Russian on-board computer for deep space missions and ExoMars landed operations;**
- **Development and qualification of throttleable braking engines for prospective planetary landing missions.**

The scientific objectives of ExoMars are:

- **To search for signs of past and present life on Mars;**
- **To investigate the water/geochemical environment as a function of depth in the shallow subsurface;**
- **To study martian atmospheric trace gases and their sources.**
- **To characterise the surface environment.**

The ExoMars Programme consists of two missions, in 2016 and 2018. ESA and Roscosmos have agreed[1] a well-balanced sharing of responsibilities for the various mission elements.

The 2016 mission will be launched on a Roscosmos-provided Proton rocket. It includes the Trace Gas Orbiter (TGO) and an Entry, descent and landing Demonstrator Module (EDM), both contributed by ESA. The TGO will carry European and Russian scientific instruments for remote observations, while the EDM will have a European payload for *in-situ* measurements during descent and on the martian surface.

The 2018 mission will land a Rover, provided by ESA, making use of a Descent Module (DM) contributed by Roscosmos. The DM will travel to Mars on an ESA-provided Carrier Module (CM). Roscosmos will launch the spacecraft composite on a Proton rocket. The Rover will be equipped with a European and Russian suite of instruments, and with Russian Radioisotope Heating Units (RHUs). The Rover will also include a 2-m drill for subsurface sampling and a Sample Preparation and Distribution System (SPDS), supporting the suite of geology and life seeking experiments in the Rover's Analytical Laboratory Drawer (ALD). The Russian Surface Platform (SP) will contain a further suite of instruments, mainly concentrating on environmental and geophysical investigations.

[1] Agreement between the European Space Agency and the Federal Space Agency (the Russian Federation) concerning cooperation on robotic exploration of Mars and other bodies in the Solar System, signed on 14 March 2013 [Ref. ESA/C(2013)19].

NASA will also deliver important elements to ExoMars: The Electra Ultra-High Frequency (UHF) radio package on TGO for Mars surface proximity link communications with landed assets (such as the Rover and Surface Platform); engineering support to EDM; and a major part of MOMA, the organic molecule characterisation instrument on the Rover.

This Landing Site Selection (LSS) User's Manual lists the scientific, engineering, and planetary protection constraints against which the ExoMars 2018 Landing Site Selection Working Group (LSSWG) will analyse proposed candidate landing sites. Please note that the landing constraints included in this document may need to be revised in case of changes in the spacecraft's expected landing performance.

1.1 ExoMars 2018 Mission Summary

Table 1 presents the 2018 mission's principal features.

Spacecraft:	Carrier Module (CM) plus 2000-kg Descent Module (DM), including Rover and Surface Platform (SP). Data relay function to be provided by ExoMars TGO.
Launch:	May 2018, from Baikonur on a Proton M (backup in Aug 2020).
Arrival:	Jan 2019 (backup in Apr 2021).
Landing:	Direct entry, from hyperbolic trajectory, after the dust storm season. Landing site: To be defined. Must be safe and appropriate for "search for life" science. Latitudes between 5º S and 25º N, all longitudes. Maximum altitude: –2 km, relative to MOLA zero level. Uncertainty ellipse: ~104 km x 19 km.
Science:	Rover with Pasteur payload: Mass ~310 kg, including drill/SPDS and instruments. Lifetime 218 sols. Surface Platform: SP Instruments to be defined. Lifetime 1 martian year
Ground Segment:	Mission operations centre: ESOC. Rover Operations Control Centre: ALTEC. Surface Platform operations: IKI. Mission science archives: ESAC and IKI.

Table 1: ExoMars 2018 mission information.

2 SCIENTIFIC CONSTRAINTS FOR EXOMARS 2018 LANDING SITES

The ExoMars programme's scientific objectives are:

1. To search for signs of past and present life on Mars;
2. To investigate the water/geochemical environment as a function of depth in the shallow subsurface;
3. To study martian atmospheric trace gases and their sources;
4. To characterise the surface environment.

The ExoMars Rover will address the first two science objectives. It will carry a comprehensive suite of instruments dedicated to geology and exobiology research named after Louis Pasteur. The rover will be able to travel several kilometres searching for traces of past and present signs of life. It will do this by collecting and analysing samples from within outcrops, and from the subsurface—down to 2-m depth. The very powerful combination of mobility with the ability to access locations where organic molecules can be well preserved is unique to this mission. The rover will also perform numerous investigations on rocks and soils, also contributing to the fourth objective.

