Robotic Exploration of Planetary Surfaces – Rover Technologies Developed for Space Exploration

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Abstract. Mobility is a key feature for any science mission and for space exploration in general. Missions with mobile systems provide a much wider spectrum of outcomes by employing a higher number of samples within an increased area of exploration. The additional degree of freedom of a rover in comparison to a lander or even a robotic arm allows the mission to be flexibly adapted to the landing site as it is encountered.

Nevertheless, rover vehicles developed for the exploration of planetary surfaces are extreme complex systems, which have to be specialised for the environmental conditions they are dedicated for. With the variation of the environmental conditions on missions to different target planets, the requirements are varying for the landing system, the rover as well as the payload.

Since 1989 the company von Hoerner & Sulger is doing research in the field of robotic systems and planetary exploration. Given that, the company is in the mean time well situated in the development and manufacture of rovers and established a good cooperation with academic institutes. The company gained the experience to develop the matching rover chassis for a variety of mission scenarios:

The Nanokhod rover is a small mobile scientific platform, designed to transport a package of scientific instruments and to carry out in-situ measurements of rocks and small craters in the vicinity of the landing point. The Microrover has a volume of 160×65×250 mm, it weighs 3,2 kg including a payload mass of 1 kg and has a peak power need of max. 5 W. The Nanokhod is a tethered system that uses the Lander for power supply and as a data relay to Earth. The Nanokhod has recently been designed to withstand the demanding requirements of a flight model on a mission to Mercury. Based on this design, an engineering-level hardware model was built which is suitable for environmental testing, preparing the rover design for a variety of possible future missions.

The Solero rover is an innovative Minirover concept, designed for regional exploration of a planetary surface. The vehicle has a passive chassis

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concept with exceptional climbing abilities, which provides the ability to adjust to all kinds of terrains and thus minimises control needs.

The company vH&S is leading already the second ExoMars rover chassis breadboard design and manufacturing activity, which is part of the rover development for the first European Mars rover. The second breadboard is designed and built by vH&S GmbH in collaboration with DLR and two Swiss collaborators. The ExoMars rover for the ESA Cornerstone Mission Aurora, will be a mobile Laboratory having an Exo-biology Payload (Pasteur), including a geochemical package, and carrying a drill that is reaching probes up to a depth of two meter.

This paper describes the gained experiences and most important aspects of a rover design for the purpose of planetary exploration. In addition it presents the newest designs and the manufactured models in relation to their missions ...

1 Introduction

von Hoerner & Sulger GmbH (vH&S) is a small scale enterprise (SME) that is working since 1971 successfully in the field of space exploration. This covers scientific space instruments, rocketborne systems, cameras and sensors for space applications as well as robotic systems for planetary exploration. The areas of operation of vH&S include concept finding, feasibility studies, development, fabrication, and qualification of space systems for applications in extraterrestrial missions.

Since its foundation the company has produced more than 10 flight-qualified scientific space instruments. Famous examples from the past are the first-ever mass spectrometers for cometary dust, PIA and PUMA (1 & 2), which were built between 1981-1984 for ESA's Giotto mission and for the Russian Vega 1 & 2 missions. These three experiments were the first and only ones that met comet Halley in 1986, giving insight into its chemical composition. After these brilliant results, vH&S became the prime company to provide mass spectrometers for both NASA and ESA missions.

This is only one example how vH&S has earned profound experience in the space mission activities and a worldwide high profile reputation in the space business, both in prime and subcontractor roles.

Based on this experience in the sector of space missions the company has expanded its portfolio in the late 1980's with the development of systems for in-situ planetary exploration. Since vH&S is active in this field it was involved in the development of various rover chassis concept matching for distinct mission scenarios. These chassis concepts cover the rover categories from a highly-integrated Mircorover to a big rover with a mass of up to 220 kg.

