ExoMars Suspension and Locomotion

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Abstract

The 2018 ExoMars mission will place a rover on the surface of Mars to search for possible biosignatures of Martian life, past or present. Canada has a long history of participation in ExoMars and will contribute the Suspension and Locomotion elements to the mission. As the overall ExoMars mission architecture has changed over the years, the design challenges facing the Suspension and Locomotion elements have remained significant. Driving requirements include mobility, mass and cold temperatures. MDA's ExoMars Suspension and Locomotion elements are designed to meet these challenging requirements. Key technologies employed include high torque density actuators and dual stage flexible wheels. Detailed design is ongoing at MDA and prototype characterisation testing of both wheel and actuator subassemblies has begun. During the second half of 2014, complete engineering and structural-thermal models will be built and tested and the critical design review will be held.

1 Introduction

The 2018 ExoMars mission [1] will place a rover on the surface of Mars to search for possible biosignatures of Martian life, past or present. The 300 kg class ExoMars rover, heavier than the NASA Mars Exploration Rovers (MER) [2] but lighter than the Mars Science Laboratory (MSL) [3], is design to explore the Martian surface for 218 sols at a rate of 40 m/h autonomously or 70 m/h flat out. This will be the first rover mission for the European Space Agency (ESA) and Canada, as an associate member of ESA, will play an important role by providing the Suspension and Locomotion elements for the rover.

2 Development History

Canada has a long history of participation in the ExoMars mission. Figure 1 illustrates the series of the ExoMars-derived prototypes built by MDA since 2004.

Figure 1: ExoMars-derived Suspension and Locomotion Prototypes

These prototypes have included research and development models for simulation validation ("Rover Chassis Prototype" – 2004-2006), a flight representative breadboard that is still in use at Airbus DS and TAS-I

(“Bruno” – 2007-2009), and full rover system prototypes ready for analogue mission deployments for the Canadian Space Agency (CSA) (“Rex” [4] – 2010 & “Mars Exploration Science Rover” [5] – 2012). Each of these prototypes has helped develop and inform the current ExoMars designfrom investigating suspension linkages and force control (RCP) to improved grouser design on flexible wheels (Bruno) to increased steering actuator travel and cable routing (Rex and MESR). The core Suspension and Locomotion elements of these prototypes are common with minor variations, and it is these elements that are to be Canada’s central contribution to the 2018 ExoMars mission.

3 Driving Requirements

As the overall ExoMars mission architecture has changed over the years, the design challenges facing the Suspension and Locomotion elements have remained significant [6].

3.1 Mobility

Carrying approximately 300 kg of structure, drill and science payloads over rough Mars terrain creates severe impact loads that must be absorbed and drives a need for excellent agility. The three-bogie configuration, coupled with aggressively grousered flexible wheels and high torque actuators, gives the system the characteristics required to climb 26º slopes and 0.25 m obstacles. Descending from these obstacles creates another challenge for the system, as this action can lead to high impact loads imparted on the primary load path. Careful consideration of stiffness both locally near the impact and throughout the system have been required to absorb this energy without damage to any components.

3.2 Mass and Volume

Both the mass requirement and the stowed volume envelope available for the Suspension and Locomotion elements are also driving requirements. The volume constraint drives the need for deployment actuators as well as small wheels. At 70 kg, the mass for the suspension and locomotion elements is a large part of the overall Rover mass. It is therefore critical to control this mass to help limit the maximum ground pressure on the wheels to ensure actuator sizing is adequate to provide good terrainability.

3.3 Thermal Environment

Operating lubricated actuators and distributed control electronics in Mars’ harsh thermal environmental is a challenge. Compounding this effect is the fact that the Rover must be able to cover a 70 m each day to meet mission goals. Maximising the number of hours available for this travel each day requires starting the Rover early in the morning when the thermal conditions are still extreme (Table 1). This leads to the use of internal heaters, conductive and insulative heat paths as well as exterior thermal insulation.

Table 1: Worst Case Cold Start-up Conditions

Parameter	Value
Temperature, Atmosphere	-89 °C
Temperature, Ground	-80 °C
Temperature, Sky	-164 °C
Wind Speed	30 m/s
Solar Flux	0
Heater Voltage	Minimum

4 Design Description

The ExoMars Suspension and Locomotion elements are designed to meet these challenging requirements. Unique features compared to the state of the art (MER and MSL) include a three-bogie suspension design shown in Figure 2, which enables the rover to passively adapt to rough terrain without a central differential.