After the rover will have egressed, the ExoMars Surface Platform (SP) will begin its science mission. The SP will conduct environmental and geophysical measurements in support of the fourth objective. These results will also provide important context information for objective 1, benefiting also the Rover mission.

Besides the investigations carried out by each element, the programme also includes an excellent potential for cross-platform scientific studies. For example, coordinated measurements between the Rover and TGO may provide insights into the past and present habitability of Mars. Likewise, the Surface Platform and Rover will be able to image each other, and implement joint scientific measurements during the first part of their surface mission, while they are close together.

From a science point of view, a landing site satisfying the Rover mission's search-for-life requirements is also expected to be extremely interesting for the Surface Platform's science.

2.1 Rover Surface Mission

The ExoMars rover will have a nominal lifetime of 218 sols (approximately 7 months). During this period, it will ensure a regional mobility of several kilometres, relying on solar array electrical power.

The rover's Pasteur payload will produce self-consistent sets of measurements capable to provide reliable evidence, for or against, the existence of a range of biosignatures at each search location. Pasteur contains: panoramic instruments (wide-angle and high-resolution cameras, an infrared spectrometer, a ground-penetrating radar, and a neutron detector); a subsurface drill capable of reaching a depth of 2 m to collect specimens; contact instruments for studying rocks and collected samples (a close-up imager and an infrared spectrometer in the drill head); a Sample Preparation and Distribution System (SPDS); and the analytical laboratory, the latter including a visual and infrared imaging spectrometer, a Raman spectrometer, and a Laser-Desorption, Thermal-Volatilisation, Derivatisation, Gas Chromatograph Mass Spectrometer (LD + Der-TV GCMS).

If any organic compounds are detected on Mars, it will be important to show that they were not brought from Earth. Great care is being devoted during the assembly, testing, and integration of instruments and rover components. Strict organic cleanliness requirements apply to all parts that come into contact with the sample and to the rover assembly process. Once assembled, the analytical laboratory drawer will be sealed and kept at positive pressure, throughout transport, final integration, launch, cruise, and landing on Mars. The ExoMars rover will also carry a number of blank calibration samples to reliably demonstrate that it is free from contaminants. Upon landing, one of the first science actions will be for the drill to pass a blank sample to the analytical laboratory.

2.2 Surface Platform Surface Mission

The ExoMars Descent Module (DM) is the part of the spacecraft composite that enters the atmosphere to achieve a controlled descent and landing. The Carrier Module (CM) will take the DM to Mars and deliver it with a very precise entry angle. The DM will hit the top of the martian atmosphere at approximately 20,000 km/h. A thermal shield at the bottom of the capsule will be used to decelerate to roughly twice the speed of sound. Thereafter, the parachute system will take over. However, even after the main parachute has reached its terminal velocity, the DM will be still traveling at more than 300 km/h. The last stage will involve the use of throttled liquid engines. A multibeam radar will measure the distance to ground and the horizontal speed over the terrain. The DM's computer will receive this information and combine it with its knowledge of the DM's attitude to decide how to exercise the engines and achieve a controlled landing. Legs will be used for the final touchdown.

The Rover, which sits on top of the Surface Platform (SP), will then unfold its solar panels, camera mast, and wheels. The SP will deploy ramps that the rover can use to move onto the martian surface. Most likely, a few days will be required to image the surroundings and decide which is the safest exit direction for the rover to leave the lander. Once the Rover has egressed, the SP will conduct environment and geophysics experiments for about a martian year, relying on solar array electrical power. The SP payload has not been selected yet.

2.3 Landing Site Scientific Constraints

For the ExoMars Rover to achieve results regarding the possible existence of biosignatures, the mission has to land in a scientifically appropriate setting.

2.3.1 Depositional Age of Terrain

The site must be ancient (older than 3.6 Ga)—from Mars' early, habitable period: Pre- to late-Noachian (Phyllosian), possibly extending into the Hesperian.

2.3.2 Preservation of Organics

Regarding the search for molecular biosignatures, the LSSWG would consider favourably sites providing easy access to locations with reduced radiation accumulation in the subsurface. The presence of fine-grained sediments (on Earth, organic molecules are better preserved in fine-grained sediments—which are more resistant to the penetration of biologically-damaging agents, such as oxidants—than in coarse materials) in units of recent exposure age would be very desirable. Young craters can provide the means to access deeper sediments, and studies on Earth suggest that fossil biomarkers can survive moderate impact heating. Additionally, impact related hydrothermal fractures may have contributed to creating habitats for microbial life in the past. However, for landing safety reasons it is better not to have many craters in the ellipse, so sites exposed by high erosion rates would appear preferable.