The mission scenarios vary from very hot to very cold environmental conditions, for targets with and without atmosphere and for planetary surfaces which are rough and rocky or smooth and covered with fine dust particles called regolith – namely environments on the planets Mars and Mercury, or our Moon. The most prominent example that made vH&S a leading European name for robotics is the *Nanokhod* Microrover, with a mass of only 3,2 kg including 1 kg of scientific payload mass. On the other end of the rover size scale vH&S is involved in ExoMars activity that is building the rover for the European Mars mission being part of the ESA Aurora programme.

2 Mobility for Space Exploration Missions

Current trends in space exploration aim for mobile systems[1]. In order to fulfil the whole range of scientific interests and to have a well-funded scientific examination of a planetary surface more than one sample has to be considered. This requires a mobile system to reach the different areas of interest.

A mobile system means that either several samples of different materials have to be collected and transported to the instrument or the instrument itself has to be moved to the different sample sites. A wide spectrum of results gives a wider view of the explored target; either way though requires the ability of movement. The application of a rover which transports instruments and carries out in-situ analysis has the advantage that the range of the rover system is farther.

The mobility aspect of the rover makes it possible to explore with a single space system a whole region of up to some tens of km around a landing point depending on the implemented system. This regional exploration provides a deeper knowledge and allows a more general characterisation of certain areas of a planetary surface. The mobility of such a system gives the scientific explorers the freedom to reach and examine specific points of interest. This offers also the opportunity to carry out a systematic exploration of the region. Depending on the system used and on the environmental conditions encountered this can even compensate in some cases the uncertainty of the landing ellipse.

For the mobility in space infrastructure the following development can be observed. For nearby planetary bodies which have been explored before, the implemented mobile systems are developed with an increasing reach (m > km). While for bodies which require a long transfer and which are examined for the first time, the focus is rather on a system with very low mass. Mission success in this case is to gain in-situ analysis in the near surroundings of the landing point.

A variety of rover systems have been developed in the previous years in order to accomplish all needs for the exploration of target surfaces. These systems differ in their range, complexity, their demands on control, power needs etc. Thus a rover system can be adjusted to the expected mission scenario.

3 Rover Technology for Science Missions

There are several performance drivers for rovers used for space applications. One of the main drivers is the perception capability. This means either their ability to recognise and understand the environment they move through, or the identification of the targets they take samples of. The rover has to percept the near surroundings, by seeing it, processing the seen information and than analyse what it means for the further rover activity. This routine has to be done for each segment of movement as well as for the taking or measuring of samples.

A further driver closely related to this is the mobility capabilities. This is necessary in order to reach scientific targets, when moving through all kinds of terrain the rover might encounter. But the mobility aspects become even more important for the processing and handling of samples to prepare them for analysis. A rover has to enable a close contact between an instrument and the sample and it may grasp and collect samples; in some cases it might even have to dig, grind or drill, to prepare the sample for the scientific analysis with certain instruments.

Especially for long distance mission targets with long signal delays, a further driver for space rovers is their operational capabilities. For rover missions, there is a high demand for autonomy, in order to cope with hard real-time situations, as well as to not put any additional constraint on the mission duration because of signal delays. Furthermore the need for a high level ground interaction is also always a cost factor for the mission. The demand for autonomy includes also autonomous decision making in an unknown and unstructured environment. The rover system has to be able to cope with unexpected situations and has to provide solutions for any contingency. Autonomous operation implemented in space rovers also simplifies the payload (P/L) operations as well as the scientific target selection.

A rover system equipped with a high number of sensors for scientific analysis can utilise these capabilities also for the planning of single operations. Like that the rover can use instruments facilities for mission planning aspects. This use of synergy effects enhances the system efficiency, by reducing any additional instrumentation and thus system overhead by a careful integration of the instrumentation into the system.

Autonomy makes the rover adaptable to a variety of situations and missions and provides the necessary flexibility which the systems needs in a completely unknown environment. An optimised space exploration approach of a rover system development can be achieved, by developing the rover together with the scientific payload, in order to plan for synergies.