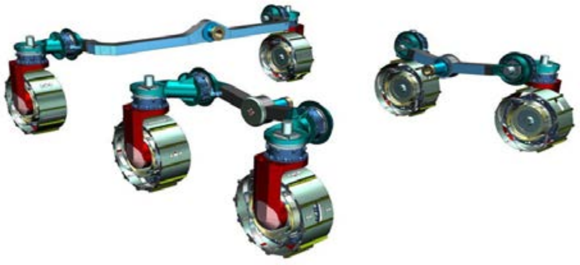

Figure 2: MDA’s ExoMars Suspension and Locomotion Design

Each wheel has a cluster of three actuators that enable several key operational behaviours. The drive (DRV) actuator rotates the wheel to provide propulsion, the steer (STR) actuator turns the wheel about the vertical axis to control the direction of the rover, and the deployment (DEP) actuator deploys each wheel from its stowed configuration. This deployment is accomplished using onboard rover DEP actuators instead of using assistance from the lander (MER). The rover STR actuators provide accurate point turning and six-wheel explicit steering (compared to four-wheel for MER and MSL) for maximum maneuverability. A mode of motion unique to six-wheel explicit steering is the crab driving mode, which can be useful for efficient driving and fine positioning near targets of interest (Figure 3).

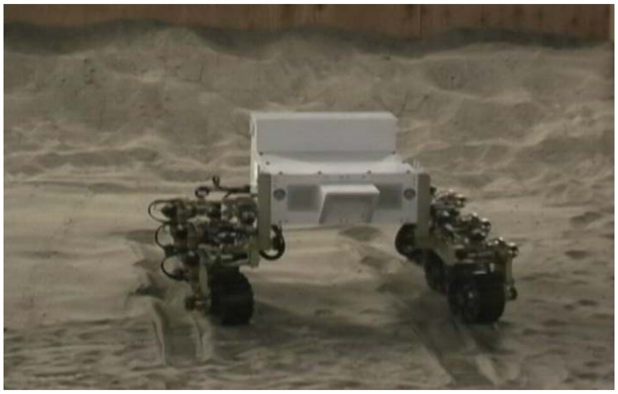

Figure 3: CSA's Rex demonstrating ExoMars Rover crab driving mode

4.1 Stowed Configuration

A key characteristic of the ExoMars design is the ability to stow in a small volume on the lander. This is accomplished using the DEP actuators and a carefully designed overall configuration layout (Figure 4). Each wheel is held down to the lander using a non-explosive TiNi Frangibolt based release mechanism. Mechanical snubbers are also employed between the lander platform and the ends of the bogie beams to help meet the natural frequency requirement of 60 Hz.

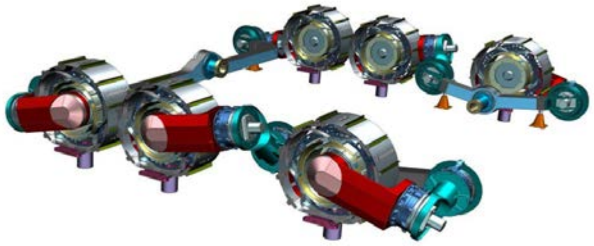

Figure 4: Stowed Configuration

4.2 Actuator

The 18 actuators used in the Suspension and Locomotion system all use a common design (Figure 5, left). At the core of the actuators are high-performance graphite brushed DC motor modules (Figure 5, right) with integrated planetary gearboxes, brakes and encoders, designed and built by maxon motor based on their proven Mars heritage on MER. Brushed motors are used based on the simplicity of their required control electronics, proven heritage and sufficient life characteristics in a Martian atmosphere as discussed in [7]. Harmonic Drives, output position sensors and energised Teflon seals complete the actuator, which is capable of meeting the required fully factored peak torque of up to 170 Nm.

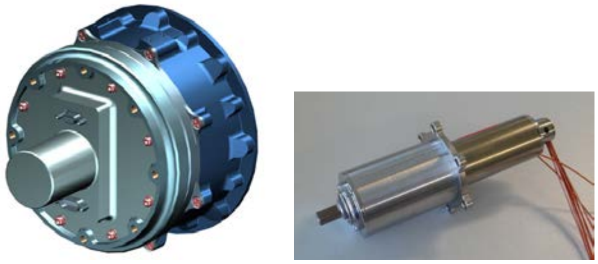

Figure 5: MDA actuator design and maxon imotor module prototype

4.3 Wheel

Flexible/deformable metal wheels (compared with more rigid MER and MSL wheels) are employed to fit inside the small ExoMars stowed volume and reduce the ground pressure to help improve overall mobility performance. Table 2 lists the some key wheel requirements.

Table 2: Wheel Requirements

Parameter	Value
Diameter	285 mm
Width	120 mm
# of grousers	12
Radial Stiffness	< 17 N/mm

Due to the highly non-linear nature of the wheel design, early prototyping has been employed to augment and validate stiffness, ground pressure and impact loading simulation activities (Figure 6).

Figure 6: Wheel simulation results and MDA flexible wheel prototype

Simulations showed high structural loads on the wheel and actuators due to high impact loads during obstacle traversal. This led to a re-design of the previous ExoMars wheel to include an inner impact absorbing stage that reduces the magnitude of the impact load on the system. The resulting two-stage wheel design is thus able to achieve the flexible, low ground pressure characteristics during normal operations, while still absorbing enough energy to protect the system from the high impact loads. This design will be characterised during the wheel prototype testing.

5 Program Status

Suspension and Locomotion detailed design is ongoing at MDA and prototype characterisation testing of both wheel and actuator has begun. During the second half of 2014, complete engineering and structural-thermal models will be built and tested and the critical design review will be held.

Acknowledgements

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