2.3.3 Signatures of Past Aqueous Activity

The site must show abundant morphological and mineralogical evidence for long duration, or frequently reoccurring, aqueous activity.

2.3.4 Availability and Distribution of Outcrops

The site must include numerous sedimentary rock outcrops. The outcrops must be distributed over the landing ellipse to ensure that the rover can get to some of them (the expected rover traverse range is a few km—during the mission's 218-sol nominal duration).

As an indication, assuming the mission lands in a scientifically interesting area, the Reference Surface Mission (RSM) scenario for the rover's 218-nominal mission duration results in roughly three quarters of the time spent performing science, and one quarter traversing to new science locations—each assumed to be on the order of 500 m apart. The rover would be able to increase its traveling range, e.g. if deemed useful to reach a particularly interesting location, but this would be at the expense of science time.

2.3.5 Paucity of Dust Coverage

It is essential to avoid loose dust deposits distributed by aeolian transport. The site must have little dust coverage. Scientifically there are two reasons for this: 1) Dust is not an interesting target for the rover. While driven by the wind, this material has been processed by UV radiation, ionising radiation, and potential oxidants in the atmosphere and on the surface of Mars. Any organic biomarkers would be highly degraded, or even completely destroyed, in these samples. 2) The usefulness of the drill will be nullified if the landing site has a dust layer thicker than the drill's maximum penetration depth.

3 ENGINEERING CONSTRAINTS AND PERFORMANCE DRIVERS FOR EXOMARS 2018 LANDING SITES

Engineering constraints are criteria that, in case they are not satisfied, can result in a candidate landing site being judged unfeasible for the mission and therefore rejected.

This section addresses landing site characteristics relevant for:
- Safe entry descent and landing;
- Safe surface operations;
- Maximization of rover performance.

3.1 EDL Engineering Constraints and Performance Drivers

The ExoMars 2018 Descent Module (DM) is in its design phase. Therefore all values reported herein are subject of continuous updates as the project work evolves.

3.1.1 Landing Elevation

The landing site's elevation must allow an adequate atmospheric column capable of providing the drag and time needed for the successful completion of all Entry, Descent, and Landing (EDL) events.

The maximum altitude achievable by the landing system is –2 km with respect to the MOLA geoid. Therefore, the terrain elevation within the landing ellipse pattern must be ≤ –2 km MOLA.

3.1.2 Local Time and Season

For a nominal launch in the 2018 launch opportunity, the ExoMars mission will land in Ls = 324º at a Local Solar True Time between 10:00 and 11:05 (morning).

For a backup launch in the 2020 launch opportunity, the ExoMars mission will land in Ls = 34º at a Local Solar True Time between 10:55 and 12:40 (late morning).

3.1.3 Landing Ellipse Size and Orientation

With robust margin to account for off-track radar operations (i.e. while oscillating under the parachute), the landing ellipse under evaluation for site selection is 104 km x 19 km.

The orientation of the landing ellipse will change depending on when the launch takes place within a given launch window. As shown in Fig 1, for the 2018 launch opportunity (in yellow), the orientation of the landing ellipse can vary between 90° and 102° azimuth (computed clockwise from the North direction). For a 2020 launch (in light-blue), the landing ellipse azimuth can span the 88°–127° range. This effectively defines a landing ellipse pattern, achieved by rotating the 104 km x 19 km (3 sigma) landing ellipse between 88° and 127°.

Since it is required that landing sites be complaint with both launch opportunities, the adequacy of candidate landing sites against the applicable scientific, engineering, and planetary protection constraints will be verified over the entire landing ellipse pattern.