4 Microrover Nanokhod for the Mercury Surface Exploration

Since 1992 the company von Hoerner & Sulger GmbH has the leading role in the development history of the Nanokhod rover. The rover is based on an originally Russian design, but has since undergone a significant development to now provide a practical flight implementation. Part of the devlopment were for example the accommodation of scientific payload instruments and the building of prototypes to test the mobility performance, like step and slope climbing abilities, and sealing concepts to prevent the rover inside from regolith.

The latest development is now a Nanokhod design which is able to cope with the challenging requirements for a flight model on the Mercury surface. A hardware model of this design is realised for environmental tests such as vibration, shock and thermal vacuum to the extreme requirements of a Mercury mission profile. The project to develop a mature rover for the Mercury environment is based on the ESA Cornerstone mission BepiColombo.

Initially, the BepiColombo mission was still including a Surface element, and the Nanokhod rover was selected to be part of it as a mobile scientific platform - the Mercury Robotic Payload (MRP). Unfortunately the Surface element, was cancelled from the BepiColombo mission and with it the flight opportunity of the rover. Nevertheless, it was decided to continue with the development to prepare the rover for future missions by solving detailed technical problems of a real implementation and thus gaining a better understanding. Also because the technology developed for the challenging nature of the Mercury environment is considered to be applicable with moderate modifications on a variety of other planetary bodies, with and without atmosphere, like Mars or Moon.

Small systems are required due to a limitation of financial resources and energetically more demanding missions. As a small and mobile system the Nanokhod thus fulfils two trends - mobility and low mass - for future missions, with additionally a very good payload mass to system mass ratio. And now with the design meeting the demanding flight model requirements for the conditions of a Mercury mission the rover is very well prepared for a variety of future mission scenarios.

4.1 Mercury Mission Profile

After some initial studies of the rover mission under day- as well as night side conditions of Mercury, the landing site was decided to be on the night side of the planet, where the absence of the sun's radiations reduces the thermal range and makes the mission feasible. Despite this the environment remains severe, coupling a high vacuum with surface temperatures estimated to $-180°C$. However, the night side landing site causes the disadvantage that all energy must be supplied chemically.

The MRP Nanokhod shall be able to move across the Mercury surface which is expected to consist of fine regolith similar to the Moon surface with a speed of 5 metres/hour and to negotiate steps of 10 cm height and trenches of 10cm width. The mission foresees one in-situ analysis per Earth day with each of its three instruments: Microscopic camera (MIROCAM), APXS and Mössbauer Spectrometers. The rover shall operate near-autonomously due to a single communication period once a day.

4.2 Design Drivers Resulting from the Mercury Mission Scenario

This mission profile induces as main design drivers mass and volume for the whole landing system. With an interplanetary journey between Earth and Mercury that requires a high amount of fuel to reach and enter the Mercury orbit, and with a landing scenario which has to rely only on chemical propulsion, it becomes obvious that every kilogram to land on the planet is very cost intensive. This is why the mass and the volume of the Lander and thus the rover have to be reduced to a minimum in order to make the mission feasible. Opposing this, the rover has to be designed to be robust enough to cope with the vibration and shock environment of such a landing scenario. In order to reduce the amount of chemical propulsion to a minimum the landing shock is expected to be 200 g for a duration of up to 20 ms.

Also related to the mass limitation issue is the energy consumption of the rover. The power is provided by the Lander batteries and with a given mission duration, the consumed energy relates directly to the battery capacity and thus to the battery mass. This makes the energy consumption to be the next significant design driver of the rover system.

During the mission, the rover has levels of different energy consumption, depending on the rover activity. Based on an analysis of the mission and the duration of the different activities the energy consumption of the rover was optimised, in order to decrease the overall power needs as far as possible. In the case of the Nanokhod for the Mercury mission the energy consumption has to be as low as possible for the measurements phases as well as for the non-active periods of the rover.