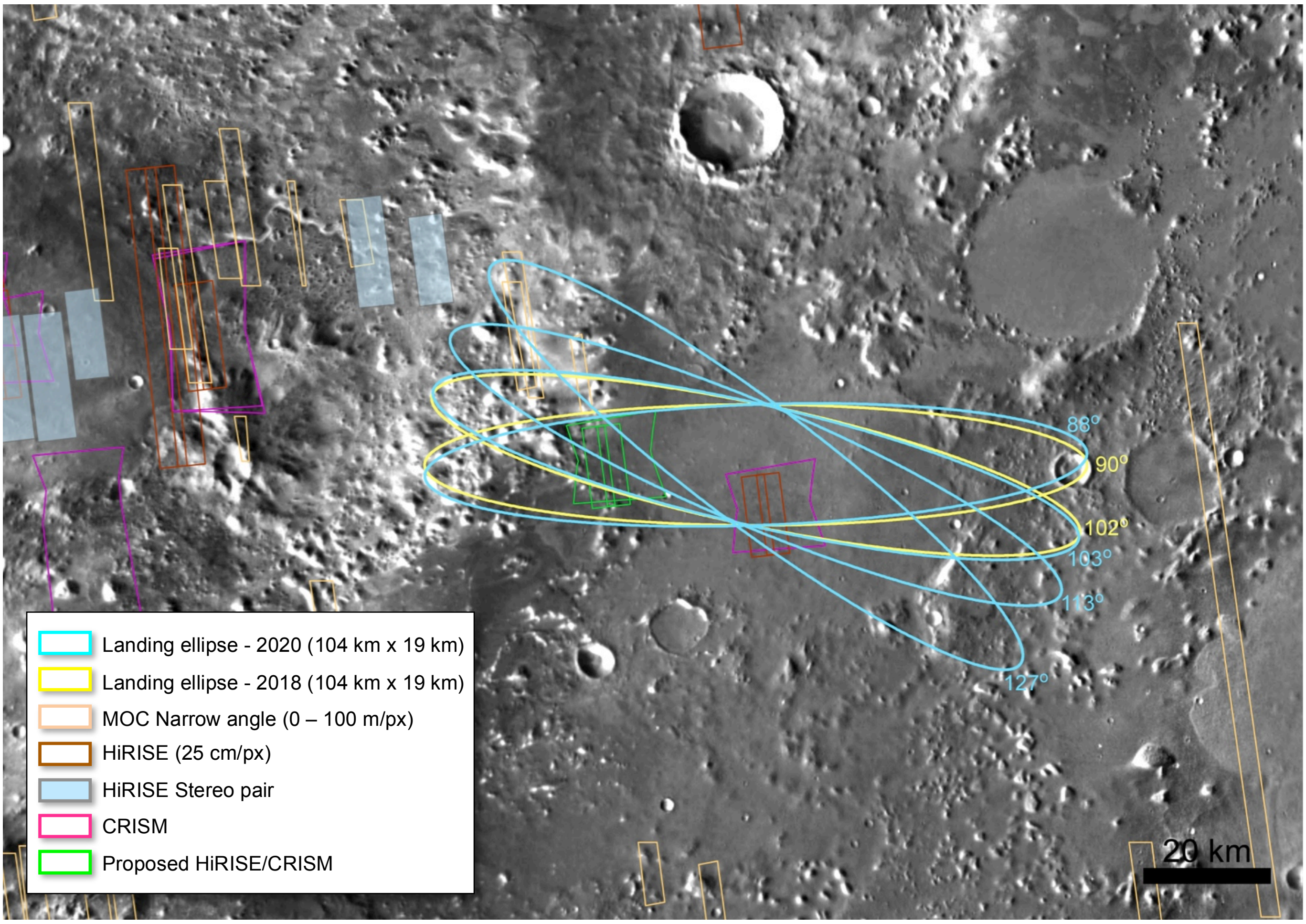

Fig. 1: Example of an ExoMars (104 km x 19 km) landing ellipse pattern. For a 2018 launch (in yellow), the orientation of the landing ellipse can vary between 90° and 102° azimuth (computed clockwise from the North direction). For a 2020 launch (in light-blue), the landing ellipse azimuth can span the 88°–127° range, depending on the launch date within the 2020 launch window opportunity. The ellipse pattern is centred at 18.36° N, 77.59° E, at an elevation of –2.66 km with respect to the MOLA geoid in planetocentric coordinates. The footprints of existing HiRISE, CRISM (in purple), and MOC (orange) images are shown. In green are depicted new, requests for a HiRISE image (rectangle) and a CRISM image (hourglass shape) centred at 18.365° N, 77.719° E.

3.1.4 Terrain Relief and Slopes

Terrain relief features and slopes constitute EDL performance drivers, as they may impact radar measurements and affect the stability of the landing platform.

The radar Doppler altimeter velocimeter uses multiple beams to measure the vertical and horizontal components of the descent velocity vector. The initial measurements are acquired after jettisoning the DM's front shield, while the vehicle is still hanging under its parachute. Continuous measurements are performed throughout the descent phase, until 10 m above the local ground level; thereafter the radar is switched off.