A low power consumption of the system is also realised by implementing a passive thermal control and mechanisms which do not require power to maintain their state. Passive thermal control in this instance means that the rover does not attempt to maintain its temperature to a set level but the rover is allowed to heat up and cool as defined by the environment, the mechanical design and selected materials and finishes. As there may be extended periods when the rover is powered off, all components have to function from the surface temperature upwards.

4.3 Overview of the Nanokhod Design

A brief overview of design is given in the following paragraph. For a more detailed description of the rover design including its instruments please refer to [2]. The main components which are generic to all Nanokhod rovers are:

- Two locomotion units (LU) enclosed by walls and the driven caterpillar tracks which provide the method of locomotion
- The tether unit (TU) which rigidly attaches both locomotion units and contains the spools from which the tether wire is deployed
- The payload cabin (PLC) containing the scientific payload instruments
- Arms connecting the PLC to each of the LU giving the PLC two degrees of freedom allowing the instruments to place next to sample sites and for the PLC to act as an extra limb for negotiating obstacles.
- Four internal drive units used to drive the caterpillar tracks and position the arms relative to the LU and the PLC.

The main components are identified on the current design in Figure 1. The overall structure has been upgraded to withstand the rigours of vibration and shock with the inclusion of four rigid yokes in the LUs. Analyses have been performed on all components to ensure that they are compatible to the mechanical

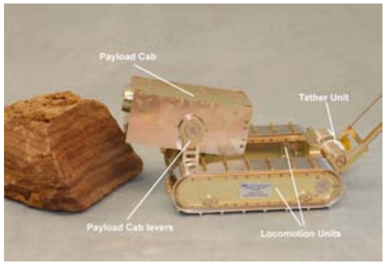

Fig. 1. Main components of the Nanokhod rover

and thermal environment. A completely new drive system based on a similar concept for all four drives within the rover has been implemented, which was developed in a close cooperation with the Harmonic Drive AG. Due to the high vacuum environment it is not possible to use standard DC motors for extended durations and so the Faulhaber AM1020 stepper motor was selected as the motor for the drives. Dicronite dry lubricant was used on the Harmonic Drive and the crown gear, the application of which had been tested at Harmonic Drive AG. The motor and the planetary gearhead were supplied pre-lubricated with MoS_2 by the manufacturer.

Electronically the system is has been partitioned into a number of nodes each of which perform a distinct function. Power for the drive system nodes is supplied by a 28 V line which is also controlled by the tether interface node. When the power is removed from this line all drive unit nodes are powered off, minimising the power consumption during instrument operations.

4.4 Conclusions for the Microrover

In table 1 the main parameters of the highly integrated Nanokhod are listed. Although a mission to the Mercury surface is currently unlikely, the Moon has now become very popular in consideration for proposed visions, but also other

Table 1. The main dimensions of the Nanokhod rover

Nanokhod properties	
Mobility:	
Overcome obstacles up to:	0,1 m
Locomotion speed:	2,7 m/h
Electrical Power:	
During movement:	5.7 W peak
Other modes:	1,3-3,4 W
Rover Dimensions	
Mass including P/L and module on Lander:	$< 3{,}2$ kg
Size:	$< 250\times160\times65$ mm

targets stay possible. The night side environmental conditions of the Moon are similar to Mercury and would allow easy adaptation of the current concept. For a dayside landing the new Nanokhod model is still very applicable although new attention would need to be given to the thermal design, having a thermal model of the rover already on hand. For missions with greater demand for mobility performance such as obstacle negotiation, rover range and greater payload capacity, the MRP Nanokhod rover provides an ideal design baseline.

The technical challenges to miniaturise a practical flight implementation to 3,2 kg have been overcome and with a relaxation of volume and mass constraints the design allows a safe and quick realisation of the new mission scenarios. Possibilities of modification include replacing the tether system with internal power provision and RF communication as well as upgrading the navigational capabilities.