Over the whole descent trajectory, slopes at various length scales can alter the knowledge of "distance to ground at landing", with potential serious consequences on fuel consumption, control authority, and landing conditions.

At present, the slope constraint set points are defined to be:

Base-length	Slope Requirement	Rationale
2000 m	≤ 3°	To ensure slant and incidence compatible with radar.
330 m	≤ 8.6°	To ensure proper fuel consumption during powered descent.
7 m	≤ 12.5°	To ensure an adequate altitude error at touchdown.
2 m	≤ 15° (TBC)	To ensure stability at landing.

The analysis of landing sites will be performed based on the following assumptions:

- *Length scales of 2 to 10 km:* *Slope ≤ 3° on base-length of 2000 m.*
  Rationale: This requirement is driven by the specification of maximum slant range to be measured. The radar may be activated in the altitude range 3.0–6.5 km, but not operated in closed-loop until an altitude of 2500 m has been reached. Unambiguous altitude measurement is necessary for altitudes below 2500 m. The radar does not operate in closed-loop on base lengths ≥ 2 km. The radar is active on base lengths ≤ 5 km.
- *Length scales of 0.33 to 2 km:* *Exponential self-affine model C·ΔX(H-1), leading from 3° at 2000 m to 8.6° at 330 m.*
- *Length scales of 7 to 330 m:* *Exponential self-affine model C·ΔX(H-1), leading from 8.6° at 330 m to 12.5° at 7 m.*
  Rationale: Ensure proper control authority and fuel consumption during powered descent.
- *Length scales up to 7 m:* *Maximum relief 1.55 m up to a maximum slope of 18°. Corresponds to 12.5° on a 7-m base length, and 17.2° over a 5-m base length.*
  Rationale: To minimise the altitude error at landing.

3.1.5 Rock Distribution

The landing platform is designed with a clearance between nozzles and terrain of 0.35 m as the legs touch down, and 0.18 m following deformation of the legs' shock absorbers. Currently, the required clearance for the landing platform is 0.18 m (TBC).

Until this parameter has been confirmed, the applicable EDL rock distribution constraint is that the site must have a rock abundance ≤ 7%— derived from the rover constraint for rock abundance.

3.1.6 Radar Reflectivity

The ExoMars 2018 EDL design requires that the surface materials present at the landing site be radar reflective, providing sufficient backscatter signal to enable measuring the altitude and velocity with respect to ground during the descent. The relevant constraints have been determined on the basis of a realistic assessment of terrain reflectivity.

The following ranges for backscattering constraints are driven by the current radar requirements.

- *Terrain Backscattering at nadir:* *–15 dB to 27.5 dB*
- *Terrain Backscattering at 10° off-nadir:* *–17 dB to –10 dB*
- *Terrain Backscattering at 20° off-nadir:* *–18 dB to –13 dB*
- *Maximum Backscattering decay from 0° to 5° off-nadir:* *–30.4 dB*
- *Maximum Backscattering decay from 0° to 10° off-nadir:* *–37.3 dB*
- *Maximum Backscattering decay from 0° to 15° off-nadir:* *–40.6 dB*

3.1.7 Atmospheric Parameters

The ExoMars 2018 DM is being designed to land safely and accurately under a range of atmospheric conditions. In order to ensure the expected performance can be achieved, “not to exceed” thresholds have been defined for atmospheric density, horizontal, and vertical winds.

The applicability of these thresholds is altitude dependent since they are associated with sensitive events in the EDL sequence, such as peak deceleration, deployment of parachutes, terminal descent velocity, initiation of powered descent, etc.

From entry through the descent phase (parachutes), altitude references for atmospheric parameters are given with respect to the local MOLA geoid. However, following front shield ejection—when the radar will start operating—altitude references are given with respect to ground. The set of atmospheric thresholds used for the DM design is listed in the summary table provide at the end of this chapter.

3.2 Rover Engineering Constraints and Design Capability

This chapter describes the rover design capabilities to allow assessing the feasibility of reaching scientific points of interest within the landing ellipse pattern.

As the rover system is still under development, the characteristics reported herein are indicative and remain to be confirmed and tested to the necessary extent.

The rover’s effective capabilities depend on the type of the terrain, on the power/energy availability, and on the environment. The season, the latitude, the nature and inclination of the terrain, the near surface wind, the atmospheric dust opacity, the dust deposition rate are all factors that can affect rover performance. For the sake of clarity, this will not be recalled systematically in the following sections.

The rover will be commanded from Earth by means of Activity Plans. These Activity Plans will be prepared and checked to ensure their compatibility with available rover resources at the time of their planned execution. The rover will include on-board intelligence, allowing it to autonomously:

- Stop the execution of an Activity Plan in case of trouble or lack of resources (e.g. the environmental conditions may have changed with respect to the ground prediction) and reach a safe state;
- Replan the Sol’s activities based on alternatives previously defined by Ground Control;
- Travel safely to a target designated by Ground Control, avoiding hazards such as rocks, steep slopes, and crevasses.

3.2.1 Mobility System Description

The ExoMars rover has six driving wheels capable of steering. Deployment actuators are available to raise the rover on the Surface Platform, before egress. The rover size is approximately 1.7 m in length by 1.5 m in width (excluding the solar arrays).

The wheels are mounted on three bogies (one on each side, and one on the rear) that can rotate relative to the body to provide passive adaptation to the terrain shape and keep the wheels on the ground. The wheels are flexible to increase their contact surface. The wheels’ diameter is 285 mm and their width is 120 mm, resulting in an approximate indicative surface load under each wheel of 14.6 kN/m^2. The landing site terrain must be able to bear such load; therefore, very thick layers of loose soil must be avoided.

The rover is designed to drive over 25 cm step obstacles and over crevasses of 15 cm width.

The rover’s nominal ground clearance is about 30 cm.

The rover can be controlled from Earth with various levels of commanding to:

- Execute low-level manoeuvre commands, such as Ackerman curves, point turns, or crabbing—thanks to its six-steering-wheels capabilities;
- Execute a trajectory using vision-based position control;
- Perform on-board path planning (based on autonomous hazard detection using stereo cameras at about 2 m above the ground mounted on a pan-tilt assembly) and execute a trajectory using vision-based position control.

Energy considerations, terrain slopes, rock distribution, and soil characteristics can affect rover trafficability. For design and test purposes, a number of reference terrains have been defined (not reported herein).

3.2.2 Latitude

The ExoMars rover is designed to operate in the latitude range between 5° S to 25° N.

3.2.3 Surface Thermophysical Properties

The ExoMars rover is designed for:

- Surfaces having thermal inertia ≥ 150 J m^{-2} $s^{-0.5}$ K^{-1}.
- Surfaces having 0.1 ≤ albedo ≤ 0.26.

3.2.4 Traverse Range and Rover velocity

The ExoMars Rover is designed to traverse 4 km along track, consistent with the requested capability of being able to drive 500 m between each of six experiment sites within its 218-sol nominal mission duration.

The rover's nominal commanded speed is about 40 m/h. However, wheel slippage can increase depending on the terrain (soil type, slope, rocks); the effective speed would then be smaller. For activities requiring very accurate positioning, the rover's speed can be reduced to about 10 m/h. On very easy terrains, the maximum 70 m/h speed could be achieved—mainly on a straight line on flat ground.

By using its on-board path planning capability every few meters, the rover can compute autonomously a path toward any Earth-specified goal coordinates. This functionality, however, reduces the rover's average speed to about 15 m/h, allowing to drive approximately 70 m/sol—along the path on a terrain with overall rock abundance of 6.9% [M. Golombek and D. Rapp (1997) "Size-frequency distributions of rocks on Mars and Earth analog sites: Implications for future landed missions" Journal of Geophysical Research 102, 4117-4129].

Assuming the following additional terrain characteristics for soil and slope distributions, representative point-to-point travel distances per sol can be estimated. Table 2 presents simulation results for a "crusty/cloddy/silty sand" type of soil.

Ls/Lat.	5°S	0°N	15°N	25°N
324°	72	68	63	41
340°	69	72	65	47
0°	64	71	69	55
30°	55	66	72	62
60°	44	61	72	66
71°	41	59	73	67

Table 2: ExoMars rover Autonomous Navigation representative travel distances (point-to-point, in metres) per sol as a function of Ls and latitude for soil of type "crusty/cloddy/silty sand" with bulk density of 1800 kg/m^3. The adi-rectional slope distribution on a 5-m scale follows a Chi-Square distribution with parameter 7 and a maximum slope of 21.5°. The on-board path planning standard settings would avoid slopes ≥ 20° and hemispheric rocks of 20 cm height.

For much easier terrains trajectories can be planned on Earth, uploaded, and executed by the rover. The achieva-ble point-to-point distance per sol would obviously depend on the terrain, but also on the ability of Ground Control to accurately assess the terrain difficulties up to the desired target. With good conditions, 150 m/sol point-to-point could be reasonably executed, although it must be noted that this remains to be tested.