The MRP Nanokhod rover is a huge advance towards a practical flight model of a highly integrated miniaturised mobile payload for planetary exploration despite limited resources that were available. Solutions for open issues have been implemented allowing the rover to be subjected to the currently ongoing thermal vacuum testing and further environmental tests.

5 Minirover Concept Solero for Regional Exploration

The mobility requirements for a chassis of the minirover type call for a typical travel distances of several kilometres. The Solero combines this with an average locomotion speed of up to 100 m/h (EXOMARS). It is evident that navigation and control of such a vehicle needs another approach as compared to local mobility systems, which remain in the vicinity of a stationary lander. Autonomous navigation is required to enable at least the typical operational increment between two consecutive ground control interventions, which is one sol for the Mars mission baseline of this design. Besides the principal autonomy requirements, the inherent stability of the locomotion concept is another feature driving the control system. If a locomotion system can cope with a large variety of terrains without active control, the whole control system overhead can dramatically decrease.

The Solero concept follows this approach; a detailed description on the activity is given in [3]. It uses an innovative locomotion concept originating from EPFL (Ecole Polytechnique Fdrale de Lausanne), which is suited to provide a high degree of design-inherent stability with respect to locomotion in rough terrain.

5.1 Solero Requirements

The mission scenario for the Solero rover is regional exploration for a geochemical mission. The payload for the Solero rover was chosen with reference to the *Nanokhod* microrover. It consists of an Alpha Particle X-Ray Spectrometer (APXS), a Mössbauer Spectrometer (MIMOS) and a microscopic camera (MIROCAM). Accordingly, the top-level requirement for the rover system is to transport and operate these instruments for in-situ geochemical exploration.

The minimum on-surface travel distance for the Solero locomotion is specified to 10 km, with an effective locomotion speed of 220 m per day. In addition the rover system must be able to withstand Mars environmental conditions (e.g. outside ambient temperatures between −100°C and +30°C, Mars atmosphere, dust).

The Solero has a max. mass of 10 kg, an autonomous power supply using solar power collection, and – similar to the Nanokhod – has no active thermal control.

5.2 Solero Flight Concept for Mars

When defining a complete rover system flight concept, a variety of system elements have to be considered, defined and adjusted in an iterative and heuristic process. The design drivers for the Solero system design are:

– *Rover configuration, operations and control:* the rover must be able to carry out operations autonomously for a duration of at least one day. This implies the capabilities to autonomously solve the problems of rover localisation, path planning, and trajectory execution.
– *Power provision, storage and control:* the system has to work with a minimum electrical storage. As a consequence the diurnal power profile is driving the operational capabilities of the rover, i. e. driving, payload operation, telecommunication sessions, hibernation.

Further subsystems need of course to be assessed for the complete system concept, they are however not the strongest drivers.

5.3 The Solero Chassis Concept

Using a rhombus configuration, the rover has one wheel mounted on a fork in the front, one wheel in the rear and two bogies on each side. The parallel architecture of the bogies and the spring suspended fork provides a high ground clearance while keeping all 6 motorised wheels in ground contact. This ensures excellent climbing capabilities.

The front fork has two roles: its spring suspension guarantees optimal ground contact of all wheels at any time and its particular parallel mechanism produce a passive elevation of the front wheel if an obstacle is encountered. The front wheel has an instantaneous centre of rotation situated under the wheel axis that is helpful to get on an obstacle.

The bogies provide the lateral stability. To ensure similarly good ground clearance and climbing capabilities, the virtual centre of rotation of the bogie is set to the height of the wheel using a parallel configuration.

The steering of the rover is realised by synchronising the steering of the front and rear wheel and the speed difference of the bogie wheels. This allows for precise manoeuvres and even turning on the spot with minimum slip.

The payloads as well as rover subsystems can be accommodated in the central body of the rover. The flight concept of the Solero rover is equipped with a solar panel, scientific payload and two navigation instruments: an omni-directional camera and a stereovision camera for 3D obstacle recognition.