Finally, for terrains presenting intermediate difficulties, Ground Control could specify the initial part of the traverse, based on available images/data, and the rest of the trajectory could be executed using on-board path planning. Simulation results for one such example are presented in Table 3.

Ls/Lat.	5°S	0°N	15°N	25°N
324°	98	95	89	68
340°	95	99	92	74
0°	91	97	95	82
30°	82	93	98	89
60°	71	87	99	93
71°	68	85	99	94

Table 3: ExoMars rover combined Trajectory Execution plus Autonomous Navigation indicative travel distances (point-to-point, in metres) per sol as a function of Ls and latitude on terrain as above. In this case the first 40 m are assumed planned by Ground Control (i.e. not autonomous navigation).

3.2.5 Static Stability and Slope Access

The rover has been designed to be statically stable on slopes ≤ 40° with respect to the horizontal plane. Some margin will be included during operations to ensure safety at all times. Additionally, on-board monitoring of the rover tilt will prevent any dangerous situations.

The rover's drill and analytical laboratory are designed to work with a rover body inclination ≤ 10° with respect to the horizontal plane.

The rover mobility system will allow driving on terrains with slopes. The rover will experience slippage that will limit the maximum slope inclination depending on the soil type. Allowable slopes are given below for various types of terrain.

- Slope ≤ 26° for gravel and medium to coarse sand;
- Slope ≤ 21° for very fine sand;
- Slope ≤ 10° for fine dust.

The rover will be able to extricate itself from a situation where two front wheels are buried up to the middle. These known dangerous situations will be avoided as much as possible by continuous slippage monitoring.

3.2.6 Surface Winds

Horizontal Wind:	≤ 30 m/s at 1 m above ground level (during rover surface operations).
Vertical Wind:	≤ 12 m/s at 1 m above ground level (during rover surface operations).

3.3 Preliminary Summary Tables for Engineering Constraints

Since the ExoMars 2018 mission is under development, these constraints are preliminary. The final constraints will be confirmed in the course of the project's life cycle.

Engineering Parameter	Requirement	Notes
Landing Latitude	5º S to 25º N	Driven by Surface Platform and Rover design. Latitudes beyond this range would cause either degraded electrical power, or challenging thermal conditions. Latitudes within the 0°–15° N band maximise the rover's travelling capabilities.
Landing Elevation	≤ –2 km MOLA	For sufficient atmospheric braking during EDL.
Landing Ellipse Dimensions	Major axis: 104 km Minor Axis: 19 km	Landing ellipse dimensions where all listed constraints must be verified.
Landing ellipse Orientation	88° to 127º	Azimuth angles measured clockwise from north. Ellipse Orientation will vary slightly depending on the landing site's latitude.
Slopes at 2- to 10-km length scale	≤ 3.0°	To ensure slant and incidence compatible with radar.
Slopes at 330-m length scale	≤ 8.6°	To ensure proper fuel consumption during powered descent.
Slopes at 7-m length scale	≤12.5°	To ensure proper altitude error in the touchdown phase.
Slopes at 2-m length scale	≤15.0°	To ensure stability at landing
Rock abundance	K < 7 %	Drives the rover traverse performance and also drives the probability of encountering a rock during landing
Thermal Inertia	≥ 150 $J\ m^{-2}\ s^{-0.5}\ K^{-1}$	Driven by rover thermal design constraints and by the need to have a load-bearing surface.
Albedo	0.1 ≤ albedo ≤ 0.26	Driven by rover thermal design constraints
Radar Reflectivity	Ka band radar backscatter cross-section at nadir: > –15 dB and < 27.5 dB	The terrain backscatter characteristics are key for the proper functioning of the radar. These values are relevant to nadir backscatter. Other conditions are described in the dedicated section.

Table 4: Summary of preliminary surface/terrain engineering constraints.