Fig. 2. The Breadboard of the Solero Minirover

5.4 Conclusions for the Solero Minirover

The development of the Solero chassis was carried out within a very low cost technical demonstration activity (TDA), leading to a first system conceptual design and a development model (breadboard) to demonstrate aspects of locomotion, payload accommodation, and power provision. Although all system areas have been addressed in a first instance, some issues need thorough design work in order to establish a detailed design suitable for a flight rover. The technical parameters of a Solero flight model are given in Table 2.

Table 2. The Solero flight concept is designed with following technical attributes

Solero Properties	Target Value
Total Mass:	10 kg
Overall Dimension:	ca. 880×600×400 mm
Payload Mass:	1 kg
Solar Power:	16 W typical daily peak power
Mean Locomotion Power:	8 W
Navigation:	Autonomous Navigation up to 1 km distance by 3D obstacle recognition and negotiation
Telemetry:	Close to the Beagle 2 design: direct telemetry link to orbiter total data size ca. 2 Mbit per day
Locomotion Speed:	20 cm/s

This concerns in particular the control system. The current Solero model has only a very simple control functions implemented. It is therefore proposed to bring all subsystem areas to a detailed design level in a first development step called *Detailed System Design*. In a second step, the design, development and manufacturing of the EQM (Model) and FM (Flight Model) rovers could be implemented efficiently and with relatively low risk.

The positive results of the Solero activity recommend the Minirover concept as a promising solution for a future rover mission as well on Mars as on other planetary surfaces. It also recommends itself as a good base platform for various kinds of payloads which require an excellent mobility.

6 ExoMars Breadboard for European Mars Mission

Bridget is the first full size ExoMars breadboard rover which was commissioned by Astrium UK Ltd. and built by a consortium of companies and institutes led by von Hoerner & Sulger GmbH, [4]. In the mean time the second ExoMars chassis breadboard was designed and built under the lead of vH&S together with institutes and the Swiss company Oerlikon Space.

The primarily intention of a full scale rover is to investigate the capabilities of the suspension and traction system for use on a future ExoMars rover. It is also used to study additional rover system components such as the navigation system or a drill. The scale of the rover chassis allows valuable experience to be gained not only in the performance of the systems but also from practical aspects such as accommodation of components and AIV aspects related to the handling of a full scale vehicle.

The breadboard chassis design reflects the shape and form of the proposed ExoMars rover at the time. However, pragmatic decisions in the use of materials and off-the-shelf hardware had to be made in order to keep to a reasonable cost for the rover whilst maintaining flexibility for its future use.

6.1 ExoMars Breadboard Design

The main design requirements of the rover chassis are based on the output from Astrium UK's Exomars/Pasteur Phase A mission study during which von Hoerner & Sulger GmbH had led the chassis study team.

The original phase A study proposed a 6 wheel rover with a RCL-C type configuration (based on the ESROL study) as the mission baseline, as it was a good compromise between complexity (and mass) and its performance in terms of stability and body movements during obstacle negotiation.

However, further comparison with miniature hardware rover models conducted for Astrium UK by ETHZ identified an undesirable characteristic which under certain conditions the outside wheels would effectively lift the centre wheel off the ground. A more complex control algorithm could be used to provide a solution to this problem but this is highly undesirable due to extra risk and resources it would entail. For this reasons plus the fact that RCL-E offers a reasonable mass advantage in a flight design, it was decided to proceed with a RCL-E type chassis configuration for the first breadboard design. This consists of a main body, two parallel bogies in the front and one lateral bogie in the rear

For the first breadboard the focus was placed onto an ideal passive suspension for obstacle negotiation in which there is only a minimum of longitudinal displacement of the wheels positions when the rover negotiates an obstacle. Longitudinal displacement of the six wheels relative to the centre of mass will cause the loads on each wheel to vary from the ideal situation where all wheels are

(a) Breadboard *Bridget* - 2006

(b) Breadboard Phase B1 - 2008

Fig. 3. Development of two full-size ExoMars rover chassis Breadboards

equally loaded. This however, ignores the effect of the rover body inclination as it changes from horizontal. The longitudinal displacement was thus minimised for the Bridget Breadboard by optimising the geometry of the parallel bogies for the step range the rover had to cover, see figure 3(a).