Altitude	Density	Horizontal Winds	Vertical Winds	Sound Speed	Event Driver
40 km MOLA	≤ 15 % (TBC) uncertainty				Deceleration
6–10 km MOLA	≤ 8 %(TBC) uncertainty	Max ≤ 25 m/s (TBC)	Max ≤ 12 m/s (TBC)	≤ 5 % (TBC) uncertainty	Drogue parachute deployment
4–6 km MOLA		Max ≤ 25 m/s (TBC)	Max ≤ 12 m/s (TBC)	≤ 5 % (TBC) uncertainty	Main parachute de-ployment
1–4 km MOLA		Max ≤ 25 m/s (TBC)	Max ≤ 12 m/s (TBC)	–	Main parachute de-scent
10–600 m above ground	> 13 g/m^3	Max ≤ 25 m/s (TBC)	Max ≤ 12 m/s (TBC)	–	Parachute terminal velocity and powered descent
0–10 m above ground		Max ≤ 25 m/s	Max ≤ 12 m/s (TBC)	–	Final descent and touchdown
1 m above ground		Max ≤ 30 m/s	Max ≤ 12 m/s	–	Rover surface opera-tions

Table 5: Summary of preliminary atmospheric engineering thresholds. The thresholds for altitudes above 6 km must not be exceeded anywhere along the portion of the descent trajectory that lies within 100 km of the proposed landing site. All thresholds for uncertainty are specified as 3-sigma (99.87 % probability) values. The thresholds for maximum horizontal and vertical wind speed apply to all landing sites, regardless of their elevation.

4 PLANETARY PROTECTION CONSTRAINTS FOR EXOMARS 2018 LANDING SITES

4.1 No Access to "Mars Special Regions"

The ExoMars 2018 mission is not compatible with landing in a Mars Special Region. A Mars Special Region is defined as any area providing an environment (even if for just a few hours a year) where both the following threshold levels are exceeded: temperature (> –25°C) and water activity (> 0.5). A proposed landing site must not contain features currently considered as Mars Special Regions: gullies, bright streaks associated with gullies, and pasted-on terrain. Any evidence of dark streaks or recurrent slope lineae (RSL) in a proposed landing site must be identified (please indicate if the resolution of the available data is insufficient to perform this task). The determination of whether any such features would constitute a Mars Special Region would be the subject of a case-by-case evaluation.

5 LIST OF ACRONYMS AND ABBREVIATIONS

AO	Announcement of Opportunity.
ALD	Analytical Laboratory Drawer.
CM	Carrier Module. The spacecraft element transporting the DM to Mars.
DM	Descent Module. The part of the spacecraft composite that enters the atmosphere for landing—typically a capsule.
EDL	Entry, Descent, and Landing.
ESA	European Space Agency.
ESAC	European Space Astronomy Centre, in Madrid (ES).
ESOC	European Space Operations Centre, in Darmstadt (DE).
ESTEC	European Space Technology and Research Centre: ESA's largest establishment, located in Noordwijk (NL).
ESWT	ExoMars Science Working Team: The group of scientists that advises ESA on all aspects of the Programme affecting its scientific performance.
GCMS	Gas Chromatograph / Mass Spectrometer: Two analytical instruments that, combined, are very useful to analyse complex gas mixtures. They can provide elemental, molecular, and isotopic abundances and composition.
HESAC	Human Spaceflight and Exploration Science Advisory Committee. Since 2010 HESAC is the senior advisory committee on matters regarding ESA's Aurora Exploration Programme.
IKI	Russian Academy of Sciences organism conducting space research.
IR	Infrared.
LSS	Landing Site Selection.
LSSWG	Landing Site Selection Working Group.
Mb	Mega-bit: a unit of data volume equal to 2^{20} bits of information.
MER	Mars Exploration Rovers: A NASA programme that landed two very successful rovers in 2004, devoted mainly to surface geochemistry and mineralogy research.
MOLA	Mars Orbiter Laser Altimeter: An instrument for measuring relief height in NASA's Mars Global Surveyor (MGS). The 0-MOLA ellipse has become the *de facto* reference for measuring altitude on Mars.
MSL	Mars Science laboratory: A NASA programme that landed the Curiosity rover on Gale crater in 2012.
NASA	National Aeronautics and Space Administration—the space agency of the United States of America.
Pyr	Pyrolysis is a technique to render organic compounds volatile by subjecting them to high temperatures. It is usually employed as a first stage in combination with a GCMS, resulting in a Pyr-GC-MS instrument. This method is sometimes also called Thermal Volatilisation (TV), and can be performed

with or without involving derivatisation agents—chemical compounds that attach to small molecules to help render them volatile.

ROCC	Rover Operations Control Centre, to be located at ALTEC, in Turin (ITA).
SOC	Science Operations Centre.
SP	Surface Platform. The science element, part of the lander, that becomes active after Rover egress.
SPDS	Sample Preparation and Distribution System.
TGO	Trace Gas Orbiter.
UV	Ultraviolet, usually used for ultraviolet radiation or ultraviolet light.