The drawback of such an ideal passive suspension unit is the additional mass, caused by the parallel beams. With the main focus on minimising mass for the second breadboard, the optimisation in the longitudinal displacement was given up. The new chassis was thus a simplified Concept E rover using simple bogies instead of parallel bogies. Only for the rear bogie the breadboard foresees the possibility to study the effects of both the parallel bogie and the simple bogie by applying or removing a locking device, see figure 3(b).

During the Phase A Study of the rover chassis it had been highlighted that the use of a flexible wheel would be beneficial to vehicle performance and efficiency in several ways:

- For a properly designed flexible wheel, the larger (and longer) ground contact footprint will lead to less slip and higher thrust as compared to a similarly sized rigid wheel, resulting in better drawbar performance (and thus improved slope climbing capability)
- Overall motion resistance of a properly designed flexible wheel is lower than that of a similarly sized rigid wheel, resulting in smaller losses or, equivalently, a better mileage (energy to be spent per distance driven).

This is why both breadboards have been equipped with flexible wheels.

For both breadboards, the main body accomplishes the chassis concept by providing the linkage in-between the bogies. In both cases the body was made of profile frame in order to easily integrate additional systems and payloads.

6.2 Conclusions for the ExoMars Breadboards

Table 3 compares the main parameters of the two ExoMars breadboards, which have been designed so far by vH&S. Since delivery Bridget has been used by Astrium (UK) for testing both in Tenerife and the UK, after the first preliminary tests at vH&S. The second breadboard is currently extensively tested at the

Table 3. Main attributes of the ExoMars Breadboards

Properties	Breadboard Bridget	Breadboard Phase B1
Overcome obstacles up to:	0,3 m	0,25 m
Locomotion speed:	100 m/h	108 m/h
Power:	60 W peak, Battery	48 W Battery
Breadboard Mass:	115 kg,	80 kg
Payload Capacity:	185 kg	40 kg
Size:	1600×815×1000 mm	1650×1000×1200 mm

company Oerlikon Space, where it was delivered to after completion of the assembly in Schwetzingen by vH&S. Valuable experience has already been gained during the project which will be put to good use for the next phases of the ExoMars project. Further field trials and performance test undertaken will build further on this experience. Both rovers have appeared extensively in press and television, being the first visible steps of the European rover mission to Mars.

7 Conclusion

The development and design of rovers is a multi-disciplinary task due to the complexity of a space system. Such a system has one common goal, which is to transport and operate scientific instruments on a planetary surface in order to collect data and provide knowledge of our solar system. Nevertheless, the space system rover consists of several different components, like drive units, the control unit, the chassis etc., which can be defined as subsystems. These subsystems have again their own properties and functions and in-between them there are a high number of interactions and exchanges. This interaction between the different elements requires an overall design, which allows the integration of all elements and subsystems and thus maximising the possible synergies. In addition, the

Fig. 4. The magnitude variety of vH&S rovers

definition of such a subsystem as well as the input and output values can change depending on the applied point of view.

Applying to a space system additional requirements imposed by the mission scenario, the encountered environment or the influences of the rover size onto the chassis, it becomes obvious that the development of a matching rover is not only the application of size factor.

Quite the contrary, each rover design has to be considered as a "network-type" problem. For all missions a new set of requirements has to be developed and designed to. This means the design follows a heuristic, non-sequential methodology to meet the demanding requirements any space mission for planetary exploration imposes.

Nevertheless vH&S has proven a large experience in this field with the rover designs on hand. The company has solutions available for issues concerning small-scale systems, minirover scale as well as large rover systems, see figure 4.

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